THE SEDIMENTOLOGY OF THE MIDDLE, UNDERSET AND CROW LIMESTONES OF THE MID-CARBONIFEROUS YOREDALE GROUP ON THE ASKRIGG BLOCK.

A thesis submitted in the University of Southampton

for the degree of Doctor of Philosophy

by

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ABSTRACT

FACULTY OF SCIENCE

GEOLOGY

Doctor of Philosophy.

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The best outcrops were measured and described in detail. From samples collected large area stained thin sections were made for microscopic study. X-ray diffraction, X-ray fluorescence and electron microscopy were used for specific investigation of certain samples.

The carbonates consist dominantly of two end members, carbonate mud and bioclastic, mainly crinoid, debris. Most are bioclastic micrites, sparse biomicrites, packed biomicrites or packed biomicrudites though biosparites and biosparrudites are seen occasionally. They contain a fauna including crinoids, brachiopods, corals, molluscs, algae and foraminifera and accumulated in a marine sublittoral environment of normal salinity. In places coral, brachiopod and algal biostromes are developed and bioherms, consisting of mounds of unbedded bryozoan calcilutite or crinoid-stem calcirudites both capped and flanked by bedded crinoid-stem calcarenites and calcirudites, occur locally. The bioherms swell the limestone thickness considerably and mark sites of exceptionally abundant carbonate production. Most of the carbonate is biogenic, the finer carbonate silt and mud resulting from post-mortem mechanical or biological breakdown of organic skeletons. Since accumulation a complicated sequence of chemical, mineralogical and textural changes has occurred during lithification, diagenesis and epigenesis including carbonate cementation, dissolution, neomorphism, dolomitisation and silicification.

The cherts associated with the Limestones are biogenic and often contain abundant siliceous sponge spicules. They result from release of silica rich connate water along faults during periods of fault movement.

The Askrigg Block was tectonically active during accumulation of the Limestones. Movements altered the depositional environment and are recorded in the sediments by variations in thickness and lithology, the location of and relationships between certain lithologies and the presence and position of erosion surfaces. The bioherms show successive displacement northwards with time in response to southward tilting of the Block. This tilting caused deepening of the sea over the southern region preventing biogenic carbonate production and formation of the Underset and Crow Limestones in this area. The major underlying cause of these movements is related to differential subsidence along the faults bounding the Askrigg Block. Locking or increased drag on the faults caused tilting or downwarp of the Block edges. Tilting was sometimes compensatory, downward movement of one edge being accompanied by uplift of the opposite edge. Movements on the Askrigg Block not directly related to motion on the boundary faults shows the Block is not monolithic.

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I also wish to record gratitude to my mother for typing this thesis and to both my parents for encouragement and financial support during this work.

Special thanks go to Dr. Derek Moore who not only guided and supervised this research but also inspired it. To him I am deeply indebted.

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PHOTOMICROGRAPHS (cont).

INTRODUCTION

INTRODUCTION.

Most recent research on rocks of the Yoredale Group has been confined to the mapping and description of small areas. It is unfortunate that these areas are commonly isolated from one another by narrow tracts of land which are too small for new research projects. Little work has been done on the regional variations of the rocks, especially limestones. This thesis sets out to trace three limestones, the Middle, Underset and Crow Limestones (with associated cherts), over the whole of the Askrigg Block and the area adjacent to its northern margin, in an attempt to gain information about their sedimentology.

The Main Limestone is not included in this study because work by another research student had commenced prior to initiation of this project.

LOCATION OF THE AREA.

The region studied (Fig.1.) comprises the Askrigg Block and the area adjacent to its northern margin. It is situated in North Yorkshire and Cumbria.

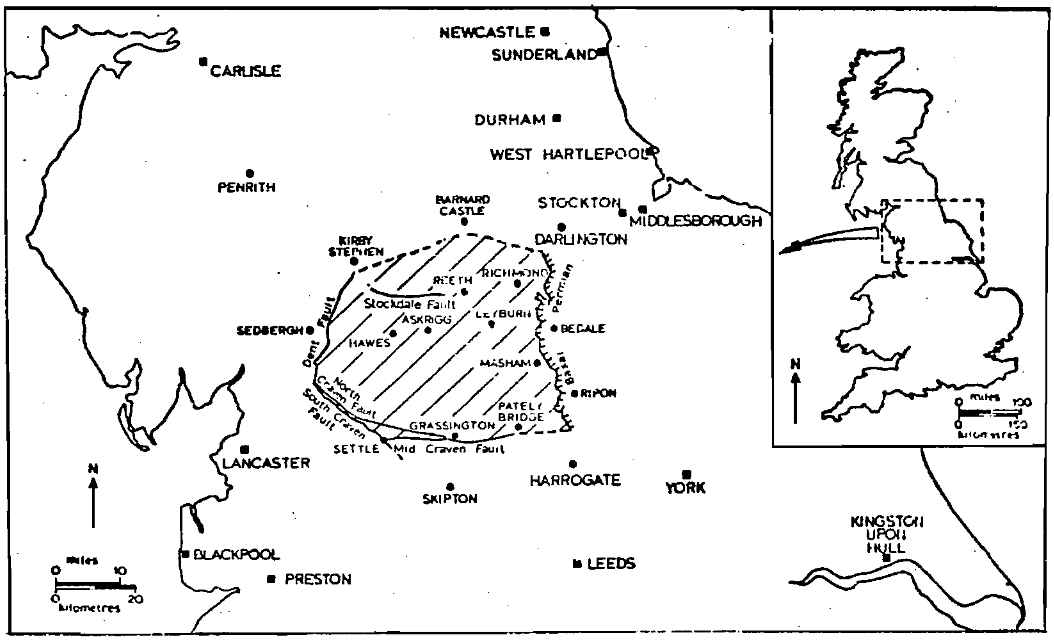


Fig.1. Map showing location of the area studied.

The area is bounded to the south by the South and Mid Craven Faults and to the west by the Dent Fault. To the east the Permian unconformity marks the eastern edge of exposed Carboniferous rocks but the Askrigg Block continues eastwards for some distance (p.10). The northern limit of the area passes westwards along the southern watershed of the River Tees, along the River Greta, down Sleightholme Beck and around the north side of Kaber Fell to Birkett Common. This is north of the Askrigg Block whose northern boundary is the Stockdale Fault.

HISTORY OF PREVIOUS RESEARCH.

Only a brief history of research is given here as an extensive bibliography can be found in Rayner (1953). A short general account of the Yoredale Group is given by Ramsbottom (1974) in 'The Geology and Mineral Resources of Yorkshire' published by the Yorkshire Geological Society. A more detailed account of the Yoredale Group in Wensleydale, the type area, is published by Moore (1958).

The early miners knew a great deal about the country rocks, especially those of economic importance, long before the first published description of rocks of the Yoredale Group by Westgarth Forster (1809). The first publication on the geology of the Yoredale Group in the area studied is by Sedgwick (1835) who described a series of transverse and longitudinal sections between Penyghent and Kirby Stephen. He recorded a group of rocks above the Great Scar Limestone and below the Millstone Grit more than 1,000 feet thick and composed essentially of limestone, shale and sandstone.

Sedgwick's pioneering work was overshadowed in the following year by Phillips' publication 'Illustrations of the Geology of Yorkshire part II The Mountain Limestone District' (1836). Phillips showed a detailed understanding of the geology of the northern part of Yorkshire and established the persistence of the more important limestones in the group of limestones, shales and sandstones that Sedgwick (1835) recorded above the Great Scar Limestone. Phillips called these rocks the 'Yoredale Series' and took upper Wensleydale as his type area. On the basis of many measured sections he documented the rocks using the thicker limestones as a framework for the succession.

After Phillips' outstanding work little research was done until the arrival of the Officers of the Geological Survey in the 1870's who commenced to map the area. Of the accompanying memoirs only those dealing with Sheet 50, the Ingleborough Memoir (1890) and Sheet 40, the Mallerstang Memoir,(1891) were published. They frequently pay tribute to the excellence of Phillips' work and adopted his succession with a few additions and minor amendments.

In 1891 Dakyns described the area between Grassington and Kettlewell but this was supplemented and expanded in 1892 when he discussed the geology of the country between Grassington and Wensleydale.

Fresh stimulus was given to the study of Carboniferous rocks by Vaughan (1906) whose zonal work was applied to the northwest province by Garwood (1907, 1912). Vaughan's coral-brachiopod zones enabled correlations to be carried much farther afield but the zones were not fine enough to enable detailed correlation and diagnostic faunas were often scarce. In 1924 Bisat established his goniatite zones but the scarcity of goniatites in the Yoredale Group made zonation difficult.

Hudson published a series of papers from 1924 onwards. He briefly dealt with the stratigraphy in 1924 when discussing the rhythmic succession of the Yoredale Group first recorded by Phillips (1836) and in 1925, in a combined paper with Chubb, (Chubb & Hudson, 1925) discussed the nature of the junction between the Lower Carboniferous and Millstone Grit of northwest Yorkshire. In the same year he described faunal horizons in the Yoredale Group and in 1929 wrote two papers, one dealing with '*Erythrospongia lithodes*' (Hudson) a 'sponge' from the Middle Limestone, the other concerned with the distribution of _Orionastraea_ spp. In 1933 and 1938 descriptions and reports of Geologists Association field meetings to the Yorkshire Dales were published by Hudson and others. Later in 1945 Hudson published on the upper beds of the Yoredale Group.

A year after Hudson's first paper Tonks (1925), aided by new exposures excavated during reservoir construction, described the rocks of the Yoredale Group in Nidderdale and gave detailed faunal lists. Later Anderson (1928) studied the beds in the Skyreholme anticline farther south and in 1931 Miller & Turner described the Carboniferous succession along the Dent Fault. In 1938 Carruthers dealt briefly with the geology around Tan Hill and Rogans Seat and the stratigraphy and structure of the Greenhow mining area was published by Dunham & Stubblefield in 1945.

Knowledge of the stratigraphy of the Yoredale Group grew rapidly in the 1950's. The Carboniferous geology of the Grassington area was described by Black (1950) and later by Joysey (1955). Black in conjunction with Bond (Black & Bond, 1952) also described the Yoredale succession in the northern flank of the Skyreholme anticline. The geology of Ingleborough was published by Dunham et al (1953) and Hicks (1959) and in 1956 Turner recorded some faunal bands of Upper Visean and early Namurian age. In 1957 Rowell & Scanlon covered the Namurian succession in the northwest corner of the Askrigg Block and Reading (1957) and Wells (1958) described the stratigraphy and structure of the Cotherstone Syncline and Middleton Tyas-Sleightholme anticline respectively. Moore's work on the Yoredale Group in Upper Wensleydale, the type area of Phillips' 'Yoredale Series', published in the following year (Moore,1958) established the full succession up to the Main Limestone. Later Moore (1959) discussed the role of deltas in the formation of the cyclothems comprising the Yoredale Group and in 1960 Wilson published details of the Carboniferous rocks of Coverdale and adjacent areas.

Work by Varker (1967) on conodonts and by Hallett (1970) on foraminifera and algae in the Yoredale Group has increased our knowledge of the microfaunas.

The cherts of the Yoredale Group were mentioned first by Hinde (1887) who considered them organic. Later, after studying the cherts in Arkengarthdale and Swaledale, Sargent (1929) concluded they were inorganic. In 1955 cherts and limestones from the Crow Series near Richmond and the cherts between the Main and Crow Limestones were described by Hey (1956) and Wells (1955) respectively. Both Hey (1956) and Wells (1955) concluded the cherts were inorganic.

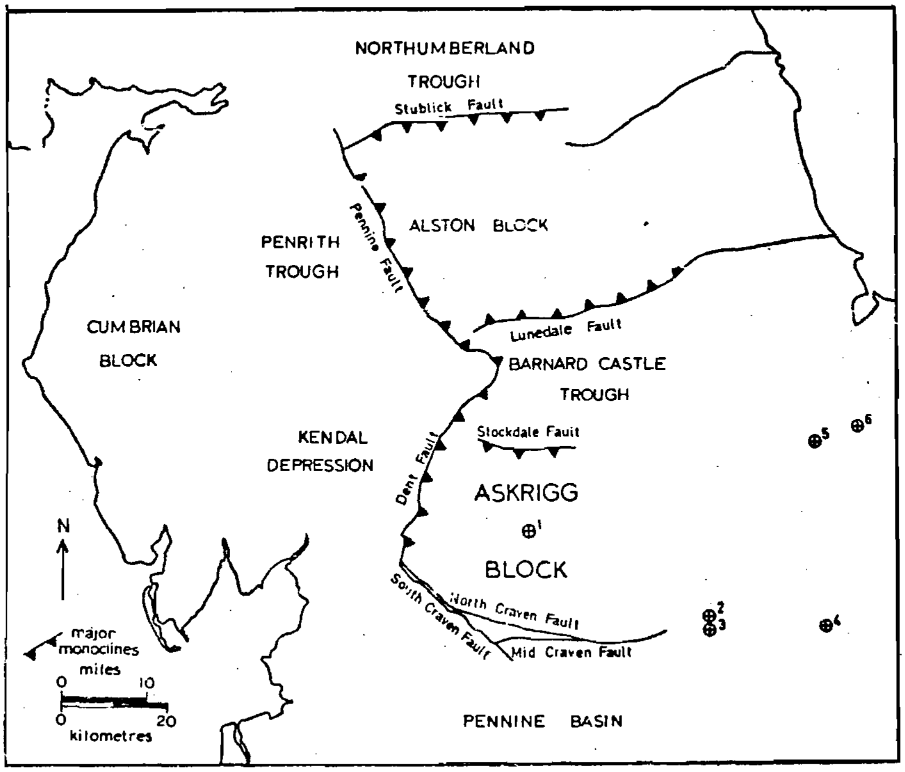
Geophysical investigations of the northern Pennines, notably those by Bott (1961, 1967) and Myers & Wardell (1967), have proved much about the basement structure of the Askrigg Block and adjacent areas. The granite postulated by Bott (1961, 1967) beneath the Askrigg Block was proved recently by the Raydale Borehole put down by the Institute of Geological Sciences in 1973 (Dunham,1974).

REGIONAL STRUCTURE.

The Askrigg Block was named by Hudson (1938) following the designation of the area to the north as the Alston Block by Trotter & Hollingworth (1928). Previously these has been known collectively as the North of England Block (Marr, 1921) an area where the Carboniferous rocks are generally flat lying with minor faulting and only a gentle regional dip to the east. In contrast, rocks of similar age adjacent to the Block are folded into long crested anticlines. On the blocks deposition was discontinuous during Carboniferous times. The sediments are relatively thin when compared with the much thicker and more complete succession of the same age in the flanking troughs and basins.

Geophysical investigations of the northern Pennines have proved much about the basement structure of the Askrigg Block. The discovery of granite beneath the Alston Block (Dunham, 1965) prompted further research on the negative gravity anomaly recorded on the Askrigg Block by Whetton et al (1965) who interpreted it as an acid Precambrian core, possibly including both metamorphic and igneous rocks. The anomaly was studied in detail by Bott (1961, 1967) and Myers & Wardell (1967). It was initially interpreted by Bott & Masson-Smith (Bott, 1961) as either a granite or a sedimentary basin, the former being preferred. A combined interpretation of detailed gravity and proton magnetometer profiles across the anomaly observed by O'Connor (Bott, 1967) provided convincing evidence favouring a granite which Bott (1961) had named the Wensleydale Granite. In 1973 a borehole sunk by the Institute of Geological Sciences in Raydale proved correct Bott's interpretation when it penetrated granite 500m beneath ground surface (Dunham, 1974).

The regional structure and the location of boreholes mentioned in the text are shown on Fig. 2.



Boreholes:- 1. Raydale. 4. Ellenthorpe.
2. Aldfield. 5. Harlsey.
3. Sawley. 6. Cleveland Hills.

Fig.2. The Structural Setting of the Askrigg Block in Northern England.

The Askrigg Block is separated from the Alston Block by the Barnard Castle Trough, a structure proved only recently by gravity surveys (Bott, 1967). It is bounded to the north by the Stockdale Fault which, though well developed in the west, is obscure east of Reeth.

The western edge of the Askrigg Block is marked by the Dent Fault with the Kendal Depression to the west. Both the Dent Fault and the Stockdale Fault are ruptured monoclines and separate Carboniferous rocks of similar lithology.

The Mid Craven Fault defines the southern margin south of which is the Pennine Basin. In contrast to the Dent and Stockdale Faults it is a clean fracture and separates dissimilar Carboniferous rocks, a consequence of its greater magnitude of throw both before and during Carboniferous deposition. It separates thin and incomplete shallow water Carboniferous sediments on the Block from much thicker, deeper water Carboniferous deposits in the Pennine Basin. Knoll limestones situated along the south side of the Mid Craven Fault mark the southern edge of the Block. They can be traced from Settle in the west to Appletreewick in the east. Knolls similar to those at Settle are seen in the Carnforth area to the west (Hudson, 1937; Moseley, 1954) and it is probable that there are knolls between Settle and Carnforth concealed beneath the cover of Namurian rocks. Evidence of their continuation east of Appletreewick is provided by Dakyns (1890) who, using shake holes as evidence, considered limestone to be present at a shallow depth beneath the Grassington Grit on Pock Stones Moor south of Greenhow. The presence of limestone at this level is explained best as belonging to a knoll rising close to the base of the Grassington Grit. A similar relationship is shown clearly by the Stebden knoll at Cracoe. East of Pately Bridge the southern edge of the Askrigg Block is not obvious at surface as the Craven Fault Line becomes indistinct and erosion has not penetrated deep enough to expose Dinantian rocks. Kent (1966) considered unlikely the possibility that the Coxwold-Gilling-Flamborough fault belt represents the easterly continuation of the Craven Fault line and hence the southern margin of the Block. He based his conslusion on the Cleveland Hills No.1. boring and geophysical evidence that indicates the Mesozoic area of folding is broadly co-extensive with basin or trough development.

The Aldfield No.1. and Sawley No.1. boreholes, 8 kilometres east-northeast and east of Pately Bridge respectively, penetrated Carboniferous 'block' successions though the succession in the Sawley No.1. borehole was originally incorrectly described as of 'gulf' type by Falcon & Kent (1960). They start at approximately the same stratigraphic horizon but in the Sawley No.1. boring, only five kilometres south of the Aldfield No.1. bore, the Lower Carboniferous was encountered almost 1,000 feet deeper (Falcon & Kent, 1960). Clearly a major structure passes between the two boreholes, possibly a continuation of the North Craven Fault System. However, the Ellenthorpe No.1. borehole about 18 kilometres farther east penetrated Lower Carboniferous rocks of 'basin' type. The margin of the Askrigg Block must, therefore, pass between the Ellenthorpe No.1. borehole and the Aldfield No.1. and Sawley No.1. boreholes.

The east edge of the Block is obscure. The 'Darlington Fault' (Fowler, 1945) could have marked the eastern edge but recent re-surveying and revision by the Institute of Geological Sciences has shown that the 'Darlington Fault' does not exist (pers. comm.) and it has now been omitted from the Richmond 1" O.S. Geol. Sheet.

Kent (1966) considered the most notable gross feature is the sharp eastward change from typically unfolded uniformly eastward-dipping Permo-Triassic rocks to the broad folding of the Cleveland Hills and northeast Yorkshire. According to Kent (1966), within the folded area the Cleveland Hills No.1. borehole proved a 'gulf' development of Carboniferous rocks and the surface indication of this structural boundary is provided by a moderate sized north-south fault just east of the Thirsk to Stockton road. He considers this approximates to the north-south trend on the aeromagnetic map and also flanks a positive gravity anomaly mapped by White (1949). In support of this interpretation Kent (1966) quotes the Harlsey No.1. boring to the west of the fault which penetrated Carboniferous rocks of 'block' type.

If Kent's interpretation that the rocks of the Harlsey No.1. boring and the Cleveland Hills No.1. boring are of 'block' and 'gulf' type respectively, then the edge of the Block must pass between them. However, the published evidence on which a north-south eastern boundary to the Block is fixed is not conclusive. The gravity data in this region, unlike the area farther west, is scanty.

Kent (1966) considered the Stainmore Syncline marked the northern edge of the Askrigg Block thus positioning the Cleveland Hills No.1. borehole to the east of the Block. However, Bott's geophysical work (1967) has proved that the Stockdale Fault, much farther south, marks the northern edge. This results in the possibility that the Cleveland Hills No.1. borehole may be in the southern part of the Barnard Castle Trough for when the general trend of the Stockdale Fault is produced eastwards it passes south of the borehole. The Cleveland Hills No.1. borehole, therefore, may be north rather than east of the Block.

The Fordon No.1. borehole near Scarborough penetrated 'block' sediments of the Yoredale Group. Kent (1966) advocated the eastern edge of the Askrigg Block passed between the Harlsey No.1. and Cleveland Hills No.1. boreholes and that a trough separated it from the positive area penetrated by the Fordon No.1. borehole. It is at least a possibility that the Askrigg Block extends farther east than previously thought. The Alston Block is known to extend eastwards beyond the northeast coast. However, only further detailed geophysical and borehole data will enable positive identification of the northeast, east and southeastern limits of the Askrigg Block.

The faults bounding the Block are pre-Carboniferous basement structures, which, in addition to their main post-Carboniferous movement, were spasmodically active throughout the Carboniferous Period.

STRATIGRAPHY OF THE YOREDALE GROUP.

i) Biostratigraphy.

Subdivision of the Carboniferous System in the north of England is based on successive cephalopod faunas. The Pennine Basin is the accepted type area for most of the Namurian Series and the upper part of the underlying Visean Series.

The Yoredale Group occupies a similar position relative to the Millstone Grit Group as does Bowland Shale wherein diagnostic goniatites of the Bollandian Stages are found. Goniatites in the Yoredale Group are rather sparse and detailed correlation between the two has proved difficult. Zone boundaries in the Yoredale Group seem to coincide with the base of major limestones i.e. at a relatively constant position with respect to Yoredale cyclothems. The goniatite faunas of the Bowland Shale are found in thin beds of shale usually with large calcareous concretions. These are separated by less fossiliferous, more silty shales which, in places, pass upwards into turbidites of the Pendleside Sandstone. The sandstone is often overlain directly by shale with calcareous concretions giving asymmetric cyclothems with rock types similar to the limestone, shale, sandstone cyclothem of the Yoredale Group (Moore, unpubl.) Moore notes there are seven goniatite zones in the Bollandian and eight major cyclothems in the corresponding part of the Yoredale Group, with a further three goniatite zones and cyclothems in the Pendlian Stage. He suggests a 'one to one' correlation between Bowland Shale goniatite zones and Yoredale cyclothems seems highly likely with the exception of the Five Yard and Three Yard cyclothems which are both equated with the Upper

Bollandian zone P_2b.

The biostratigraphy of the Yoredale Group and its correlation with the lithostratigraphy is shown in Fig. 3.

LITHOSTRATIGRAPHY		BIOSTRATIGRAPHY				
GROUP	FORMATION	STAGE			SERIES	SYSTEM
MILLSTONE GRIT GROUP	Grassington Grit					
YOREDALE GROUP	Upper Stonesdale Limestone	E_{1c}	E_1	Pendlian	NAMURIAN	UPPER CARBONIFEROUS (=SILESIAN SUBSYSTEM)
	Lower Stonesdale Limestone					
	Crow Limestone					
	Little Limestone	E_{1b}				
	Main Limestone	E_{1a}				
	Underset Limestone	P_{2c}	P_2	Upper Bollandian	VISEAN	LOWER CARBONIFEROUS (=DINANTIAN SUBSYSTEM)
	Three Yard Limestone	P_{2b}				
	Five Yard Limestone					
	Middle Limestone	P_{2a}				
	Simonstone Limestone	P_{1d}	P_1	Lower Bollandian		
	Hardraw Scar Limestone	P_{1c}				
	Gayle Limestone	P_{1b}				
	Hawes Limestone	P_{1a}				
GREAT SCAR GROUP	Kingsdale Limestone	B_2 B_1	B	Cracoean		

Fig.3. Stratigraphy of the Yoredale Group.

ii) Lithostratigraphy.

The Yoredale Group on the Askrigg Block rests conformably on, or interdigitates with, the Kingsdale Limestone of the Great Scar Group and is overlain unconformably by the Millstone Grit Group, being cut out totally in the southeast. A northwest to southeast section across the Askrigg Block from Shunner Fell to Grassington is shown in Fig. 4.

The Yoredale Group consists of limestones, shales and sandstones arranged in well defined cyclothems in which the clastic rocks display a coarsening upward sequence sometimes capped by seatearth and coal. Within the major cyclothems smaller cycles can often be recognised, Fig.5.

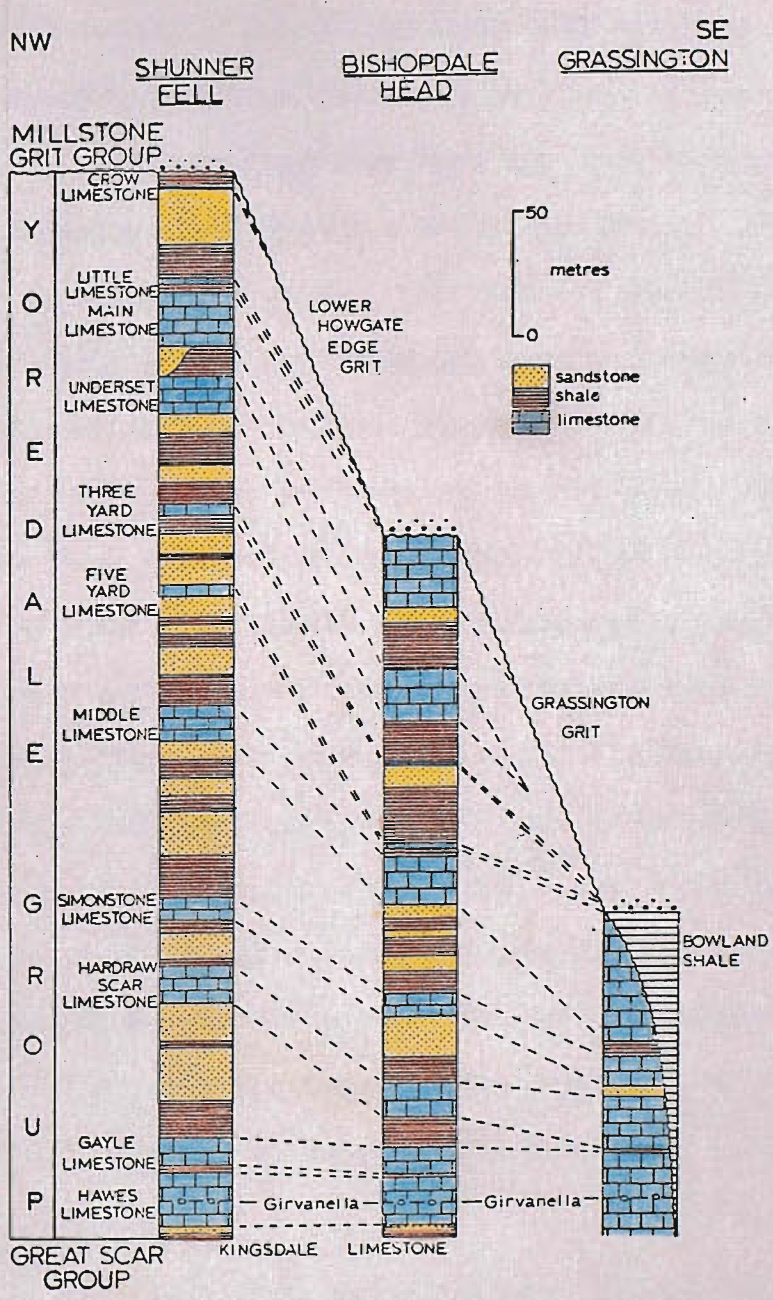


Fig.4. Lithostratigraphic correlation of the Yoredale Group across the Askrigg Block.

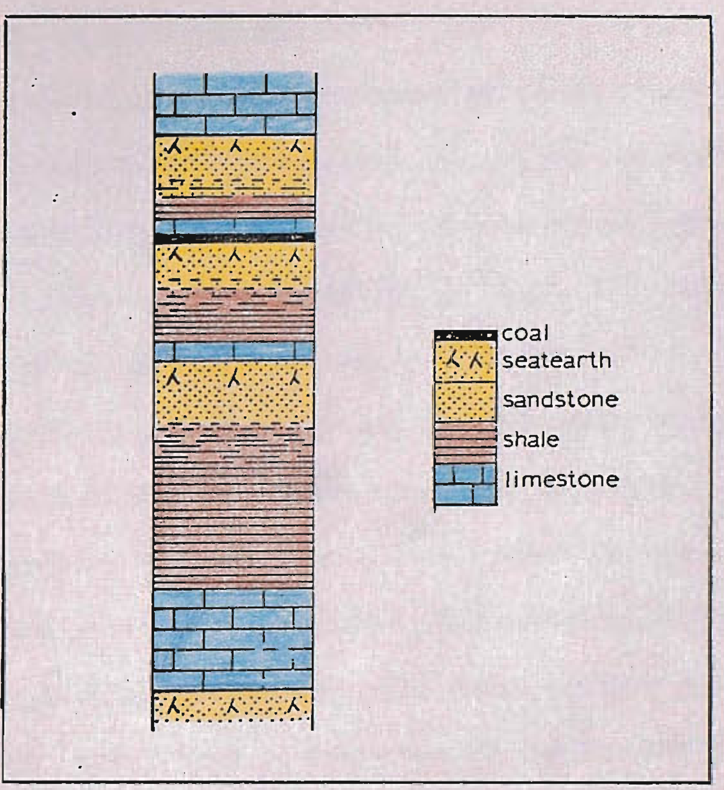


Fig. 5. A major cyclothem comprising three minor cyclothems. (generalised).

Locally cutting these beds are linear bodies of sandstone containing very coarse plant debris (logs) and mudclast rudite lenses. In the north-eastern part of the Block thick cherts are associated with the limestones in the upper part of the Yoredale Group. The thick limestones are usually persistent and form terraces which can be mapped easily in the field. They are named individually and form a framework for the lithostratigraphy of the Yoredale Group (Fig. 6.)

Intra-Carboniferous movements on the faults bounding the Askrigg Block altered the depositional environment and are documented in the sediments. They are recorded by variations in thickness and lithology, the location of, and relationships between, certain lithologies and the presence and position of erosion surfaces. Such movements affecting the Limestones studied are discussed.

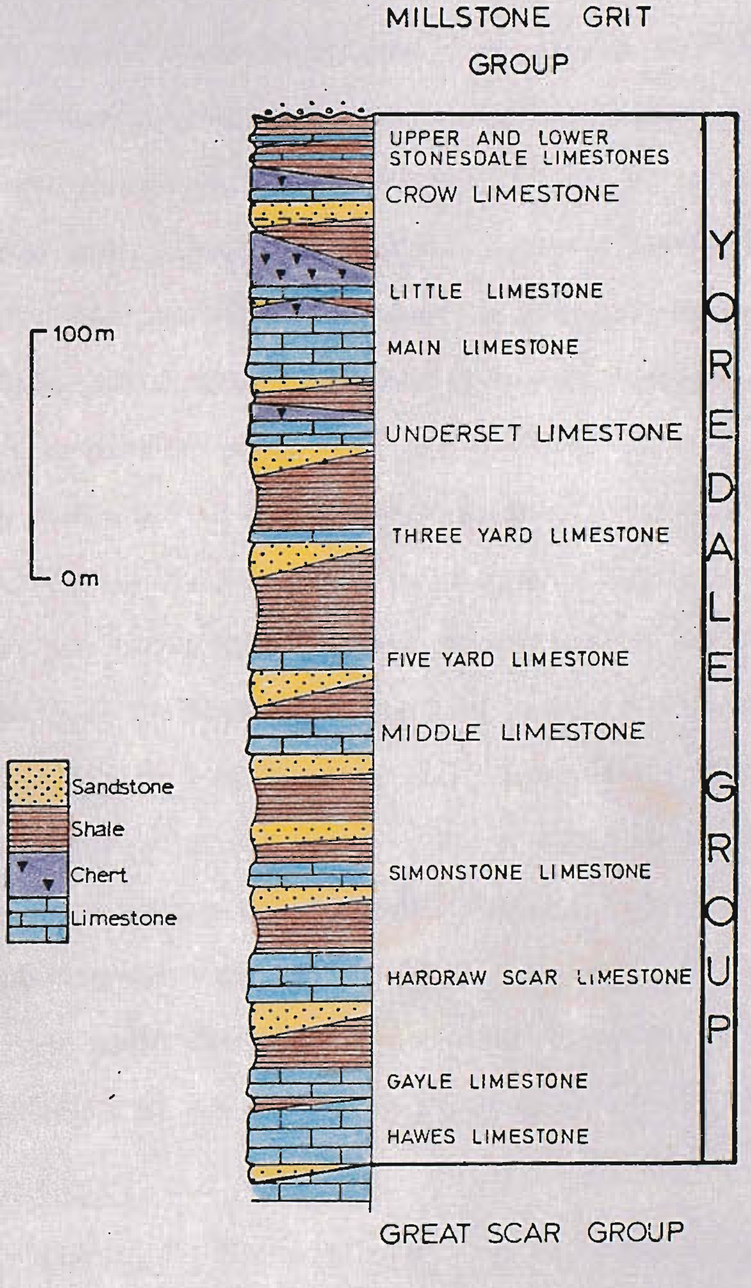


Fig. 6. Lithostratigraphy of the Yoredale Group on the Askrigg Block (generalised).

PROCEDURES.

Research commenced after initial reconnaisance in September, 1971. A regional approach was necessary to cover 2,500 square kilometres but areas of rapid change in lithology were studied in detail. An extensive field work programme was undertaken in April and from June to August, 1972, from May to September, 1973 and in April and August, 1974. The large size of the area precluded tracing the outcrop of each formation on foot so good exposures were selected for study. Most of the good outcrops are recorded in the literature (published and unpublished) and confined usually to streams, hillside scars and man-made exposures.

Sections in the field were measured by steel tape and Abney Level. Wherever possible vertical faces of outcrop were measured by steel tape and linked together by tracing bedding planes. Where this was not possible an Abney Level was used. The long sighting distances in many sections made precise measurement difficult. Some sections were measured separately by both steel tape and Abney Level; the thicknesses obtained fell within 10% of one another with no consistent bias. Measurements were made on a bed-by-bed basis wherever possible. In poorly exposed ground all the available information was recorded for comparison with better exposed sections nearby. Some extremely thin shale films, too thin to produce persistent partings, although noted, were discounted during measurement when the beds above and below were similar. The limestones were described according to colour, mineral composition, grain size, fossil content, nature and abundance of allochems and content of terrigenous impurity. The initial sampling programme was one hand specimen of each rock type from every outcrop but it soon became apparent that some rock types were common to most outcrops and these were less rigorously sampled as work proceeded. Any unusual rock types were always collected.

From selected samples large area thin sections were made and stained with an acidified solution of alizarin red S and potassium ferricyanide to differentiate the various carbonate minerals present. X-ray diffraction, X-ray fluorescence and transmission and scanning electron microscopy were used for specific investigation of certain samples.

NOMENCLATURE.

The classifications used in this thesis are described below.

i) Stratal terminology.

The classification used for bedding and lamination and shown in Fig. 7. is that proposed by Campbell (1967).

metres	BEDDING AND PARTING	LAMINATION	millimetres.
	very thick		
1.0			
	thick		
0.30			
	medium	very thick	
0.10			100
	thin	thick	
0.03			30
	very thin	medium	
			10
		thin	
			3
		very thin	

Fig. 7. Classification of bedding, lamination and parting after Ingram (1954) and Campbell (1967).

A bed is defined as an individual unit of sedimentation bounded by bedding surfaces which are essentially time planes. A group of beds with identical lithologies is termed a bedset. Beds may be internally laminated, each lamina being internally homogeneous with no internal structure. When laminae are oblique to the bedding cross-lamination results. This can be classified according to Allen (1963).

A parting is defined as a tectonic fracture parallel to the bedding. Classification of parting thickness, the distance between adjacent partings, is also shown in Fig. 7.

ii) Classification of Carbonate Rocks.

Many classifications of carbonate rocks have been proposed (Ham & Pray, 1962; Bissell & Chillingar, 1967) but, as yet, no single classification has been adopted universally. This is because single classifications can include only a few of the multitude of parameters that the carbonate rocks possess. Not only are primary carbonate sediments highly complex and varied but they are extremely susceptible to post-depositional modification. Classifications therefore concentrate, to a greater or lesser degree, on certain aspects of the rock, some being more specific than others. It is readily apparent that there is no ideal classification of carbonate rocks. Single terms, although very useful, cannot hope to describe such complex rocks adequately. There is no substitute for concise but detailed descriptions both in the field and under the microscope which can, if necessary, be supplemented by data obtained from application of other techniques.

Two classifications are used in this study, a field classification based on the Wentworth-Udden Grade Scale (Pettijohn, 1957) shown in Fig. 8. and a petrographic classification modified after Folk (1959) and Dunham (1962) discussed in the section on petrography (p.337, Fig. 64)

a) Field Classification.

The vast majority of limestones encountered in this study have a fine grained matrix with a highly variable content of allochems, dominantly bioclastic debris, and terrigenous material. They were classified broadly in the field into calcilutites, calcarenites and calcirudites, terms introduced by Grabau (1904, 1913). An attempt was made to distinguish between grain-supported and matrix-supported carbonates (Dunham, 1962) and the terms calcarenite and calcirudite are applied only to carbonates in which allochems of the appropriate grain size clearly form a framework to the rock. Carbonates with allochems of arenite and rudite size but which are not abundant enough to form a framework are classified as calcilutites with an adjective expressing the abundance of allochems visible e.g. sparse, scattered or abundant. Unless stated otherwise allochems are of arenite size.

The particle size scale used, shown in Fig. 8, is based on the Wentworth-Udden Scale discussed by Pettijohn (1957). This is a geometric scale based on the grain diameter in millimetres.

Size (mm)	Grade	Particle	Sediment	Carbonate Sediment
		BOULDER	RUDITE	CALCIRUDITE
256	coarse	COBBLE		
128	fine			
64	very coarse	PEBBLE		
32	coarse			
16	medium			
8	fine			
4	extremely coarse	SAND	ARENITE	CALCARENITE
2	very coarse			
1	coarse			
1/2	medium			
1/4	fine			
1/8	very fine			
1/16	coarse	SILT	LUTITE	CALCILUTITE
1/32	medium			
1/64	fine			
1/128	very fine			
1/256		CLAY		

Fig. 8. Particle Size Scale (after Pettijohn, 1957).

b) Rock Colour.

Rock colours are described in accordance with the Rock Colour Chart prepared by the Rock Colour Chart Committee and distributed by the Geological Society of America. However, rocks described as light grey and dark grey include those of medium light grey and medium dark grey colour respectively, because differences in illumination and sample wetness made meaningful distinction of these values impossible.

THE MIDDLE LIMESTONE.

THE MIDDLE LIMESTONE

The Middle Limestone was named first by Phillips (1836) though Sedgwick (1835) had previously called it the Mosdale Moor or Wold Limestone. It is present over the entire area and is usually easily divisible into three persistent limestone members which are separated in the north by clastics and thin limestones. Dakyns (1891) stated in the Mallerstang Memoir that the three massive divisions of the Middle Limestone, "correspond so well with those of the Scar, the Cockleshell and the Single Post Limestones of Upper Teesdale, Alston Moor etc., that we do not hesitate to correlate the parts of the Middle Limestone with those bands". Hudson (1924, 1929) and Turner (1927) published faunal evidence which Hudson believed to substantiate the Geological Survey's correlation. Hudson based his correlations on a Cyathaxonia fauna in the shales above the Middle Limestone in Wensleydale and the Scar Limestone of Teesdale and the occurrence of Orionastraea spp.at the base of the Middle Limestone and the Single Post Limestone. He also used the presence of 'Erythrospongia lithodes' (Hudson) in the Middle Limestone of Wensleydale and the Single Post Limestone of Teesdale. 'Erythrospongia' is not a sponge as Hudson suggested but a bioturbation structure (p.183) therefore this faunal correlation is invalid. On the basis of these correlations the terms Single Post Limestone, Cockleshell Limestone and Scar Limestone have been applied occasionally to parts of the Middle Limestone.

Further evidence in support of this correlation is the presence of a coral biostrome at the base of the Middle Limestone and at the base of the Single Post Limestone and the similarity in distinctive lithology of the Single Post Limestone and the lowest part of the Middle Limestone;

both are typically unbedded and mottled. The Cockleshell Limestone with numerous Gigantoproductus is similar faunally to the central division of the Middle Limestone which also contains Gigantoproductus. Finally, Gigantoproductus occurs at the base of the Scar Limestone and at the base of the upper division of the Middle Limestone. There is, therefore, good evidence to correlate the three members of the Middle Limestone, separated by clastics and thin limestones in the north of the Askrigg Block, with the Single Post, Cockleshell and Scar Limestones of the Alston Block which are separated also by clastic sediments (Fig. 9.)

Varker (1967) showed by studying the numerical distribution of conodonts in the Yoredale Group that in the limestone they are least common at the base but increase upwards in number and are usually most abundant in the upper part. He found that the Middle Limestone, unlike the other limestones sampled, showed a three fold numerical distribution suggesting the presence of three limestones.

In this study the three main divisions of the Middle Limestone are considered equivalent to the Single Post, Cockleshell and Scar Limestones and are referred to by these names. They are separated over the northwestern and central parts of the Askrigg Block by less persistent, more lithologically varied rocks informally named the Lower and Upper Partings. The Lower Parting separates the Single Post and Cockleshell Limestones whilst the Upper Parting separates the Cockleshell and Scar Limestones. In the northwest the Lower and Upper Partings are thick and contain deltaic shales and sandstones. On the northern edge of the Askrigg Block the Middle Limestone exceeds 29m

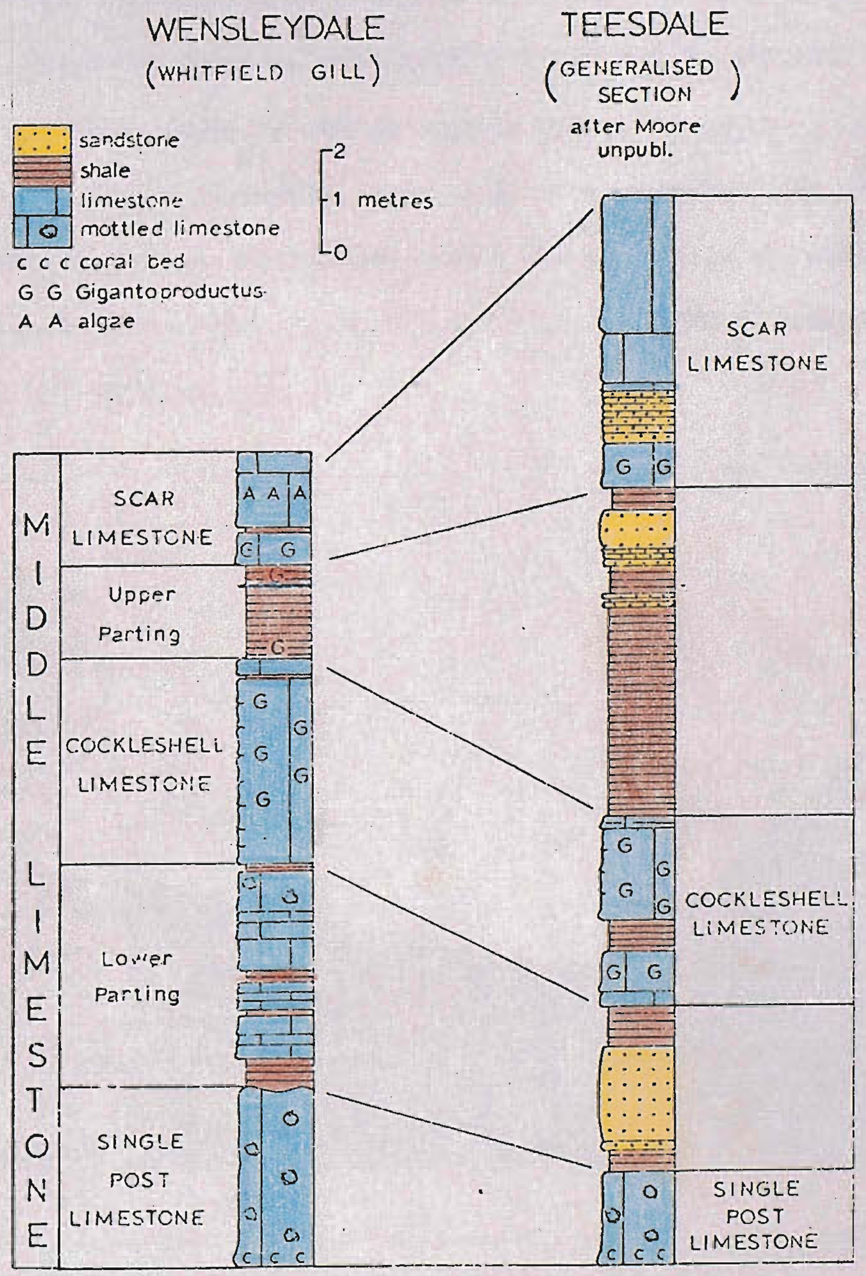


Fig. 9. Lithostratigraphic subdivision of the Middle Limestone on the Askrigg Block and correlation with the Single Post, Cockleshell and Scar Limestones of the Alston Block.

in thickness but farther north, in the southwestern part of the Barnard Castle Trough where the deltaic sediments are even thicker, it exceeds 36m. However, its maximum thickness of more than 50m is attained in the southeast where the Partings are absent and the Middle Limestone is composed almost entirely of coarse crinoid debris. A minimum thickness of 3m is seen in the southwest. Figure 10 shows a west-northwest to east-southeast section through the Middle Limestone from the River Rawthey across the Askrigg Block to Penhill. Isopachs of the Middle Limestone are shown in Fig. 11.

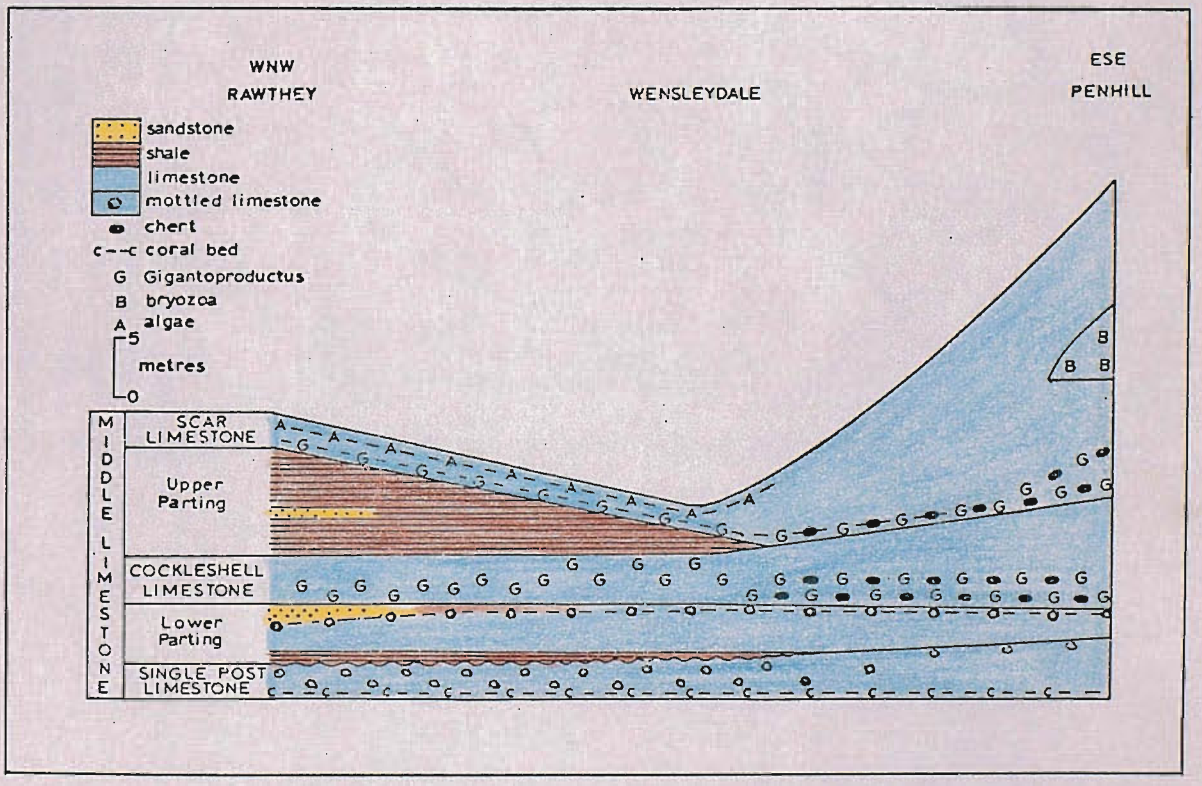


Fig.10. Section of the Middle Limestone from the River Rawthey to Penhill.

The Middle Limestone accumulated over the entire Askrigg Block although in the extreme southeast it was later removed by intra-E_1 erosion immediately preceding deposition of the Grassington Grit.

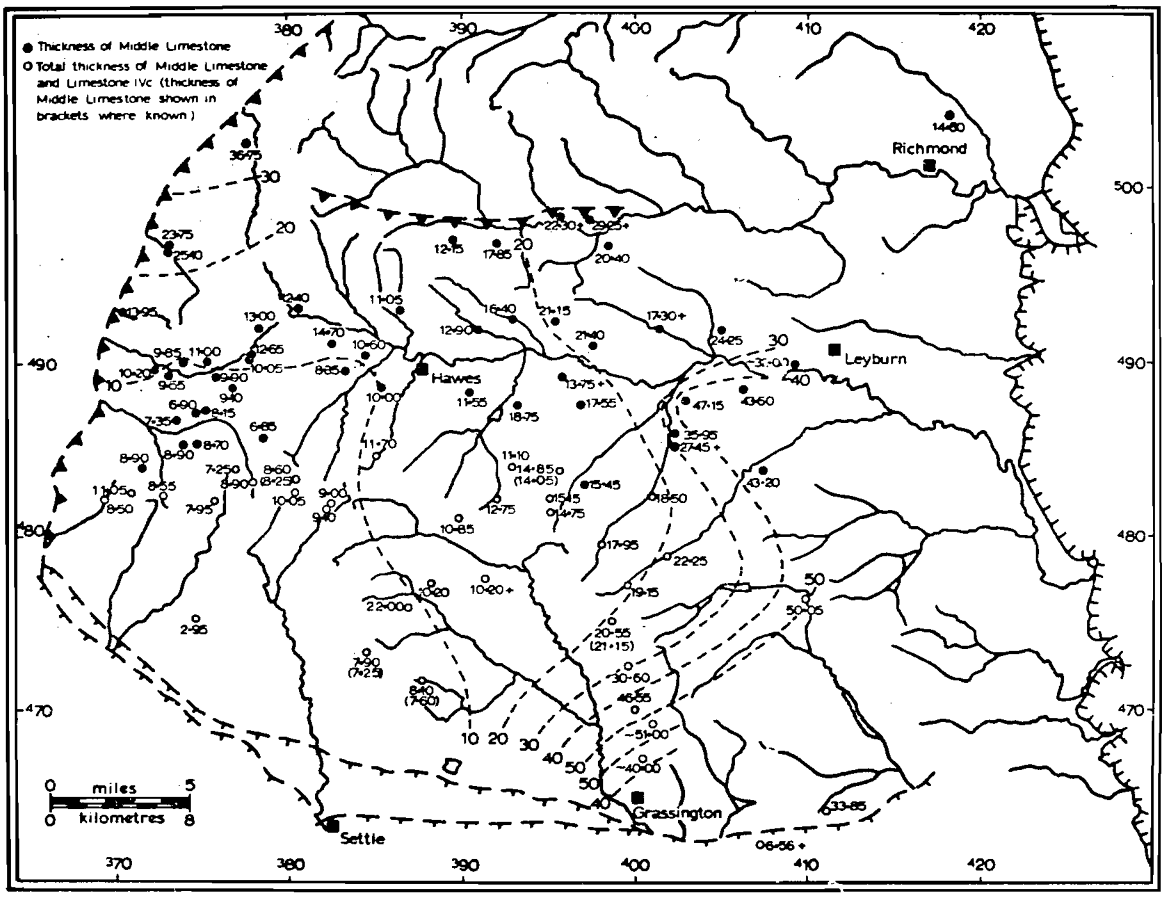


Fig. 11. Isopach map of Middle Limestone.

Most of the main valleys have cut through the Yoredale Group to a level below the Middle Limestone, leaving this Limestone exposed where superficial deposits are absent. Its gentle easterly regional dip is modified only where the Limestone is caught up in the monoclines associated with the Dent and Stockdale Faults, where drag along other faults has produced flexing or where it is locally folded.

Good outcrops are usually restricted to the larger streams, quarries and railway cuttings; rarely is it exposed well on hillsides. The extent and quality of outcrop depends greatly on lithology although other factors such as geographical position and relationship to superficial cover are important. The difference in resistance to weathering and erosion of the five members comprising the Middle Limestone, determined largely by lithology, is reflected in their outcrop. The Single Post Limestone, characteristically a very thick unbedded calcarenite resistant to weathering and erosion, is well exposed in stream sections and sometimes crops out on hillsides forming small scars. The overlying Lower Parting is exposed poorly in streams especially where it contains shale but rarely crops out on hillsides. In Garsdale, however, where it consists of thick and very thick bedded sandstones, good outcrops are seen. The Cockleshell Limestone is moderately well exposed in stream sections and sometimes crops out patchily on fell sides. Where it is well bedded, as in the northwest, its outcrop is often stepped. The Upper Parting, consisting dominantly of shale, is fully exposed only occasionally in streams and rarely crops out on hillsides. The Scar Limestone is exposed moderately well in streams especially where it is thick and underlain by the Upper Parting shale.

Hillside outcrops are not uncommon although in areas where the Scar Limestone is thin, the blocks exposed are often displaced.

To facilitate description of the Middle Limestone the region studied has been divided into six areas, Wensleydale (and its tributary dales), Swaledale and the northeast, Garsdale and the northwest, Dentdale and the southwest, Wharfedale (and its tributary dales) and Nidderdale and the southeast (Fig. 12.) A brief description of the outcrop of the Middle Limestone in these areas is given below.

Wensleydale.

The Middle Limestone crops out on both sides of Wensleydale from Ure Force (SD 801932) at the head of the dale eastward to around Middleham (SE 126878) where it disappears beneath the valley floor. On the northern side its outcrop is generally linear but on the deeply dissected south side it follows the sides of the tributary dales. Exposure is good in the streams draining the north side of the dale although it deteriorates in the east as the Middle Limestone approaches the valley floor. On the south side of the dale good outcrops are sparse. They are normally confined to the upper reaches of the tributary dales, commonly their heads, and to streams draining the northern flanks of the interposed spurs.

Swaledale and the northeast.

The Middle Limestone crops out from Ivelet (SD 936983) on the north side of Swaledale and from Thwaite (SD 884981) on the south side of the dale eastwards to Marrick (SE 077975) where it disappears beneath the valley floor. Between Thwaite and Ivelet on the north side of the dale it is cut out by the Stockdale Fault. The best outcrops are in the

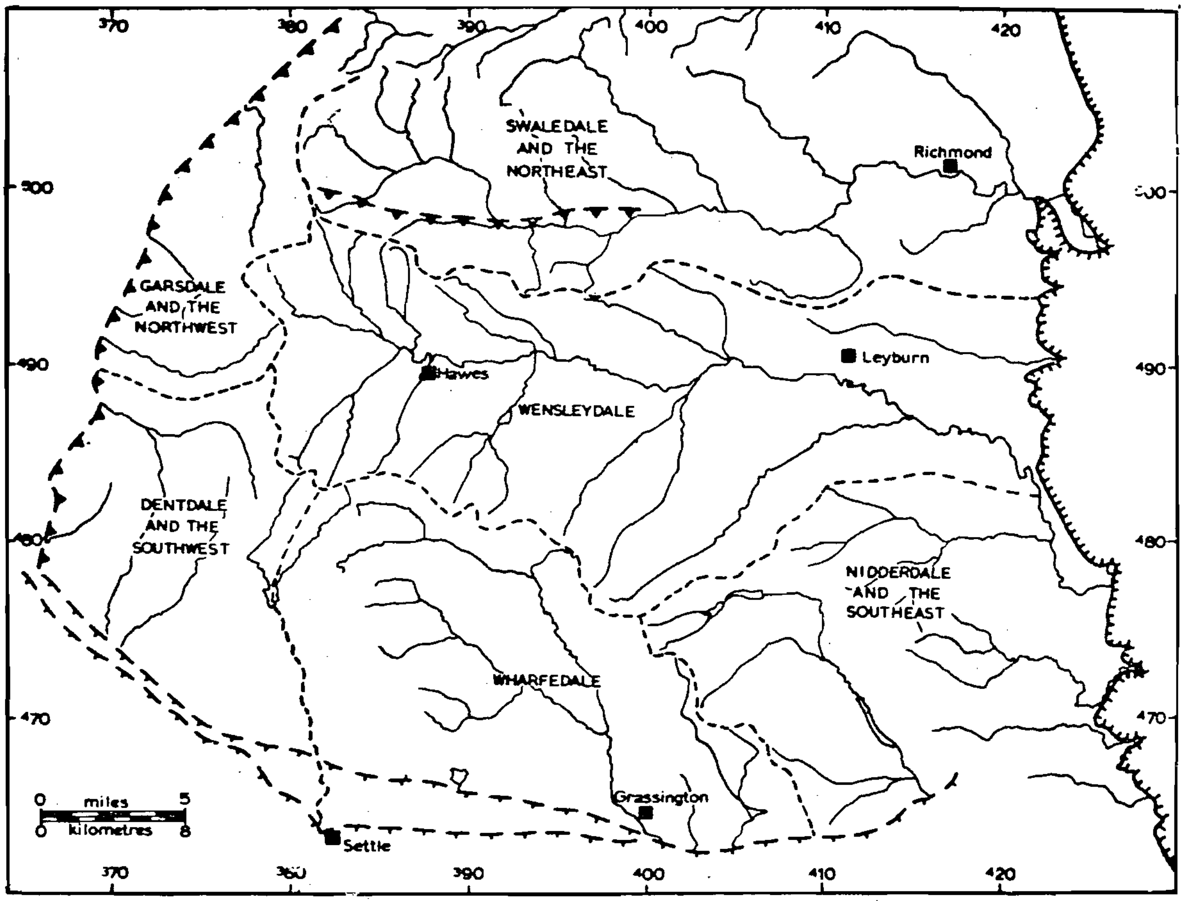


Fig. 12. Areas used for description of Middle Limestone.

vicinity of Low Row Pasture (SD 970980) on the north side of the dale and from Thwaite Beck (SD 884981) to Birks Gill (SD 985969) on the south side. Elsewhere exposure is poor. Northeast of Swaledale the Middle Limestone crops out in the Middleton Tyas-Sleightholme anticline where, despite the poor outcrop generally, a good section is seen in Long Acres Quarry (NZ 181043).

Garsdale and the northwest.

Good outcrops of the Middle Limestone occur from Garsdale Head (SD 790922) westwards to Thrush Gill (SD 745900) along the north side of the dale and as far as Pegs Gill (SD 723899) along the south side of the dale, in the small streams draining the fell sides. Farther west the outcrop is obscured by boulder clay or alluvium. Northwest of Garsdale the Limestone is exposed at several localities on the west side of Baugh Fell as far as Needlehouse Gill (SD 733971). North of Needlehouse Gill the exposure is very poor until the good section in the Birkett Railway Cutting (NY 774029) is reached.

Dentdale and the southwest.

Along the north side of Dentdale the Middle Limestone is exposed well only from Stock Beck (SD 734870) eastwards to Dent Head (SD 779833); to the west it is obscured by boulder clay. On the southern side of Dentdale the outcrops are good from Dent Head westwards around the northern slopes of Whernside and at Deepdale Head (SD 709827). West of Deepdale around the north, west and south slopes of Crag Hill, exposure is very poor with the exception of the good outcrop in Ease Gill (SD 692820). Southeast of Crag Hill the ground is exposed poorly and only a few good sections are seen, notably in Force Gill (SD 758821) on the east flank of Whernside, in some of the small streams around Gearstones (SD 782802) and in Mere Gill (SD 745753) on Ingleborough.

Wharfedale and the southeast.

In this area the Middle Limestone is exposed best from Cam Houses (SD 824821) eastwards along the north side of Langstrothdale and southwards along the east side of Wharfedale to just north of Grassington (SD 006653). Most exposures are in left bank tributaries of the River Wharfe but in the areas between Kettlewell and Grassington the Middle Limestone forms scars which are extensive north of Grassington. Southwest of the River Wharfe the exposure deteriorates and on the south side of Langstrothdale and in Littondale only a few good outcrops are seen. South of Littondale the Middle Limestone is very poorly exposed; the good outcrops in Crooke Gill (SD 845733), Penyghent and in Darnbrook Beck (SD 878717), Fountains Fell are exceptional. Only one outcrop of the Middle Limestone is seen in the area between the North Craven and Mid Craven Fault at Gorbeck (SD 858657) (Moore pers. comm.)

Nidderdale and the southeast.

In this region the outcrop of the Middle Limestone is confined to four small areas. In Nidderdale it is seen in inliers at Limley and Lofthouse, the best outcrops being in the core of the Limley anticline (SE 099764) and in Howstean Gorge (SE 093735) respectively. The other exposures are seen to the southeast in Trollers Gill (SE 072625) on the north flank of the Skyreholme anticline and in the small quarries around Toft Gate (SE 132696), Greenhow.

In the following account the five members constituting the Middle Limestone are described individually except in Nidderdale and the southeast where, because correlation is difficult in the south, they are discussed together.

THE SINGLE POST LIMESTONE.

SUMMARY.

The Single Post Limestone, characteristically a mottled crinoid-ossicle biomicrite and internally unbedded, rests on a slightly irregular pavement of sandstone in the north and limestone in the south. It varies in thickness from only 40cm in Dentdale, where it is sandy and cross-laminated, to 9m in the southeast. A thin persistent coral biostrome dominated by small Lithostrotionidae marks its base where it overlies sandstone but where it rests on limestone coral development is patchy. The distribution of corals shows the sand substrate was more favourable for coral development than the bioclastic carbonate mud substrate. Absence of the biostrome where the Single Post Limestone is sandy in Dentdale is related to instability of the sand substrate preventing polyp establishment.

The coral biostrome reaches a maximum thickness of 50cm in Garsdale and maintains a thickness of 30cm to 40cm eastwards along the north side of Wensleydale as far as Arn Gill. It thins in all directions away from this area. Its fauna is dominated by Diphyphyllum lateseptatum (McCoy), Lithostrotion decipiens (McCoy), Dibunophyllum bipartitum (McCoy) and Orionastraea garwoodi (Hudson) but whereas the others are common Orionastraea is found at only a few localities. The supporting fauna includes small brachiopods, notably Sinuatella sinuata (De Koninck), which are sometimes abundant and sparse small pelecylods and gastropods. Saccaminopsis carteri (Brady) is patchily distributed but also occurs where the coral biostrome is absent. Above the biostrome the Limestone is devoid of any macrofauna except in the southeast. Here sparse scattered

colonies of Orionastraea occur in a poorly developed horizon 37cm to 1.8m above the base of the Limestone.

Over all except the southeastern part of the Askrigg Block the Single Post Limestone has a well defined abrupt top. In the northwest it is irregular with a relief of up to 75cm. Beneath the irregular top the limestone is mottled. Grey patches of unaltered biomicrite are surrounded by brown weathering areas which contain bioclasts with corroded edges in a matrix of ferroan microspar. Small, irregular, usually elongate vugs up to a few centimetres in diameter are also common. They truncate bioclasts and are infilled with ferroan calcite cement and sometimes dickite. These features are interpreted as evidence of dissolution by percolation of rainwater through the sediment. They record a period of subaerial exposure caused by uplift of the northwest corner of the Askrigg Block.

To the northwest of the Askrigg Block a thin breccia occurs at the top of the Single Post Limestone. It consists of clasts of microspar up to a few centimetres in diameter in a microspar matrix which grade down into biomicrite. The clasts contain fractures, infilled with calcite and siderite and are sometimes laminated concentrically. The breccia is considered tentatively to be a caliche.

THE SINGLE POST LIMESTONE.

DETAILS.

Wensleydale.

On the north side of Wensleydale the Single Post Limestone is thinnest in the west and thickens eastwards. From only 1.6m at Ure Force (SD 801932) it thickens rapidly to 2.55m in Tarn Gill (SD 807929). A similar thickness is seen in Fossdale Gill (SD 861930) but above Sedbusk in Coal Gill (SD 881917) it thins locally to only 1.3m. The Single Post Limestone thickens eastwards to 3.05m in Sar Gill (SD 908918) and 3.6m in Whitfield Gill (SD 930923) and maintains a thickness of about 3.5m as far as Beldon Beck (SE 013918) except at Disher Force (SD 981904) where 4.1m are exposed. East of Beldon Beck (SE 013918) it thickens to around 4m, a thickness maintained as far as Wensley Beck (SE 092898), the last good outcrop.

Throughout the north side of Wensleydale the Single Post Limestone rests on a sandstone pavement and has a well developed coral biostrome at its base. The pavement is slightly irregular and has shallow hollows in its surface, usually less than 5cm deep. Small compact dendroid and cerioid Lithostrotionidae are abundant in the coral biostrome. Many colonies adhere, and are moulded, to the underlying sandstone surface. They are often situated in hollows but others occur above and between the colonies at the base. The individual colonies are small, compact and bun-shaped; they never adopt a sheet-like form. They tend to be largest where the coral bed is thick. Some colonies reach 50cm in diameter but their maximum dimension is usually less than 20cm. All appear to be in their position of growth but large solid structures for anchorage are absent. The largest particles present are sand-sized quartz grains, crinoid ossicles, shell fragments and other bioclastic debris. Although no visible change in lithology takes place, the coral colonies disappear abruptly at the top of the biostrome. Their bun-like form gives the biostrome an irregular top defined by the surfaces of the uppermost colonies.

The fauna is dominated by dendroid and cerioid Lithostrotionidae mainly Lithostrotion decipiens (McCoy) and Diphyphyllum lateseptatum (McCoy). Orionastraea garwoodi (Hudson) occurs sporadically and is seen occasionally in the small outcrops of coral biostrome. Though it was recorded by Hudson (1929) from Sar Gill (SD 908918) and Arn Gill (SD 953923), extensive searching by Moore in Arn Gill between 1952 and 1954 failed to locate a single specimen (Moore pers. comm). Since then blocks have fallen from the outcrop and Orionastraea is again exposed (from 1961 , Moore pers. comm). Clisiophyllidae, usually Dibunophyllum bipartitum (McCoy), and small brachiopods, notably Sinuatella sinuata (De Koninck), are scattered between the coral colonies. Saccaminopsis carteri (Brady) is spasmodically distributed in the coral biostrome but also occurs in the overlying limestone. It is abundant in Sar Gill (SD 508908), Whitfield Gill (SD 930923) and Arn Gill (SD 953923). Sparse small pelecypods and gastropods are also present. The fauna of the coral biostrome is recorded in detail by Moore (1958).

The corals occur in a calcilutite matrix with sparse crinoid and shell debris. Scattered quartz grains are common in the basal part of the biostrome. Rarely it is visibly sandy at outcrop as in the lowest 25cm of the biostrome at Sar Gill (SD 908918).

On the north side of Wensleydale the coral biostrome is thickest in the west and thins eastwards. From Arn Gill (SD 953923) westwards it is 30cm to 40cm thick except for local thinning to 15cm in Fossdale Gill (SD 861931) and 20cm in Coal Gill (SD 881917). East of Arn Gill (SD 953923) it thins to 20cm at Disher Force (SD 981094), a thickness maintained eastwards in Apedale Beck (SE 043922), Barney Beck (SE 049919) and Wensley Beck (SE 092898).

West of Apedale the Single Post Limestone is an unlaminated single thick bed of crinoid-ossicle calcarenite. It exhibits a strong colour mottling and contains small irregular patches of coarsely crystalline calcite which are often iron-oxide stained.

The colour mottling results from patchy variation in the colour of the calcilutite matrix. It is most pronounced and displayed exquisitely in Whitfield Gill (SD 930923) (Plates 1 and 2). Here the limestone contains numerous patches of medium grey to brownish-grey carbonate surrounded and separated by areas of paler coloured yellowish brown matrix. The darker areas are irregular in shape and of variable size. Their contacts with surrounding calcarenite are abrupt and sometimes stylolitic. Where the limestone is water-eroded, the dark-coloured patches adopt a fine polish unlike the surrounding limestone which retains a rough surface. Differences in fabric and mineralogy of the matrix seem responsible for the colour mottling, a conclusion proved in thin section (Plate 47).

Irregular patches of coarsely crystalline calcite are also common in this area. They are seen best in Whitfield Gill (SD 930923) and, like the colour mottling, show best on water-eroded surfaces. The patches are usually elongate, irregular, lensoid or vein-like in shape and common in

Plate 1. The Single Post Limestone, Whitfield Gill (SD 930923) Wensleydale. General view of the highly mottled, unbedded crinoid-ossicle calcarenite.

Plate 2. The Single Post Limestone, Whitfield Gill (SD 930923) Wensleydale. Small area of water-polished calcarenite showing the vivid colour mottling. Small elongate patches of coarsely crystalline ferroan calcite are poorly seen in the left of the photograph.

the upper part of the Single Post Limestone. They are generally less than 5cm in length, though some of the veins exceed this, and have abrupt contacts with the surrounding limestone.

The milky-coloured calcite is stained light brown in places at surface and along stylolites, indicating the presence of ferrous iron in its crystal lattice. Staining with potassium ferricyanide shows the calcite to be ferroan (Plate 47).

Dickite (identified microscopically and by X-ray diffraction) is found in tiny patches throughout the Limestone. It occurs with the coarsely crystalline calcite, along stylolites and sometimes infils Saccaminopsis tests.

East of Apedale the Single Post Limestone becomes more crinoidal and partings appear within the Limestone. The partings are not shaly and separate rocks of identical lithology. There is no evidence to suggest that they are bedding planes. The colour mottling, so apparent to the west, becomes indistinct and the patches of coarsely crystalline calcite disappear.

Throughout the north side of Wensleydale the Limestone above the coral biostrome is devoid of any macrofauna. Only scattered Saccaminopsis occur with the crinoid-ossicle and shell debris.

The Single Post Limestone has an abrupt irregular top in the west. It is best seen and most pronounced in Whitfield Gill (SD 930923) where the surface has a visible relief of 50cm but by comparisons of overlying bed thicknesses a maximum relief of 75cm can be proved (p.65). The irregular top of the Limestone is pitted and dark yellowish-brown. Freshly broken surfaces are stained patchily with haematite. The Limestone never shows any transition into the overlying mudstone or shale which infil its surface irregularities. The most easterly exposure showing an irregular top is in Arn Gill (SD 953923). Farther east the irregularity disappears and the top is planar.

On the south side of Wensleydale the Single Post Limestone is thickest in the southeast and thins westwards. In the lower reaches of the southern tributary dales it overlies sandstone but at the heads of these tributaries it rests on, and is commonly fused to, Limestone IVc.

The Single Post Limestone is separated from the overlying beds by a well developed parting. Its top is abrupt in upper Coverdale and upper Waldendale in the southeast, abrupt and irregular in the northwest around Widdale Fell but nodular elsewhere.

In lower Coverdale the Single Post Limestone is well exposed in Great Gill (SE 073840) where it is a thick to very thick parted, medium grey, crinoid-ossicle calcarenite 5.6m thick. The coral biostrome, moulded to the underlying sandstone, is thin (10cm) but contains numerous small brachiopods and Saccaminopsis which is also abundant in the overlying limestone. The overlying limestone is slightly mottled except between 4.25m and 5m above the base where mottling is well developed.

Farther up Coverdale the Single Post Limestone thickens. The internal partings, the coral biostrome and the underlying sandstone all disappear and the Limestone becomes fused to Limestone IVc. Limestone IVc is typically a dark grey crinoidal calcilutite, often with Saccaminopsis, whereas the Single Post Limestone is a paler medium grey crinoid-ossicle calcarenite. Although the gross lithologies of the two Limestones are different the change is gradational and this, with the absence of the coral biostrome and, usually, of any parting between the two Limestones, makes their precise separation impossible. In Ridge Gill (SE 022790)

7.65m of limestone are exposed. At the base are two beds of crinoidal calcilutite 30cm and 85cm thick which may constitute Limestone IVc. They are overlain by crinoid-ossicle calcarenite, its upper part mottled with small irregular patches of coarsely crystalline calcite similar to those seen in Whitfield Gill (SD 930923). In Slape Gill (SE 001778) at the head of Coverdale, Limestone IVc and the Single Post Limestone have a combined thickness of 8m and cannot be separated.

Along the north side of Penhill the Single Post Limestone is about 4m thick and overlies sandstone. Scattered Diphyphyllum and Lithostrotion colonies with sparse Dibunophyllum form a patchily developed biostrome 10cm thick at the base. At Mount Park (SE 085882) and near Chantry (SE 055880) sparse scattered Orionastraea colonies in growth position occur 1.8m and 1.35m above the base of the Limestone respectively.

On the west side of Penhill at Morpeth Scar (SE 029877) the Single Post Limestone is 5.1m thick and has a well developed but thin (10cm) coral biostrome at the base. As on the north flanks of Penhill it overlies sandstone and is a thick to very thick parted crinoid-ossicle calcarenite. It has a rubbly weathering, haematite stained, nodular top. Scattered Orionastraea colonies and sparse Dibunophyllum are seen along a single horizon 1.3m to 1.5m above the base, probably the same horizon as at Mount Park and Chantry. At Long Ing Wood (SE 022860) and Scar Folds (SE 020849) the Limestone is similar in lithology and thickness but Orionastraea is absent.

The Single Post Limestone thickens southwards up Waldendale and at Ashes Farm (SE 008821), Dales Farm (SD 992808) and in Walden Beck

(SD 980796) it rests on Limestone IVc. The coral biostrome at the base of the Single Post Limestone is only present and poorly developed (10cm) at Dales Barn. It contains Diphyphyllum, sparse Dibunophyllum and numerous small brachiopods and rests on 50cm of dark grey crinoidal calcilutite with Saccaminopsis, Limestone IVc. At Ashes Farm (SE 008821) and in Walden Beck (SD 980796) the base of the Single Post Limestone cannot be recognised as the coral biostrome is missing. The combined thickness of the two Limestones is 7.1m and 8.85m respectively. At all three localities the Single Post Limestone is a poorly parted, medium grey crinoid-ossicle calcarenite with sparse small chert nodules.

In Bishopdale the Single Post Limestone overlies sandstone except at the head of the dale where it rests on Limestone IVc. It is an unparted medium grey crinoid-ossicle calcarenite with a slightly rubbly-weathering top. On the southeast side of the dale in Myers Garth Gill (SD 970820) the coral biostrome, 15cm thick, rests on sandstone. Opposite in Foss Gill (SD 956838) on the northwest side of the dale, the Single Post Limestone has thinned to 4.6m . Its base is defined by the coral biostrome, 10cm thick, which overlies 80cm of slightly sandy crinoidal calcilutite, Limestone IVc. To the southwest in Back Gill (SD 951822) and Raffen Gill (SD 951814) the Single Post Limestone also overlies Limestone IVc but its base cannot be recognised as the coral biostrome is absent. Here the two Limestones have a combined thickness of 5.7m.

Between Bishopdale and the head of Wensleydale the Single Post Limestone can be traced around the sides of the southern tributaries of Wensleydale but good outcrops are sparse. They are confined to the upper reaches of the tributary dales and to the northern flanks of the interposed spurs.

The outcrops on the spurs occur in a belt 3km or less in width south of, and parallel to, the River Ure. In Gill Beck (SD 966876), Scar Top Sike (SD 958888) and at Burnett Force (SD 942873) on the flanks of Addleborough, the Single Post Limestone is a mottled, medium grey crinoid-ossicle calcarenite 4.4m, 3.8m and 4.5m thick respectively with a haematite stained, nodular, rubbly weathering top. It thins westwards to 3.3m in Horton Gill (SD 903883) on the northeast slopes of Wether Fell and to 2.35m in Gaudy House Sike (SD 855887) on the north side of Ten End where it is of similar lithology but has an abrupt rather than a nodular weathering top. On the north slopes of Widdale Fell the Single Post Limestone is similar and thickens from 2.35m in Cragfold Sike (SD 839906) to 4m in Hollin Gill (SD 823913) where it is locally thick. The top of the Limestone is not well exposed at either locality but in Hollin Gill it is abrupt and irregular. Farther east, in Badger Sike (SD 815922) the Limestone thins to 3.3m. At all these outcrops the Single Post Limestone overlies sandstone with the coral biostrome at its base. The biostrome is thin in the east, 10cm - 15 cm, but thickens westwards to 40cm in Hollin Gill (SD 823913) and Badger Sike (SD 815922). It is exceptionally well exposed in the railway cutting east of Moorland Cottage (SD 809924).

The poor outcrops on the east side of Widdale Fell show the coral biostrome to thin southwards. On Widdale Side (SD 823888) in a section exposing only the lowest 1.9m of the Single Post Limestone, the coral biostrome is 10cm to 20cm thick and rests on a sandstone. Farther south in Lings Beck (SD 802866) only scattered corals are seen at the base of the Limestone which is 3m thick and also rests on sandstone.

At the outcrops in the upper reaches of the southern tributaries of Wensleydale the Single Post Limestone rests on, and is fused to, Limestone IVc. Throughout this area it is a poorly mottled, medium grey crinoid-ossicle calcarenite but the absence of the coral biostrome makes recognition of its base impossible. Its top is nodular except in Long Sike (SD 817842) and North Scar Gill (SD 818841). In Cragdale at Middle Tongue Gill (SD 920824) and Shaw Gate (SD 926844) the combined thickness of the Single Post Limestone and Limestone IVc is 3.8m and 3.3m respectively. It is also 3.3m thick in Ash Gill (SD 893867), Bardale but thins westwards to 3m in Bank Gill (SD 853850), Sleddale and to 2.1m in Long Sike (SD 817842) and North Scar Gill (SD 818841), Snaizeholme.

Throughout the southern side of Wensleydale the fauna of the coral biostrome is similar to that seen on the north side of the dale. Diphyphyllum and Lithostrotion are abundant, Dibunophyllum is common but Orionastraea is rare and has been recorded only from Gill Beck (SD 966876) and Badger Sike (SD 815922). Small brachiopods are common and Saccaminopsis is distributed patchily.

The irregular top of the Single Post Limestone, so well developed on the north side of Wensleydale from Arn Gill westwards, is seen only in Hollin Gill (SD 823913) on the south side of the dale. Unfortunately, outcrops on the south side nearest those showing irregularity on the north side of the dale are poor.

Swaledale and the northeast.

In Swaledale the Single Post Limestone rests on a slightly irregular sandstone surface usually less than 5cm in maximum relief and has the coral biostrome 10cm to 20cm thick at its base. The coral biostrome is similar to its development on the northern side of Wensleydale except that the coral colonies, like the total thickness of the biostrome, are smaller. Many of the colonies are less than 15cm in maximum dimension and few exceed 20cm. Small compact dendroid and cerioid Lithostrotionidae are abundant in a calcilutite matrix with sparse crinoid debris and small brachiopods. Many adhere to the underlying sandstone surface but others occur above and between the colonies at the base. Diphyphyllum and Lithostrotion are numerous with Clisiophyllidae, dominantly Dibunophyllum, interspersed between them. Orionastraea garwoodi (Hudson) occurs sporadically and is recorded from Birks Gill and Mirk Gill by Hudson (1929).

Above the coral biostrome the Single Post Limestone is an unparted mottled crinoid-ossicle calcarenite with small irregular patches of coarsely crystalline calcite less than 5cm in length in the upper part. It has an abrupt irregular top which is exposed best in Routin Gill (SD 919969) where a relief of 20cm is seen.

On the north side of the dale the Single Post Limestone is exposed in Smarber Gill (SD 972980) and Staney Gill (SD 959986) where it is 5.7m and 3.5m thick respectively. Along the south side of Swaledale it thins westward from 2.6m in Birks Gill (SD 985968) to 2.3m in Crag Sike (SD 984965), Routin Gill (SD 919969) and Noon Gill (SD 893975).

The section in Long Acres Quarry (NZ 181043), 3km north of Richmond, shows the character of the Single Post Limestone to change to the northeast. The Limestone becomes medium to thick bedded and finer grained with much shell debris. The mottling and patches of coarsely crystalline calcite disappear. At this locality it overlies sandstone and though the coral biostrome at its base was not found it is recorded by Hudson (1924). The top of the Limestone, so easily recognised to the southeast, cannot be identified with certainty. By comparison with sections to the southwest the first appearance of shale 3.15m above the base of the limestone may mark its top. If the shale does mark its top then a coral biostrome 20cm thick with Diphyphyllum, Lithostrotion and scattered Dibunophyllum, 2.5m above the base of the Limestone, occurs within the Single Post Limestone.

Garsdale and the northwest.

In this area the Single Post Limestone is an unbedded, mottled crinoid-ossicle calcarenite. It varies from 1.1m to 3.65m in thickness, rests on a sandstone pavement and has small irregular patches of coarsely crystalline ferroan calcite scattered sparsely throughout the upper part. The coral biostrome is usually present at its base.

In Birkett Railway Cutting (NY 774029), situated in the southern part of the Barnard Castle Trough, the Single Post Limestone is 2.65m thick. It has a sandy base but no coral biostrome. It is mottled and contains tiny elongate patches of coarsely crystalline ferroan calcite. The uppermost 60m is a nodular, iron-oxide stained, carbonate breccia which grades down into non-brecciated mottled limestone. The clasts support the breccia and vary greatly in size up to a maximum dimension of about 5cm but most are less than 2.5cm. They are generally round to subround, consist of light to medium light grey calcilutite with no visible bioclasts, have a porcellanous appearance and are commonly veined by both sparry carbonate and matrix. Most of the sparry carbonate veins are confined to the clasts. The clasts are set in a calcilutite matrix which weathers dark reddish brown indicating the presence of ferrous iron.

To the south, on the northwest corner of the Askrigg Block, the Single Post Limestone is exposed in Needlehouse Gill (SD 733971) and in the River Rawthey (SD 729966). Here it is 3m and 3.65m thick respectively with the coral biostrome 10cm thick at its base. In Nor Gill (SD 703440) and Penny Farm Gill (SD 702932) to the southwest the Limestone thins to 2.65m and 2.45m respectively. The coral biostrome is present at both outcrops, 30cm thick in Nor Gill and 10cm thick in Penny Farm Gill where it can still be recognised in spite of secondary dolomitisation. At all these localities the top of the Limestone is abrupt and irregular though poorly exposed.

Throughout Garsdale the Single Post Limestone is a mottled crinoid-ossicle calcarenite with an irregular top. The coral biostrome is well developed and was found at all the exposures visited with the exception of the small outcrop in Thrush Gill (SD 725900). Sparse scattered, small, irregular patches of coarsely crystalline ferroan calcite up to 5cm in length occur in the upper part of the Limestone.

On the north side of Garsdale the Single Post Limestone is exposed in Thrush Gill (SD 745900), Greenside Gill (SD 753901), Grinning Gill (SD 762904), and at Clough Force (SD 782922). The coral biostrome is 10cm to 20cm thick except at Clough Force where it reaches a maximum thickness of 50cm.

Along the southern side of the dale the best exposures are in

Cote Gill (SD 780910), Ingheads Railway Cutting (SD 777906), Assey Gill (SD 772902), Blea Gill (SD 958893), Aye Gill (SD 730896) and Pegs Gill (SD 723899). The coral biostrome is variable in thickness, 40cm in Ingheads Gill (SD 776905) and 50cm in Assey Gill and Pegs Gill but at the other localities it is thinner, between 10cm and 25cm. Diphyphyllum, Lithostrotion and Dibunophyllum are abundant with associated small brachiopods.

In Garsdale the Single Post Limestone is thickest at Clough Force (SD 782922), 2.6m. It thins westward to 2.35m in Cote Gill (SD 780910) where, in an inaccessible section, it infils a broad hollow in the underlying sandstone at least 50cm deep. A minimum thickness of 1.1m occurs in Thrush Gill (SD 745900), the most westerly outcrop on the northern side of the dale, but throughout the rest of Garsdale its thickness variation is small and the Limestone is about 1.5m thick. The southerly thinning along the west side of Baugh Fell therefore continues into Garsdale, the 2.45m of limestone in Penny Farm Gill (SD 702932) thinning to 1.5m in Pegs Gill (SD 723899), the nearest exposure in Garsdale.

Dentdale and the southeast.

Throughout Dentdale the Single Post Limestone is a thin, mottled crinoid-ossicle calcarenite and overlies sandstone except at the head of the dale where it rests on, and is fused to, Limestone IVc. It has a minimum thickness on the northern slopes of Whernside and thickens away in all directions.

Along the north side of Dentdale the coral biostrome at the base of the Single Post Limestone is 15cm to 25cm thick except in Spice Gill

(SD 746874) where the biostrome thickens locally to 40cm. Throughout this area the Limestone is generally less than 1m thick but it thickens in the west to 1.5m in Scotcher Gill (SD 725874). The outcrop in Cowgill Beck (SD 770806), farther north than the other exposures, also shows an increased thickness. Here, the top of the Limestone is markedly hollowed (Plates 3 and 4). The broad hollows, up to 40cm deep, are infilled by the overlying sandstone of the Lower Parting and give the Limestone a variable thickness of between 85cm and 1.25m.

At the head of Dentdale, in Long Gill (SD 779833), the Single Post Limestone overlies, and is fused to, Limestone IVc. Its base cannot be recognised as the coral biostrome is absent and the two Limestones have a combined thickness of 1.35m. The lowest 30cm with numerous Saccaminopsis is probably Limestone IVc which has a similar thickness in other parts of Dentdale.

In Stock Beck (SD 736854) the Single Post Limestone has an exposed thickness of only 20cm but a gap of 75cm between it and the overlying beds prevents positive identification of its top. It is sandy at the base with scattered crinoid-ossicles but no coral biostrome. To the east in How Gill (SD 744855) sand is absent and the coral bed, 15cm thick, appears at the base of the 40cm thick Limestone. Farther east in Great Blake Beck (SD 762851) the Single Post Limestone is also 40cm thick but is sandy, particularly at the base. It is a cross-laminated calcareous sandstone in the lowest part but becomes increasingly calcareous upwards and passes into a nodular crinoid-ossicle calcarenite. Although the coral biostrome is absent, small brachiopods normally associated with the corals are abundant. Towards the head of Dentdale the sand disappears,

Plate 3. The Single Post Limestone, Cowgill Beck (SD 770886) Dentdale. General view showing the Single Post Limestone resting on flaggy sandstones and overlain by calcareous sandstones of the Lower Parting.

Plate 4. The Single Post Limestone, Cowgill Beck (SD 770886) Dentdale. The irregular top of the Single Post Limestone with the hollows infilled by calcareous sandstone of the Lower Parting.

the coral biostrome reappears and the Limestone thickens. In Hazel Bottom Gill (SD 770839) it is 55cm thick with the coral bed 15cm thick at its base.

In Deepdale the Single Post Limestone is similar in lithology where exposed in Broken Gill (SD 716841), Gastack Beck (SD 709827) and Coombe Gill (SD 726825). On the west side of Deepdale in Broken Gill it is 2m thick with the coral biostrome, 30cm thick, at its base overlying sandstone. At the head of the dale, however, in Gastack Beck and Coombe Gill it rests on Limestone IVc and the coral biostrome is absent. The two Limestones are inseparable and have combined thicknesses of 2.45m and 2.9m respectively.

West and south of Deepdale exposures are very poor. In Ease Gill (SD 692820), on the southern side of Crag Fell, only 30cm of the Single Post Limestone is exposed. It is a mottled, crinoid-ossicle calcarenite less than 1.5m in total thickness.

On the eastern flank of Whernside in Force Gill (SD 958821) the Single Post Limestone overlies Limestone IVc. A dark to medium grey crinoidal calcilutite 70cm thick with Saccaminopsis in the lowest 30cm is overlain by 1.65m of poorly mottled medium grey crinoidal calcarenite. The absence of the coral biostrome makes positive recognition of the base of the Single Post Limestone impossible but it is probably at the base of the mottled calcarenite.

East of Force Gill in the area around Gearstones several good sections are seen. In Gate Cote Gill (SD 783816), Hazel Gill (SD 785821), Long Gill (SD 803835) and Lat Gill (SD 802819) the Single Post Limestone is a poorly mottled crinoid-ossicle calcarenite with scattered, small, irregular patches of coarsely crystalline calcite. It overlies and is sometimes fused to Limestone IVc.

In Long Gill (SD 803831) the coral biostrome, 10cm thick, contains scattered compact colonies of Lithostrotion and Diphyphyllum, usually less than 15cm in maximum dimension, Dibunophyllum and Saccaminopsis. Unlike the corals, Saccaminopsis is not restricted to the biostrome but also occurs in the limestone above and is abundant in the overlying 20cm. The Single Post Limestone rests on 35cm of calcilutite with scattered crinoid ossicles and abundant Saccaminopsis, Limestone IVc.

Farther south in Gate Cote Gill (SD 783816) and Hazel Gill (SD 785821) the coral biostrome is absent but scattered to rare Dibunophyllum occur at this horizon. Here, the Single Post Limestone is 2.25m thick and fused to Limestone IVc, a calcilutite 35cm thick with scattered crinoid debris. In Lat Gill (SD 802819) Limestone IVc is probably similar in thickness but its top cannot be recognised as corals are completely absent from the base of the overlying Single Post Limestone. A thin bed of calcilutite 8cm thick, with scattered crinoid ossicles and abundant Saccaminopsis is overlain by 2.3m of crinoid-ossicle calcarenite. The lowest 20cm of the calcarenite is sparsely crinoidal and contains abundant Saccaminopsis. The top of the Single Post Limestone is irregular.

Several poor outcrops are seen on the northeast slopes of Ingleborough but the best sections are in Mere Gill (SD 745753) and its tributaries on the western flank. The coral biostrome at the base of the Single Post Limestone is 10cm thick and contains Diphyphyllum.

It rests on Limestone IVc here 50cm thick. The Single Post Limestone is a patchily dolomitised mottled crinoid-ossicle calcarenite 1.35m thick and contains small patches of light brown to dark yellowish-orange-weathering, coarsely crystalline ferroan calcite.

Where the coral biostrome is present in Dentdale and the southwest Diphyphyllum, Lithostrotion and Dibunophyllum are common. Orionastraea, however, only occurs sporadically and is recorded from Doctors Spring (SD 696859) and Aye Gill (SD 741872) by Hudson (1929) and from Broken Gill (SD 716841) by the author. The Limestone contains small irregular patches of coarsely crystalline ferroan calcite which weather light brown. They are especially prominent in the north where the colour mottling is best developed but are seen as far south as Ingleborough. Dickite is sometimes seen infilling tiny cavities associated with the coarsely crystalline calcite, along stylolites and in Saccaminopsis tests. In all outcrops the Limestone has a well defined abrupt top and some of the best outcrops show it to be irregular. The irregularity is often difficult to determine because of the very limited width of the outcrops but it is well displayed in Cowgill Beck (SD 770896) and can be recognised as far south as Lat Gill (SD 802819).

Wharfedale.

The Single Post Limestone is moderately well exposed northeast of the River Wharfe but to the southwest the exposure is poor. Throughout this area it rests on, and is usually fused to, Limestone IVc. They thicken from a combined minimum thickness of 1.65m in the northwest to 9m in the southeast. The Single Post Limestone has a sporadically developed coral biostrome at its base but never an irregular top.

In the vicinity of Cam Houses (SD 823832) the Single Post and Limestone IVc are fused. They form an unbedded crinoid-ossicle calcarenite, sparsely crinoidal at the base and poorly mottled above, 2.1m thick in Tur Gill (SD 825822), 1.9m in Grainings Gill (SD 828324) and 1.65m in Far End Gill (SD 833825). In Swarth Gill (SD 848828) a bedding plane separates Limestone IVc, a sparsely crinoidal calcarenite 75cm thick, from the overlying Single Post Limestone, an unbedded crinoid-ossicle calcarenite, 1.8m thick. In Hazel Bank Gill (SD 865826) the two Limestones, 3.2m thick, are fused together. Their lithology is the same as in Swarth Gill but the Single Post Limestone has a well developed bedding plane 2m above the base of Limestone IVc. Farther east in Deepdale Gill (SD 898811) the base of the Single Post Limestone cannot be identified with certainty. The two lowest beds, a dark grey, pyritic calcilutite 15cm thick with scattered crinoid debris, small brachiopods and numerous Saccaminopsis, overlain by a crinoidal calcilutite 40cm thick, probably belong to Limestone IVc. They are overlain by 2.95m of poorly bedded, medium grey crinoid-ossicle calcarenites. On the south side of Langstrothdale in Bowther Gill (SD 906772) the Single Post Limestone is fused to Limestone IVc and has one bedding plane 2.3m above the base of Limestone IVc. The base of the Single Post Limestone cannot be recognised and the combined thickness of the two Limestones is 5.2m. The lowest part of the Limestone is a dark grey crinoidal calcilutite which passes up into a paler, medium grey, mottled crinoid-ossicle calcarenite. The coral biostrome is absent from all these localities.

Besides being absent in Langstrothdale and to the northwest, the coral biostrome is also absent in Littondale. At Cosh Beck Head (SD 844777) the Single Post Limestone is fused to Limestone IVc. They are unbedded crinoid-ossicle calcarenites at least 3.5m thick. In Halton Gill (SD 882773) the Single Post Limestone is a thick bedded crinoid-ossicle calcarenite but, because its base and top cannot be distinguished from Limestone IVc and the Cockleshell Limestone respectively, its thickness is unknown. On the south side of the dale on Hesleden High Bergh (SD 871751) a crinoidal calcilutite 25cm thick with abundant Saccaminopsis is overlain by a crinoidal calcilutite 85cm thick, beneath crinoid-ossicle calcarenites belonging to the Single Post Limestone. The calcilutite with Saccaminopsis certainly belongs to Limestone IVc but the exact position of the base of the Single Post Limestone is unknown.

In Crooke Gill (SD 845733) the Single Post Limestone is an unbedded medium grey crinoid-ossicle calcarenite 3.1m thick. Its base is marked by the coral biostrome, 10cm thick, composed of small compact colonies of Diphyphyllum. It rests on Limestone IVc, a slightly darker, sparse crinoid-ossicle calcarenite, 65cm thick. At this locality Limestone IVc also has a coral fauna at its base.

To the southeast, in Darnbrook Beck (SD 878717) numerous small compact colonies of Diphyphyllum are seen in the patchily developed biostrome at the base of the Single Post Limestone. It rests on Limestone IVc, 55cm thick, and contains Orionastraea (Hudson, 1929). The Single Post Limestone is 2m thick and thick bedded at this locality but its top is difficult to recognise.

South of Darnbrook Beck the outcrops are poor. Mapping by Moore(unpubl.) has shown that only one good outcrop of Middle Limestone is seen between the North and Mid Craven Faults at Gorbeck (SD 858657). The lowest exposed bed, a medium grey crinoidal calcarenite, of which only 45cm is seen, is probably part of the Single Post Limestone. It has been secondarily dolomitised and is bioturbated. No outcrops occur beneath and a gap of 65cm separates it from the next exposed overlying bed.

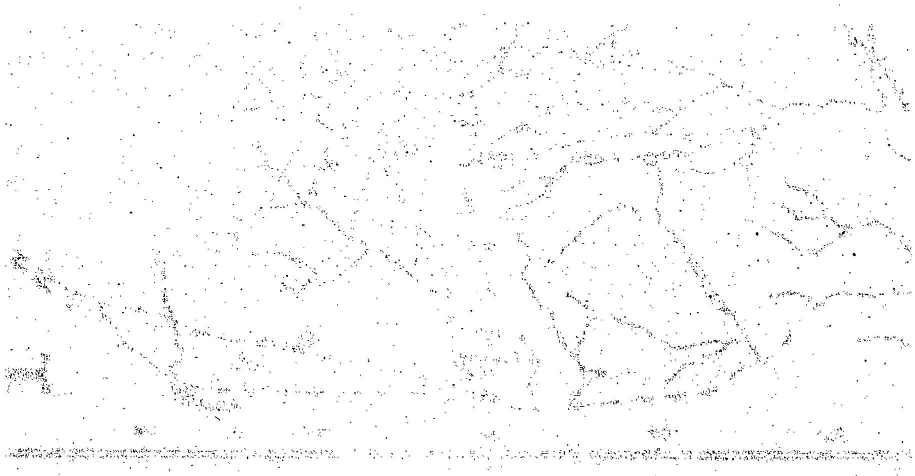
Along the east side of Wharfedale the Single Post Limestone is well exposed. It is fused to Limestone IVc and thickens southwards. In Buckden Beck (SD 952779) the coral biostrome is absent and the Single Post Limestone, an unbedded medium grey crinoid-ossicle calcarenite, and Limestone IVc, a crinoidal calcilutite, have a combined thickness of 6.45m.

To the southeast in Park Gill Beck (SD 987753) the base of the Single Post Limestone is identified easily as the coral biostrome is present. It is 15cm thick with small, compact colonies of Diphyphyllum and Lithostrotion resting on crinoidal calcilutite 60cm thick, Limestone IVc. The Single Post Limestone is a medium grey crinoid-ossicle calcarenite 8.65m thick with Orionastraea 60cm above its base.

South of Park Gill Beck the coral biostrome is absent though scattered corals are sometimes seen in the lower part of the Single Post Limestone. At Providence Mine (SD 993728) the Single Post Limestone and Limestone IVc form an unbedded medium grey crinoid-ossicle calcarenite 8.4m thick. Orionastraea is recorded from the 'base' of the Middle Limestone above Kettlewell by Garwood & Goodyear (1924) and more specifically from Dowber Gill and Providence Mine by Chubb (1926). In 1929, Hudson recorded both <u>Orionastraea garwoodi var pristina</u> (Hudson) and <u>Orionastraea rete</u> (Hudson) from this horizon in Whernside Pasture. Reference in these publications to <u>Orionastraea</u> at the base of the Middle Limestone (i.e. at the base of the Single Post Limestone which at this time included Limestone IVc) is slightly misleading as the coral occurs above the base of the Limestone as shown in Chubb's section of the strata in Providence Mine (Chubb,1926). The small scattered colonies of <u>Orionastraea</u> in their position of growth are seen along a single horizon about 1.2m above the base of Limestone IVc, probably about 60cm above the base of the Single Post Limestone as in Park Gill Beck.

To the south the two Limestones become more crinoidal and thicken to about 9 metres, maintaining this thickness as far south as Bare House (SE 005669). Although the coral biostrome is absent, in the region of Capplestone and Kelber, small poorly developed colonies of <u>Diphyphyllum</u> are seen rarely in the lower part of the Single Post Limestone up to 2 metres above the base of Limestone IVc. Chubb (1926) recorded <u>Orionastraea</u> from the 'base' of the Middle Limestone (i.e. the lower part of the Single Post Limestone, see above) in the area of Kelber Gate (SD 002684) and Gill House (SD 012683).

South of Bare House the two fused Limestones thin and above the spring (SD 003665), southwest of Bare House, they form a medium to medium light grey crinoid-ossicle calcarenite 8.5m thick. The basal 1.2m has suffered intense secondary dolomitisation and is a greyish-orange, coarsely crystalline dolomite in which only a few relics of bioclasts survive. Farther south the crinoidal calcarenites pass into sparse crinoidal calcarenites and become darker in colour. At the southern most exposure (SD 005658) the Single Post Limestone and Limestone IVc are 7m thick. The basal 90cm is highly dolomitised and small chert nodules are scattered sparsely throughout the Limestone above. To the south the Single Post Limestone is obscured by the overstepping Bowland Shale.



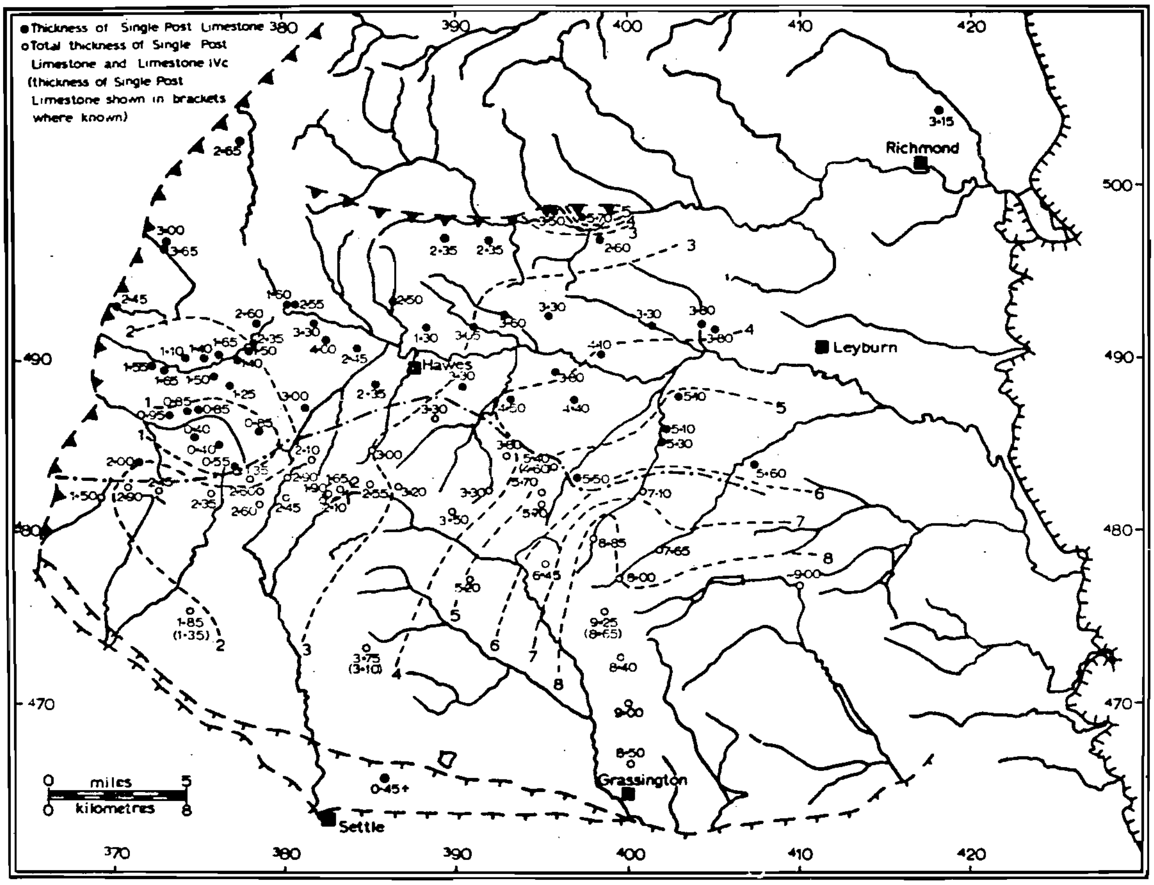


Fig. 13. Isopach map of Single Post Limestone.

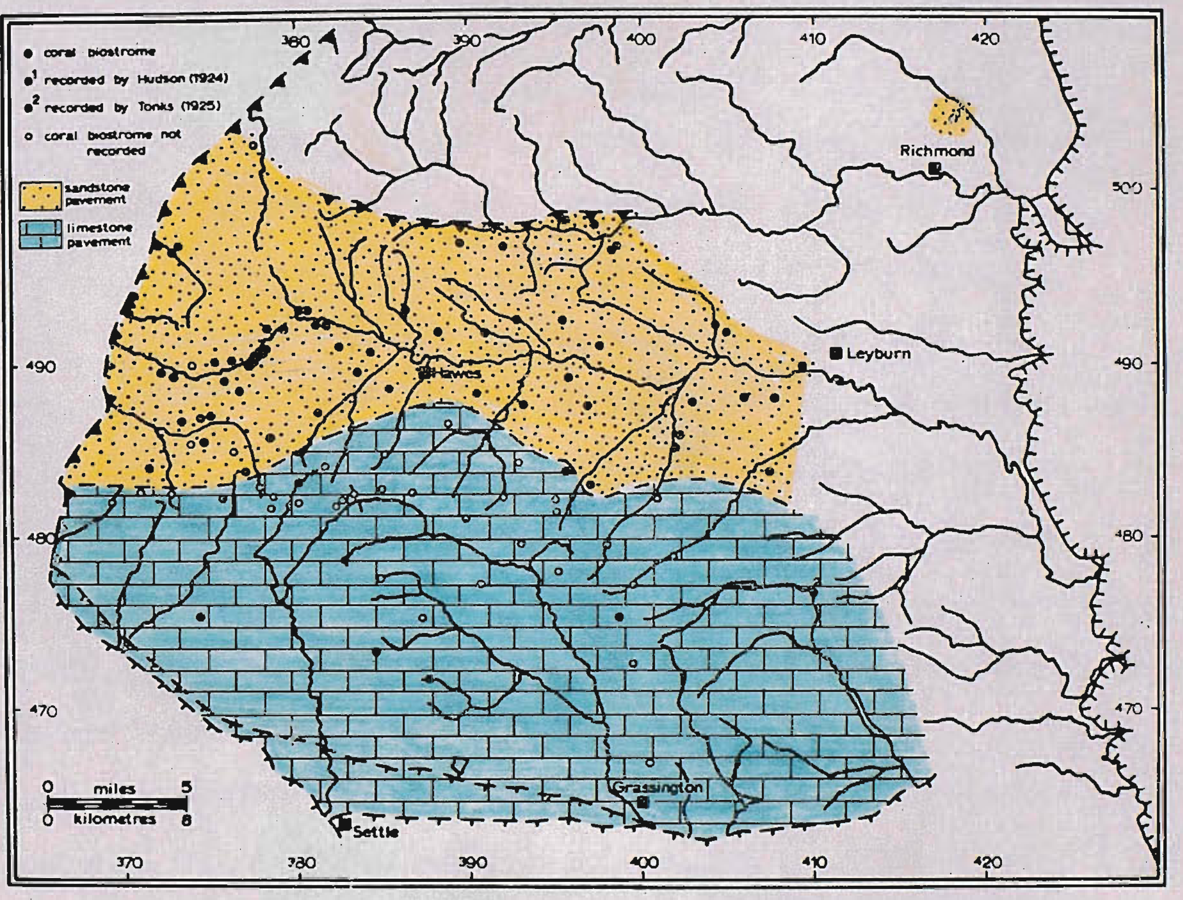


Fig. 14. Map showing pavement and distribution of coral biostrome at base of Single Post Limestone.

THE LOWER PARTING.

SUMMARY.

The Lower Parting overlies the Single Post Limestone. Its top, defined by the base of the Cockleshell Limestone, is marked by a distinctive mottled calcilutite over much of the Askrigg Block. The Lower Parting is thickest to the northwest of the Askrigg Block in the southern part of the Barnard Castle Trough. Here it is 9m thick and consists dominantly of deltaic micaceous sandstones and shales. It thins southeastwards. The deltaic sandstones reach only the northern edge of the Askrigg Block where calcilutites become prominent. As the Lower Parting thins further calcilutites form more of the succession and the shales thin and eventually fail. Farther south the calcilutites also thin and fail so that over the southern and southeastern parts of the Askrigg Block the Lower Parting is absent.

In Garsdale the Lower Parting consists entirely of calcareous sandstone. The sandstone is marine with brachiopods and was derived from west of the Dent Fault. It is located near the area of maximum uplift which post-dated accumulation of the Single Post Limestone. Evidence suggests that during this uplift the Single Post Limestone was completely removed in the area west of the northwest corner of the Askrigg Block exposing the underlying sand. The sand was eroded by currents and redeposited in Garsdale to form the Lower Parting.

Over most of the Askrigg Block the uppermost calcilutite of the Lower Parting contains grey mottles which weather pink. Hudson (1929) considered they were siliceous sponges and named them _Erythrospongia lithodes_. They are now shown to be burrows.

THE LOWER PARTING.

DETAILS.

Wensleydale.

Along the northern side of Wensleydale the Lower Parting is well exposed and complete sections are seen at Ure Force (SD 801932) and in Tarn Gill (SD 807929), Fossdale Gill (SD 816930), Whitfield Gill (SD 930923) and Arn Gill (SD 953923). It increases in thickness eastwards from 2.1m at Ure Force and in Tarn Gill at the head of the Dale to 2.9m in Fossdale Gill and 4.55m in Whitfield Gill attaining a maximum of 5.1m in Arn Gill. East of Arn Gill it thins to about 2.9m in Beldon Beck (SD 013913). The Lower Parting consists of medium to thick bedded calcilutites and very thin to thick interbedded shales. The shales are well developed in the west but thin and eventually fail to the east where the succession is composed entirely of calcilutites. The top of the Lower Parting, defined by the base of the Cockleshell Limestone, is at the top of the shale directly overlying a distinctive mottled calcilutite (the 'Erythrospongia' bed of Hudson, 1929) or where the shale is absent, at the top of the mottled calcilutite. The beds contain only a sparse fauna of small productids, including spinose types, and bellerophontids.

West of Beldon Beck (SE 013913), shale overlies the irregular top of the Single Post Limestone except in Whitfield Gill (SD 930923) where mudstone underlies the shale. They infill hollows in the irregular top of the Single Post Limestone and therefore are variable in thickness. The relationship between the irregular top of the Single Post Limestone and the overlying beds of the Lower Parting is well seen in Whitfield Gill. Here the largest hollow exposed in the top of the Limestone is infilled by 30cm of medium grey mudstone overlain by 45cm of dark to medium grey calcareous shale with small spirifers and productids. Both the mudstone and the shale thin rapidly towards the edges of the hollow and are absent over the highest parts of the Limestone. Here the calcilutites which usually overlie the calcareous shale rest directly on the Single Post Limestone showing the top of the Limestone to have relief of 75cm. West of Whitfield Gill the shale averages 50cm thick but thins eastwards to 20cm in Arn Gill (SD 953923). Exposures at this level are poor east of Arn Gill but the shale is absent in Barney Beck (SE 049919) and Wensley Beck (SE 092898). Medium to thick bedded calcilutites with very thin to thick interbedded calcareous shales overlie the shale west of Beldon Beck (SE 013913) but from Beldon Beck eastwards shales are absent, except for occasional thin shaly partings, and the Lower Parting is composed entirely of calcilutites.

In the west, the calcilutites, interbedded with calcareous shales, are medium to dark grey, often sparse in bioclastic debris and argillaceous. They have a dirty grey-brown appearance where weathered. In the east, where interbedded calcareous shales are absent, the calcilutites are less muddy and weather grey rather than grey-brown. Thin chert stringers and nodules are developed in the upper part of these beds in Whitfield Gill (SD 930923) and Arn Gill (SD 953923) at a similar horizon to the chert seen in Routin Gill (SD 919969) in Swaledale. In Whitfield Gill (SD 930923) the thin cherty horizons are developed at the top of individual beds of calcilutite and have irregular contacts with the carbonate beneath. The chert is most abundant in Arn Gill (SD 953923) where it is more widely distributed through the upper beds, occurring in both thin stringers and nodules.

The uppermost calcilutite of the Lower Parting, lithologically distinctive over much of the northwest Arkrigg Block, is especially conspicuous in parts of Wensleydale. At outcrop this pale grey-weathering, often mottled, calcilutite contrasts with the darker grey underlying and overlying beds of the Lower Parting and Cockleshell Limestone respectively. It was first described in detail by Hudson (1929) who considered it contained the siliceous sponge 'Erythrospongia lithodes' (Hudson). This horizon is seen best in Whitfield Gill (SD 930923) and Arn Gill (SD 953923).

In Whitfield Gill (SD 930923) it is a medium to light grey calcilutite 85cm thick with numerous, well developed, dark grey, pink-weathering mottles. On exposed surfaces the mottles are usually circular to subcircular or elongate, commonly 1cm to 5cm in maximum dimension (Plate 5). Tiny veins of coarsely crystalline calcite, confined to the dark grey, pink-weathering patches, are abundant. Most have a radial orientation but concentric veins are also common. They appear to be calcite infilled tension fractures.

In Arn Gill (SD 953923) the horizon is thicker, a 1.05m medium to pale grey calcilutite with a shaly, nodular-weathering central 25cm. The upper and lower parts of this bed are similar to the exposure in Whitfield Gill (SD 930923) except that the dark grey mottles do not show a vivid pink colouration on exposed surfaces but weather grey or only slightly pink. The central part, a shaly calcilutite, contains calcilutite nodules similar in size and form to the dark grey patches

Plate 5. The Lower Parting, Whitfield Gill (SD 930923), Wensleydale.

The bioturbated calcilutite at the top of the Lower Parting

(the '*Erythrospongia*' bed of Hudson, 1929) in the lower and upper parts of the bed. The nodules, 1cm to 5cm in diameter, are dark grey, sometimes weather pink and are round to subround or occasionally elongate. They often have an irregular mammilated surface and are sometimes agglutinated. Hudson (1929) described the nodules from Arn Gill (SD 953923) and considered they were siliceous sponges naming them '<u>Erythrospongia lithodes</u>'(Hudson). His conclusion is disputed here as they are proved to be bioturbation structures (p. 183)

The mottling becomes less distinct in all directions away from the Whitfield Gill - Arn Gill area. Where faint, its recognition depends on the state of weathering of the outcrops. It shows best on clean-weathered and water-eroded surfaces and if often difficult or impossible to recognise on freshly-broken or badly weathered surfaces. On the north side of Wensleydale the mottling can be recognised from the head of the dale eastwards to Beldon Beck (SE 013913) but it has not been recorded farther east.

Throughout this area the mottling is confined to a single bed of calcilutite except in Arn Gill (SD 953921) and Fossdale Gill (SD 861930) It is thickest in Arn Gill 1.05m and thins eastwards to 30cm in Beldon Beck and westwards to 45cm in Tarn Gill (SD 807929). Local thinning occurs in Coal Gill (SD 881917) where it a slightly nodular calcilutite only 30cm thick. In Fossdale Gill (SD 861930) a lower mottled calcilutite 15cm thick is separated by a 10cm shale with calcilutite nodules from an overlying calcilutite 45cm thick mottled in its lower 20cm. The outcrop is comparable to the section in Arn Gill (SD 953923) except that the shaly nodular central part of the calcilutite in Arn Gill is represented here by a well developed calcareous shale containing calcilutite nodules.

West of Beldon Beck (SE 013913) a calcareous shale of variable thickness overlies and separates the mottled calcilutite from the Cockleshell Limestone. It is thickest in Whitfield Gill (SD 302923), 20cm., but elsewhere it is less than 10cm thick. In Arn Gill (SD 953923) and Fossdale Gill (SD 861930) it is 5cm thick but at most localities it is very thin forming only a shaly parting.

The Lower Parting thins south from the north side of Wensleydale but on the southern side of the dale exposures are sparse and poor. In this area its top is not identified easily because the mottling which characterises the uppermost calcilutite is faint or absent. The beds also become more bioclastic southwards. They assume a lithology similar to the overlying beds of the Cockleshell Limestone making differentiation between them difficult.

In the west partial sections of the Lower Parting are exposed in Hollin Gill (SD 823913), Mossdale and in Cragfold Sike (SD 839906) to the east. It is 2.4m and 2.35m thick respectively but the lowest 80cm at Hollin Gill and 1.2m at Cragfold Sike are not exposed. Shale probably directly overlies the Single Post Limestone followed by calcilutites. The exposed beds are pale grey weathering, medium grey, medium to thick bedded calcilutites with sparse bioclastic debris. The mottling in the uppermost bed is faint and best seen in Cragfold Sike.

The Lower Parting is not exposed in Gaudy House Sike (SD 855887) on the north side of Ten End but farther east in Horton Gill (SD 903883) on the northeast slopes of Wether Fell calcilutites are poorly exposed and blocks of mottled calcilutite are displayed in the walls nearby. A better section is seen at Burnett Force (SD 942873) on the flanks of Addleborough though the absence of the mottled calcilutite makes recognition of the top difficult. The Lower Parting is probably 2.2m thick but the lowest 45cm is not exposed. The exposed beds are medium to dark grey, medium to thick bedded calcilutites with sparse bioclastic debris. A shale, 25cm thick, occurs 80cm above the base. South of these outcrops the Lower Parting is difficult to recognise. Nearly all exposures of this horizon are confined to the heads of the southern tributary dales of Wensleydale.

In the west in Long Sike (SD 817842) and North Scar Gill (SD 818841) at the head of Snaizeholme the beds of the Lower Parting are difficult to distinguish from the overlying Cockleshell Limestone. They are medium to thick bedded calcilutites 1.7m thick with scattered bioclastic debris. The uppermost bed shows only a vague mottling. The Lower Parting is also exposed to the east at the head of Sleddale in Bank Gill (SD 853850). Here, the Single Post Limestone is overlain by 20cm of calcareous shale followed by medium bedded argillaceous calcilutites with shell debris and scattered crinoid ossicles. The calcilutites become less muddy upwards and pass into medium to thick bedded calcilutites with scattered crinoid debris. The top of the Lower Parting is difficult to recognise but occurs at the top of a medium grey calcilutite 80cm thick with scattered crinoid debris, giving the Parting a thickness of 2.20m.

Farther east in Cragdale, at Middle Tongue Gill (SD 920824) and Shaw Gate Gill (SD 926844) the beds of the Lower Parting, if present, cannot be distinguished from the Cockleshell Limestone.

At the head of Bishopdale, the Lower Parting consists of one bed of poorly mottled calcilutite 1m thick in Foss Gill (SD 956838), 90cm thick in Myers Gill (SD 970820) and 85cm in Back Gill (SD 951822). At all these localities it is a pale grey weathering medium grey calcilutite with dark grey to greyish-pink mottles. In Raffen Gill (SD 951814) to the south a gap of 50cm occurs at this horizon but the beds below and above belonging to the Single Post Limestone and Cockleshell Limestone respectively show the Lower Parting to be 50cm or less in thickness.

In lower Waldendale the beds of the Lower Parting are poorly exposed around the northwestern flanks of Penhill. They are medium to thick bedded, pale grey-weathering, medium grey calcilutites. At Long Ing Wood (SE 022860) and Scar Folds (SE 020849) the calcilutite with grey to greyish-pink mottles is exposed at the top of these beds which are 2.20m and 2.25m thick respectively. Farther up the dale at Ashes Farm (SE 008821) and in Walden Beck (SD 980798) the Lower Parting cannot be recognised and appears to have thinned out completely, allowing the Cockleshell Limestone to rest directly on the Single Post Limestone.

A similar situation is seen in Coverdale where, in the upper part of the dale in Slape Gill (SE 001778) the Lower Parting appears to be absent but in lower Coverdale in Great Gill (SE 073840) the Lower Parting is 1.35m thick and consists of two beds of medium grey calcilutite with shell debris.

Swaledale and the northeast.

In Swaledale the Lower Parting is exposed completely only in Routin Gill (SD 919969) but partial sections are seen in Staney Gill (SD 959986), Birks Gill (SD 985969), Crag Sike (SD 984968) and in Noon Gill (SD 893975).

In Routin Gill the Lower Parting, 5.8m thick, is similar to its development in Whitfield Gill (SD 930923) and Arn Gill (SD 953923), Wensleydale but sandstone is present in addition. A silty shale, 20cm thick, rests on the Single Post Limestone and is overlain by three medium to thick bedded micaceous sandstones with thin interbedded shales. A thick argillaceous calcilutite and calcareous shale follow, overlain by medium and thick bedded calcilutites with two thin chert stringers and thin shale partings. The lower calcilutites are dark grey and muddy but the clay content decreases in the upper beds which are medium grey in colour. The uppermost calcilutite, 1m thick, contains poorly defined, dark grey mottles and is separated from the Cockleshell Limestone by a very thin shale parting.

The Lower Parting contains no sandstone in Wensleydale to the south, in Noon Gill (SD 893975) to the west, or in Birks Gill (SD 985969) or Crag Sike (SD 984968) to the east but in Staney Gill (SD 959986) to the northeast sandstone is present. It occupies a position in the Lower Parting similar to the sandstone in Routin Gill. It is at least 40cm thick but only the upper part is exposed. A gap of 60cm separates it from 70cm of shale, overlying the Single Post Limestone. A pale grey-weathering medium grey calcilutite 1m thick with pink mottles forms the uppermost bed of the Parting and is separated from the underlying sandstone by a gap of 60cm. The Lower Parting is therefore 3.3m thick.

On the southern side of Swaledale the outcrops in Birks Gill (SD 985969) and Crag Sike (SD 984968) are similar. The best exposure is in Crag Sike though the shale, at least 40cm thick, overlying the Single Post Limestone is only exposed in Birks Gill. In Crag Sike the shale is less than 65cm thick as calcilutites are exposed at this distance above the Single Post Limestone. The lowest medium bedded, dark grey calcilutites are overlain by two thick medium grey calcilutites the upper of which is mottled. The shale parting separating the mottled calcilutite from the Cockleshell Limestone in Routin Gill has thickened here to at least 40cm but its total thickness is unknown as a gap of 90cm separates it from first exposure of the Cockleshell Limestone. In Crag Sike the Lower Parting is at least 3.6m thick but does not exceed 4.5m. In Birks Gill it is less than 4.15m thick.

To the west of Routin Gill, in Noon Gill (SD 893975) the poorly exposed Lower Parting is 3m thick. Only 80cm of muddy calcilutites, 55cm above the base of the Single Post Limestone, and the uppermost 40cm of the calcareous shale, immediately beneath the Cockleshell Limestone, are seen, though loose blocks of mottled calcilutite with pink weathering mottles were recorded.

Northeast of Swaledale in Long Acres Quarry (NZ 181043) the beds of the Lower Parting cannot be recognised with certainty. Two thin calcareous shales separated by a calcilutite 18cm thick which overlie the Single Post Limestone and underlie beds belonging to the Cockleshell Limestone may represent the Lower Parting.

Garsdale and the northwest.

In the area studied the Lower Parting reaches its maximum thickness in the Birkett Railway Cutting (NY 774029), north of the Askrigg Block in the southern part of the Barnard Castle Trough. It is 9m thick and consists dominantly of shales with sideritic nodules overlain by micaceous sandstones and shales. The sandstones are very fine to medium grained, carbonaceous and commonly parallel- or ripple-cross-laminated. A poorly exposed coal 5cm to 15cm thick resting on 30cm of mudstone occurs 60cm above the base of the Parting and two limestones, a lower, red weathering, pyritic, slightly sandy, dark grey calcilutite 8cm thick and an upper, dark grey calcilutite 22cm thick are seen 5.75m and 8.45m above the base respectively.

The Lower Parting thins southwards to 4.9m in Needlehouse Gill (SD 033971) on the northwest corner of the Askrigg Block. Calcareous shales with thin to medium bedded calcilutites interbedded in their upper part form the lowest beds and pass up into medium to thick bedded calcilutites overlain by calcareous sandstone. Bedding planes in the interbedded calcilutites and shales are irregular and compressionally deformed. The uppermost calcilutite, 90cm thick, contains small chert nodules in the upper part and is mottled in its lower 30cm. It overlies a similarly mottled calcilutite 25cm thick which in turn rests on a shaly nodular calcilutite, 13cm thick, similar in appearance to the nodular calcilutite in Arn Gill (SD 953923, Wensleydale). The top bed of the Lower Parting is a medium grained calcareous sandstone 1.2m thick, with only a slightly calcareous central part.

Further thinning takes place to the south and sandstone appears beneath the nodular calcilutite. In Penny Farm Gill (SD 702932) the Lower Parting is 2.65m thick. It consists of a lower shale 85cm thick overlain by a calcareous sandstone and sandy limestone 25cm and 65cm thick respectively. The sandy limestone is separated by a 30cm nodular calcilutite from a slightly sandy limestone 60cm thick, the uppermost bed of the Parting.

To the south and southwest the nodular calcilutite passes into a very thin shale before disappearing and the underlying and overlying sandy limestones become increasingly sandy and pass laterally into variably calcareous sandstones.

In northern Garsdale the most westerly exposure of these beds is in Thrush Gill (SD 745900). Here the Lower Parting is 2.25m thick and consists of a thick shale overlain by two thick bedded calcareous sandstones. The sandstones are separated by a very thin shale, the lateral equivalent of the nodular calcilutite seen farther north, but this disappears to the south and west. The lower part of each sandstone is more calcareous than the upper part and traces of cross-lamination can be detected on suitably weathered surfaces. In northern Garsdale the only complete section of these beds is seen in Greenside Gill (SD 753901). The shale at the base is silty and has thinned to 40cm whilst the overlying sandstones have thickened giving the Lower Parting a total thickness of 2.7m. The sandstones are also well exposed in Ay Gill (SD 756903), Grinning Gill (SD 762904) and Garth Gill (SD 771910). All are at least slightly calcareous but differential weathering enables distinction to be made between the slightly calcareous and highly calcareous sandstones. Those with a low carbonate content weather with planar faces but with increasing carbonate content the faces become rounded and dissolution of the carbonate gives a porous weathered surface. The upper parts of individual beds are frequently less calcareous than the lower parts. Traces of cross-lamination are visible on some of the surfaces etched by weathering.

On the southern side of Garsdale shales are absent in the west. In Pegs Gill (SD 723878), the most westerly section, only the sandstones at the top of the Lower Parting are exposed but the complete section in Aye Gill (SD 730896) shows the Lower Parting to consist of 1.65m of thick bedded variably calcareous sandstones. East of Aye Gill (SD 730896) these beds are fully exposed in Blea Gill (SD 758893) where they are thick bedded, calcareous sandstones but farther east in the railway cutting above Ingheads (SD 777906) a medium bedded shale is seen. Here the Lower Parting reaches its maximum exposed thickness in Garsdale of 3.1m. A calcareous sandstone 30cm thick overlies the Single Post Limestone and is overlain by a buff coloured sandy dolomitised limestone 55cm thick containing brachiopods. Shale 20cm thick follows, overlain by thick bedded, calcareous sandstones. The tops of the sandstone beds are bioturbated but traces of cross-lamination are preserved in places beneath. In Smout Gill (SD 779908), the most easterly section on the south side of Garsdale, 2.15 m of thick bedded calcareous sandstones are exposed.

Northeast of Garth Gill (SD 771910) and Smout Gill (SD 779908), on the north and south sides of Garsdale respectively, the calcareous sandstones pass laterally into limestones. At the head of the Dale in the River Clough (SD 782922) the Lower Parting is about 2.65m thick but only the upper part is sandy. It consists of a lower shale, medium to thick bedded calcilutites and an upper very thick calcarenite which contains quartz sand in its upper 80cm, most abundant at the top. East of the River Clough the sand disappears completely.

Dentdale and the southwest.

In this area the Lower Parting is sandy only in Cowgill Beck (SD 770886), the most northerly exposure. At this locality it is 1.65m thick and consists of thick bedded, medium grained, calcareous sandstones. The lowest bed infills hollows up to 40cm deep in the top of the Single Post Limestone and is of variable thickness (Plates 1 & 2). The sandstone at the top of the Lower Parting becomes increasingly calcareous and passes from a calcareous sandstone into a sandy limestone in its upper 20cm. Sparse small brachiopods including Eomarginifera occur in the calcareous sandstone.

Southwest of Cowgill Beck in Aye Gill (SD 741872) and Stock Beck (SD 734870) sand is absent and the Lower Parting consists of dark to medium grey, medium to thick bedded calcilutites with scattered crinoid debris. The top of the Parting cannot be recognised and its thickness is unknown.

Southeast of Cowgill Beck along the north side of Dentdale the Lower Parting thins to 1.25m in Arten Gill (SD 785859) and to 80cm in Long Gill (SD 779833) at the head of the dale. The lowest beds are not exposed in Arten Gill but the complete section in Long Gill exposes thin bedded dark grey shaly calcilutites overlain by a pale weathering, medium grey calcilutite with poorly defined dark grey mottles. The mottled calcilutite has an irregular base and a thickness varying between 30cm and 60cm. In Arten Gill it is 65cm thick.

The Lower Parting thickens along the south side of the Dentdale from the head of the dale westwards. On the northern slopes of Whernside it increases from 95cm in Hazel Bottom Gill (SD 770839) to 1.25m in Great Blake Beck (SD 762851) and How Gill (SD 744855) reaching about 1.45m in Stock Beck (SD 736854). The uppermost calcilutite also thickens westwards from 55cm in Hazel Bottom Gill (SD 770839) to 70cm in Stock Beck (SD 736854). In Great Blake Beck (SD 762851) it is locally thin varying from 25cm to 45cm and has an irregular base, as in Long Gill (SD 779833). The colour mottling at this horizon is well developed in Hazel Bottom Gill where it is associated with large spreite burrows but at the other localities it is only seen poorly.

The thickening continues into Deepdale. In Broken Gill (SD 716841) the Lower Parting is 1.7m thick but at the head of the dale in Coombe Gill (SD 726825) and Gastack Beck (SD 709827) it has increased to 2.35m and 2.45m respectively. The best section, in Gastack Beck, exposes medium to thick bedded, dark to medium grey crinoidal calcilutites and calcarenites with thin shaly partings and a central very shaly calcilutite 25cm thick. A calcareous shale, 15cm thick, absent in Coombe Gill and Broken Gill, forms the upper bed of the Parting. In Coombe Gill the calcilutite at the top of the Parting is at least 1.2m thick. Its lower part is mottled and contains tiny elongate patches of coarsely crystalline calcite usually less than 1cm long.

The calcilutites in Deepdale are extensively burrowed. The burrow systems are commonly horizontal and best observed on bedding planes. They are large, sometimes exceed 20cm in length and 2cm in diameter, branch sparsely and often have spreite.

Southwest of Deepdale the Lower Parting is poorly exposed in Ease Gill (SD 692820). It is at least 2.2m but not greater than 2.9m thick. The highest bed of pale weathering, medium grey calcilutite, 25cm thick, is not mottled and overlies poorly exposed dark grey calcilutites.

The section in Force Gill (SD 758821), southeast of Deepdale, is similar to the exposure in Gastack Beck except that the beds have thinned to 1.6m. As in Gastack Beck, the crinoidal calcilutites with thin shaly partings are burrowed and a thin shale forms the uppermost bed. Farther east around Gearstones the Parting is fully exposed in Long Gill (SD 803835), Lat Gill (SD 802819) and Hazel Gill (SD 785821). In Long Gill and Lat Gill it is composed of medium and thick bedded crinoidal calcilutites. It thins to 1.1m in Hazel Gill where it consists of only two beds of calcilutite, the lower being crinoidal. The upper bed is characteristically mottled but in Long Gill the mottling is absent and in Lat Gill it is restricted to the lowest part of the highest bed.

To the south on Ingleborough the beds of the Lower Parting cannot be recognised and appear to be absent. The possibility that they are present but cannot be distinguished from the Cockleshell Limestone cannot be excluded. However, by comparison with the area to the east where southerly thinning and eventual disappearance of the Lower Parting can be proved, it seems probable that the Lower Parting is absent.

Wharfedale.

In Wharfedale the thin Lower Parting is restricted to a few outcrops on the north side of Langstrothdale. It fails to the south where the Cockleshell Limestone directly overlies the Single Post Limestone. In the northeast near Cam Houses it contains sandstone.

The sandstone is exposed only at three localities, Tur Gill (SD 825822), Far End Gill (SD 833825) and Grainings Gill (SD 828324). It is absent from the rather sparse surrounding outcrops though it forms nearly all the Lower Parting in Garsdale (p. 76). The Lower Parting is 1.2m thick in Far End Gill and consists of two medium bedded limestones overlain by a calcareous sandstone, 60cm thick. The lowest bed, a crinoidal calcilutite, is overlain by a calcarenite with bioclastic debris concentrated at its centre. It becomes sandy towards the top and is succeeded by the calcareous sandstone which has a highly calcareous central part. Southeast, in Tur Gill (SD 825822), the calcareous sandstone rests directly on the Single Post Limestone. It is slightly thinner, 55cm thick, and has a highly calcareous central part as in Far End Gill. In Grainings Gill (SD 828324), east of Tur Gill, only the uppermost 25cm of the calcareous sandstone is exposed.

To the east in Swarth Gill (SD 848828), Hazel Bank Gill (SD 865826) and Deepdale Gill (SD 898811) the Lower Parting is absent but in Crook Gill (SD 929797) it is represented by a thin calcareous shale overlain by 70cm of mottled calcilutite. Over the rest of this area south of these outcrops the Lower Parting is absent.

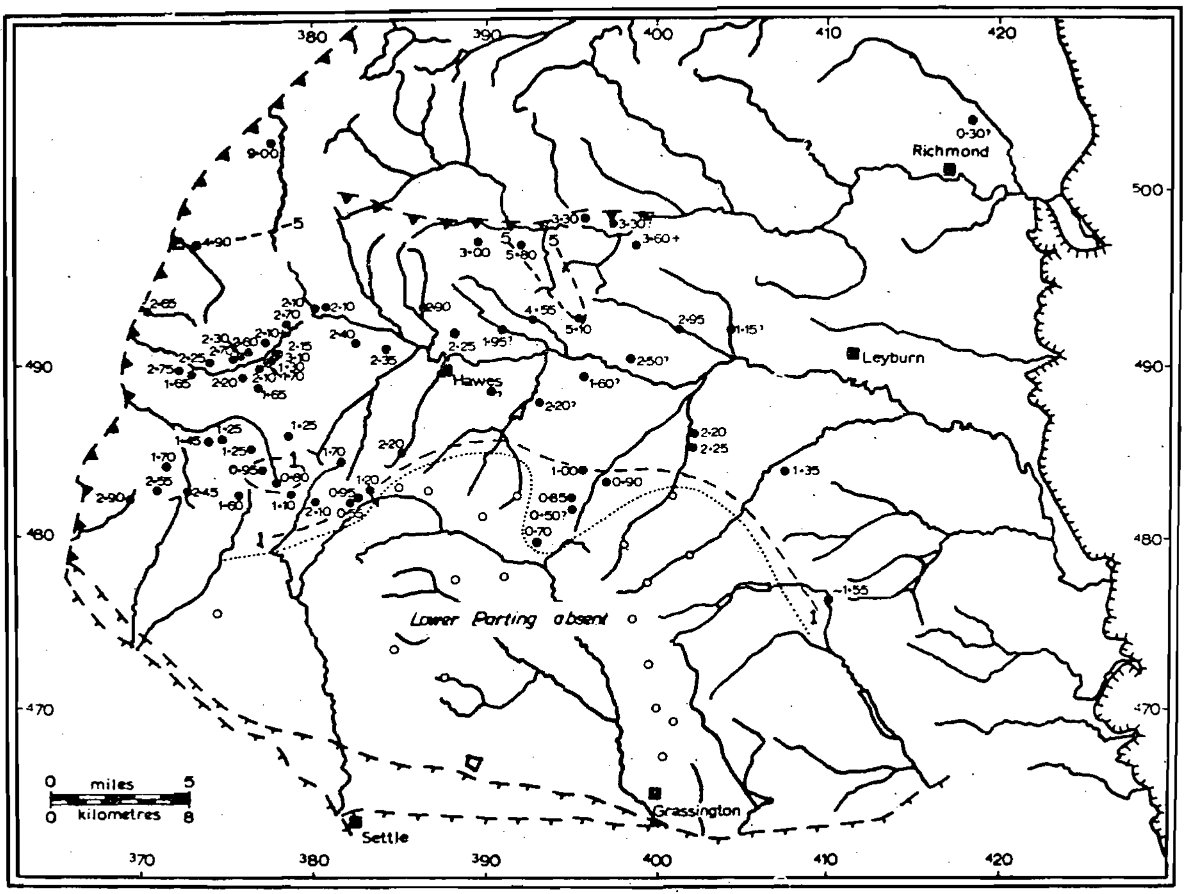


Fig. 15. Isopach map of Lower Parting.

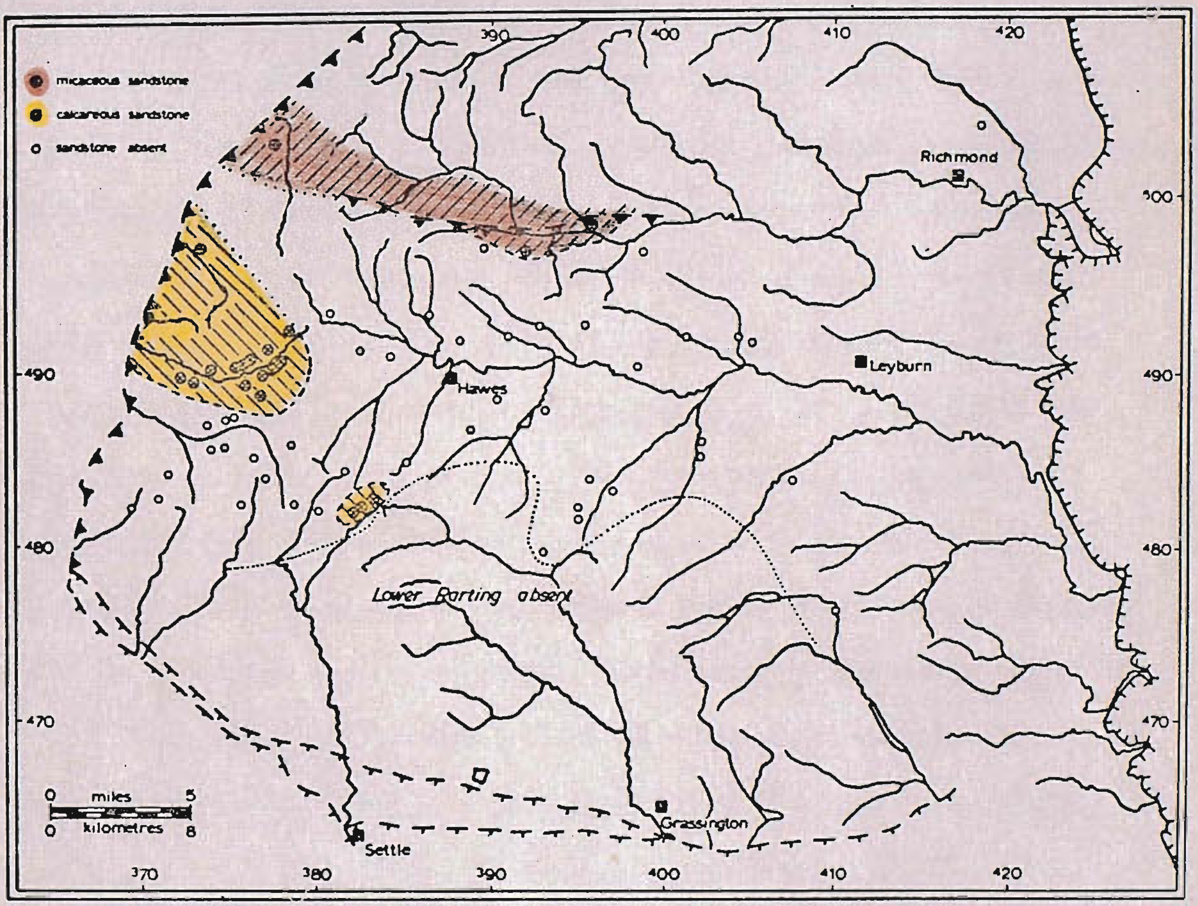


Fig. 16. Map showing distribution of sand in Lower Parting.

THE COCKLESHELL LIMESTONE.

SUMMARY.

The Cockleshell Limestone accumulated over the entire Askrigg Block. In the north it rests on the Lower Parting but in the south, where the Lower Parting is absent, it overlies the Single Post Limestone. The Cockleshell Limestone is thinnest in the west (35cm to 4m) and thickens in the east (10m) and southeast (15m). Over all except the southern and central western parts of the Askrigg Block it has a fauna of *Gigantoproductus* and sometimes *Lithostrotion*. It is cherty in the east with numerous chert nodules, often situated in the concavity of gigantoproductid valves most of which are in their position of growth. Decomposition of gigantoproductid organic matter after death is thought to have created a locally favourable environment for silica precipitation.

Thickening of the Cockleshell Limestone is accompanied by a change in lithology from crinoidal calcilutites to crinoid calcarenites and in the southeast, where thickest, bioherms are developed. The bioherms consist of bryozoan calcilutite cores up to 4m high capped and flanked by coarse crinoid-stem calcirudites. Depositional dips and geopetal structures in the flanking calcirudites show the bioherms existed as primary mounds on the sea floor.

THE COCKLESHELL LIMESTONE.

DETAILS.

Wensleydale.

Along the north side of Wensleydale the Cockleshell Limestone thickens from 3.3m in Tarn Gill in the west to over 6m in the east. Most of the thickening occurs between Whitfield Gill (SD 930923) and Disher Force (SD 981904) where it increases from 4.1m to 9.9m. In Fossdale Gill (SD 861930) it is locally thin, only 2.65m thick.

From the head of the dale east to Whitfield, the outcrops at Ure Force (SD 801932), Tarn Gill (SD 807929) Fossdale Gill (SD 861930), Coal Gill (SD 881917), Sar Gill (SD 908918) and Whitfield Gill (SD 930923) show the Cockleshell Limestone to consist of medium and thick bedded, dark to medium grey crinoidal calcilutites with very thin shale partings. The calcilutites are sparsely crinoidal and have a bluish tint. Gigantoproductus, rare in the west, becomes numerous in Sar Gill and Whitfield Gill in all but the lowest part of the limestone.

East of Whitfield Gill the Cockleshell Limestone thickens rapidly and becomes very cherty. In Arn Gill (SD 953923) it is 6.7m thick and magnificently exposed in the side of a small gorge. It is a dark grey calcilutite with scattered crinoid ossicles up to 3cm in diameter and sometimes articulated into short lengths of stem. The shaly partings seen to the east and west are represented here by thin argillaceous streaks too thin to produce partings. The Limestone is full of Gigantoproductus and chert nodules in all but the lowest 40cm. Many of the chert nodules are situated in the concavity of Gigantoproductus valves which are nearly all in their position of growth. In addition to nodular chert, disseminated chert is also present. It is easily recognised on weathered surfaces because the silicified areas are abrasive and stand proud from the surrounding limestone. Freshly broken surfaces show the milky opalescence of chalcedony. In addition to Gigantoproductus, Moore (1958) recorded a prolific and varied fauna including many brachiopods and corals and the teeth of Petalodus acuminatus (Agassiz).

At Disher Force (SD 981904), east of Arn Gill, the Cockleshell Limestone has only sparse chert nodules and is medium to thick bedded with thin shale partings. Gigantoproductus is less common than in Arn Gill but Lithostrotion junceum (Fleming) and Diphyphyllum fasciculatum (Fleming) are abundant.

The Cockleshell Limestone maintains a thickness of about 6m eastwards but only incomplete sections are seen. In Beldon Beck (SE 013913) and Apedale Beck (SE 043922) it is a medium to thick bedded crinoidal calcilutite with thin shale partings and a fauna of Gigantoproductus and Lithostrotion. Farther east in Barney Beck (SE 049919) and Wensley Beck (SE 092898) the shale partings are absent and Gigantoproductus and Lithostrotion were not recorded.

On the southern side of Wensleydale, in Great Gill (SE 073840), Coverdale, the Cockleshell Limestone is a dark to medium grey, medium to thick bedded crinoidal calcilutite about 11.8m thick. It contains numerous Gigantoproductus, Lithostrotion and chert nodules and sparse clisiophyllids and zaphrentids in all but the lowest 1.7m. Farther up Coverdale the chert disappears and is absent in Ridge Gill (SE 022790) and Slape Gill (SE 001770). Gigantoproductus and Lithostrotion persist but, as in Great Gill (SE 073840), they are absent from the lowest beds. In upper Coverdale the medium to thick bedded crinoidal calcilutites rest directly on the Single Post Limestone. In Ridge Gill (SE 022790) they are at least 7.3m thick but less than 8.35m thick and in Slape Gill (SE 001778) they are 8.25m thick.

In upper Waldendale and upper Bishopdale the Limestone is similar in lithology and fauna though in Bishopdale _Gigantoproductus_ is less common. In upper Waldendale it is exposed at Ashes Farm (SE 008821) and in Walden Beck (SD 980796) where it is 8.7m and 7.2m respectively. On the east side of Bishopdale it is 6.55m thick in Myers Garth Gill (SD 970820) but thins westward to between 5m and 6m in Foss Gill (SD 956838), Back Gill (SD 951822) and Raffen Gill (SD 951814) on the opposite side of the dale.

In lower Waldendale, as in lower Coverdale, the Cockleshell Limestone is cherty and contains _Gigantoproductus_ and _Lithostrotion_. At Scar Folds (SE 020849) and Long Ing Wood (SE 022860) the Cockleshell Limestone, 9.4m and 9.55m thick respectively, consists of dark to medium grey crinoidal calcilutites except in the upper part at Scar Folds where the beds are locally coarse crinoid-ossicle calcarenites. _Gigantoproductus_ first appears about 1m above the base and is abundant in the overlying calcilutites but absent from the calcarenites at Scar Folds. Chert nodules, frequently situated in the concavity of _Gigantoproductus_ valves, are numerous and sparse clisiophyllids are present. Farther north at Morpeth Scar (SE 029877) the Cockleshell Limestone is similar in thickness but its base is not well exposed and very thin to thin shale partings separate the medium to thick bedded calcilutites. A fauna of trepostome bryozoa and latissimoid brachiopods occurs in the lower beds but Gigantoproductus and Lithostrotion appear above and are numerous in the upper part of the Limestone. Chert nodules, abundant to the south, are sparse. Around the north side of Penhill these beds contain only rare Gigantoproductus and sparse chert nodules but are poorly exposed.

In Gill Beck (SD 966876), west of Penhill, only the upper 4.45m of the Cockleshell Limestone is exposed. It is unparted and consists of lower and upper crinoidal calcilutites, 1.65m and 1.2m thick respectively, separated by 1.6m of crinoidal calcarenite. The lower part contains abundant Gigantoproductus and chert nodules but with gradual increase in crinoid debris and passage into crinoidal calcarenites both Giganto-productus and chert nodules decrease in abundance and become scattered. At the top of the calcarenite Gigantoproductus and chert nodules increase in abundance and become numerous in the basal part of the overlying crinoidal calcilutite. Towards the top of the crinoidal calcilutite their numbers decrease and only rare Gigantoproductus and scattered chert nodules are seen at the top. In addition to nodular chert, disseminated chert is abundant throughout the Limestone and sparse colonies of Lithostrotion and scattered Clisiophyllidae are present.

Farther east in Scar Top Sike (SD 958888) the Cockleshell Limestone is also cherty and contains Gigantoproductus. Its base is not seen but the 6.35m of crinoidal calcilutites and calcarenites exposed is probably near its total thickness. Gigantoproductus is absent from from the lowest 1.55m but common above except in the uppermost 1.5m where it is scattered, becoming rare at the top. Chert nodules are abundant except at the top where they are sparse. The lowest 1.55m contains only scattered crinoid debris unlike the limestone above where crinoid debris is abundant.

The chert disappears to the west and is absent at Burnett Force (SD 942873), Raydale, where the Cockleshell Limestone is a medium to thick bedded, medium to dark grey crinoidal calcilutite 9.55m thick. Gigantoproductus, absent from the lowest 3m, is scattered above and becomes abundant in the upper 4m. Gigantoproductus is also seen in Shaw Gate Gill (SD 926844), where it is sparse, and in Middle Tongue Gill (SD 920824), where specimens are scattered throughout the upper part, and numerous just beneath the top of the Limestone. In Middle Tongue Gill the Cockleshell Limestone, a medium to thick bedded crinoidal calcilutite appears to rest directly on the Single Post Limestone as the beds of the Lower Parting cannot be recognised. It is 7.35m thick.

Gigantoproductus disappears west of the River Bain and is absent in Horton Gill (SD 903883) where the Cockleshell Limestone has thinned to about 4.45m. Farther west at Gaudy House Sike (SD 855887) on the north slopes of Ten End the beds are similar and at least 3.2m thick.

In Bank Gill (SD 853850) at the head of Sleddale and in Long Sike (SD 817842) at the head of Snaizeholme, the Cockleshell Limestone is 3.45m and at least 2.9m thick respectively. It overlies the Lower Parting and consists of medium to thick bedded calcilutites with scattered crinoid debris.

On Widdale Side, the Limestone is very poorly exposed but on the northern end of Widdale Fell two good sections are seen in Cragfold

Sike (SD 839906) and Hollin Gill (SD 823913). In Cragfold Sike it consists of 2.35m of thick bedded calcilutites but the Limestone thickens westwards to 4.9m in Hollin Gill where it is of similar lithology but has very thin shale partings and a fauna of sparse Gigantoproductus and Lithostrotion.

Swaledale.

In Swaledale the only complete section of the Cockleshell Limestone is in Routin Gill (SD 919969). The Limestone, 3.2m thick, is composed of medium to dark grey, medium and thick bedded calcilutites with scattered crinoid and shell debris. Gigantoproductus and occasional colonies of Lithostrotion are seen in the upper 1.85m.

To the west in Noon Gill (SD 893975) the Cockleshell Limestone is similar in lithology and thickness. Gigantoproductus occurs in all but the lowest 80cm with sparse Lithostrotion and Dibunophyllum.

In Birks Gill (SD 985969) east of Routin Gill, the Cockleshell Limestone is at least 3.75m thick but neither its base nor top is exposed. Unlike the exposures farther west sparse chert nodules are present. Gigantoproductus appears about 1m above the base of the lowest bed exposed and is scattered throughout the overlying beds with sparse Lithostrotion colonies.

North of the River Swale the outcrops are poor and incomplete sections are exposed in Staney Gill (SD 959986) and Smarber Gill (SD 972980) where the Cockleshell Limestone is at least 3.6m and 4.3m thick respectively. It is a medium to thick bedded, medium to dark grey calcilutite with scattered crinoid ossicles. A sparse fauna of Gigantoproductus is seen at both localities associated with Lithostrotion in Staney Gill.

Northeast of Swaledale at Long Acres Quarry (NZ 181043) the Cockleshell Limestone is probably 3.15m thick but cannot easily be distinguished from the Lower Parting. It consists of medium to thick bedded crinoidal calcilutites with very thin interbedded shales. Gigantoproductus is common in both the calcilutites and the thicker shales. In the calcilutites nodules of dark grey to greyish-black chert are common and often rest in the valves of the gigantoproductids which are in their growth position. A coral biostrome 20cm thick containing numerous Lithostrotion is seen 1.7m above the top of the Single Post Limestone.

Garsdale and the northwest.

North of the Askrigg Block in the Birkett Railway Cutting (NY 774029) the Cockleshell Limestone is 3.1m thick and consists of dark to medium grey, variably bedded calcilutites with thin to medium interbedded shales. Gigantoproductus is absent.

Farther south in Needlehouse Gill (SD 733971), just on the Askrigg Block, the Limestone has thickened to 4.15m. The lowest beds are thick bedded calcilutites with scattered crinoid debris and Gigantoproductus. They are separated by a thin shale from overlying crinoid-ossicle calcarenites which coarsen upwards into crinoid-stem calcirudites. Small brachiopods, mainly productids, many of which are spinose, and Dibunophyllum occur in the coarser beds.

The Cockleshell Limestone thins southwards to 3.35m in Penny Farm Gill (SD 702932), where it is composed entirely of medium to thick bedded crinoidal calcilutites. Gigantoproductus is not present but Lithostrotion occurs in the upper beds.

Along the north side of Garsdale the Cockleshell Limestone is fully exposed in Thrush Gill (SD 745900), Ay Gill (SD 756903), Garth Gill (SD 771910) and in the River Clough (SD 782922). It overlies calcareous sandstone except in the River Clough where it rests on sandy limestone. In the west the Limestone is 3.2m thick in Thrush Gill and 4.25m thick in Greenside Gill (SD 753901) but thins eastwards to 2.4m in Ay Gill and 1.6m in Garth Gill. East of Garth Gill it thickens and reaches 2.55m in the River Clough where it contains shale partings. Throughout the region it is a dark to medium grey, medium to thick bedded crinoidal calcilutite. Gigantoproductus is absent in the west but to the east appears sparsely in Greenside Gill and Garth Gill becoming numerous in the River Clough.

On the south side of Garsdale the Cockleshell Limestone is similar in lithology, but Gigantoproductus is absent even in the most easterly outcrops. It is well exposed in Pegs Gill (SD 723899), Aye Gill (SD 730896), Blea Gill (SD 753893), Ray Gill (SD 768897) and in Ingheads Railway Cutting (SD 777906). At all these localities it rests on sandstone except in Aye Gill where it is separated from sandstone by a very thin shale. Its contact with the overlying shale of the Upper Parting is only visible in Ingheads Railway Cutting. From the Railway Cutting westwards the Limestone has a thickness between 3.25m and 3.7m but to the east it thins to 2.85m in Smout Gill (SD 779908), the most easterly exposure. Lithostrotion colonies are seen near the top of the Limestone in Ray Gill (SD 768897).

Dentdale and the southwest.

Throughout Dentdale the Cockleshell Limestone is a dark to medium grey, medium to thick bedded crinoidal calcilutite. Both Gigantoproductus and Lithostrotion are absent.

On the north side of the dale it is well exposed in Stock Beck (SD 734870), Aye Gill (SD 741872) and Spice Gill (SD 746874) but as the top of the Lower Parting cannot be recognised the exact thickness of the Cockleshell Limestone is unknown. Farther east in Cowgill Beck (SD 770886) and Arten Gill (SD 785859) the Limestone is 3.95m and 2.95m thick respectively. It reaches a maximum thickness of 4.5m at the head of the dale in Long Gill (SD 779833). Exposures in Hazel Bottom Gill (SD 770839), Great Blake Beck (SD 762851), How Gill (SD 744855) and Stock Beck (SD 736854) on the northern slopes of Whernside show thicknesses between 3.2m and 3.5m.

In Deepdale the Cockleshell Limestone is only 2m thick in Coombe Gill (SD 726825) but thickens to 2.95m in Gastack Beck (SD 709827) and Broken Gill (SD 716841). The good exposure in Gastack Beck shows thin shale partings separating the medium to thick bedded crinoidal calcilutites. The calcilutites are bioturbated and contain large, dominantly horizontal, simple-branching burrows, sometimes with spreite and Zoophycos which are seen best on bedding surfaces beneath the shale partings. The Limestone maintains a thickness of about 3m in Ease Gill (SD 692820) to the south east.

On the east flank of Whernside the Cockleshell Limestone is 2.35m thick in Force Gill (SD 758821). It is medium to very thick bedded and consists of bioturbated crinoidal calcilutites which become increasingly crinoidal upwards. Around Gearstones the total thickness is unknown but in Lat Gill (SD 802819) it is at least 3.3m thick.

In Mere Gill (SD 795753) on the west side of Ingleborough the Cockleshell Limestone cannot be recognised. The Single Post Limestone is overlain by 35cm of slightly shaly-weathering crinoidal calcilutite. This may belong to the Lower Parting but comparison with the sections to the east suggests that the Lower Parting is probably absent in this region. If this is so then the crinoidal calcilutite represents either all or part of the Cockleshell Limestone. It is overlain by calcarenite, a lithological change often associated with the Cockleshell Limestone - Scar Limestone junction. The 35cm of crinoidal calcilutite may therefore represent the total thickness of the Cockleshell Limestone.

Wharfedale.

In Wharfedale the Cockleshell Limestone rests on limestone except in Tur Gill (SD 825822) and Far End Gill (SD 833825) where it overlies sandstone of the Lower Parting. In Crook Gill (SD 929797) it lies on limestone of the Lower Parting but over most of the region the Lower Parting is absent and it rests directly on the Single Post Limestone.

A complete section is exposed in Deepdale Gill (SD 878811) where the Cockleshell Limestone is 4.60m thick and consists of medium to dark grey, medium to thick bedded calcilutites with scattered crinoid debris. A similar thickness is exposed in Tur Gill (SD 825822). To the south crinoid debris becomes more abundant and Cockleshell Limestone is difficult to distinguish from the beds above and below.

In Crooke Gill (SD 845733) 2.1m of thin to medium bedded, medium grey calcarenites comprise the Cockleshell Limestone. In Darnbrook (SD 878717) its thickness is unknown because it cannot be distinguished from the Single Post Limestone and in Halton Gill neither the base nor top of the Cockleshell can be recognised. Here, it consists of bioturbated, medium to very thick bedded coarse crinoid-ossicle calcarenites.

To the south the Cockleshell Limestone is exposed at Gorbeck (SD 858571) where it at least 3.2m thick. The lowest bed seen, a dark grey calcilutite, is separated from the Single Post Limestone by a gap of 65cm and overlain by a medium grey crinoid-ossicle calcarenite 60cm thick with Linoproductus and Caninia. The upper beds are medium grey, thick bedded, bioturbated calcilutites with cherty streaks throughout and small chert nodules in the uppermost 50cm.

In Bowther Gill (SD 906772) the Cockleshell Limestone is at least 5m thick with scattered Gigantoproductus but farther southeast the limestone thickens and Gigantoproductus becomes abundant. In Park Gill Beck (SD 987653) numerous Gigantoproductus occur in the 8.25m of calcilutite with scattered ossicles forming the Cockleshell Limestone. The Limestone becomes more crinoidal to the south and thickens to 9m. It is well exposed in Dowber Gill (SD 993728) and at Mossdale Scar (SE 016697) where the medium to very thick bedded crinoid-ossicle calcarenites contain abundant Gigantoproductus. South of Mossdale Scar Gigantoproductus is abundant at distinct horizons rather than scattered throughout the entire limestone.

Farther south Gigantoproductus decrease in number and disappear in the vicinity of Bare House (SE 005669). The most southerly specimen is recorded from the Old Quarry (SE 004668) 150m southwest of Bare House (Joysey, 1955). The disappearance of Gigantoproductus coincides with a change in lithology. South of Bare House the Cockleshell Limestone thickens to about 15m and the calcarenites with Gigantoproductus pass into lenses of unbedded calcilutite capped and flanked by calcarenites and calcirudites; the knoll limestones described by Black (1950) and Joysey (1955). The resistant unbedded calcilutite lenses which core the knolls are mound shaped and, being far more resistant to erosion than the overlying thin bedded crinoidal calcarenites and calcirudites, frequently form small hillocks (Plate 6). They are not restricted to a single horizon but occur throughout the Cockleshell Limestone. Black (1950) mapped eighteen knolls in this region with diameters from 40' (12m) to 90' (27.5m) and height from 4' (1.2m) to 12' (3.65m) and considered at least two other concealed knolls of comparable size present. In addition many knolls of smaller size are seen.

The varying stages reached in the erosional dissection of the knolls helps in elucidation of their structure. The knoll cores consist of lensoid or mound shaped masses of unbedded calcilutite and rest on bedded crinoidal limestones (Plate 6). The cores sometimes have a pseudo-brecciated appearance and contain trepostome and fenestellid bryozoa as a characteristic faunal element. Crinoid debris, small brachiopods and gastropods are also present but the former is usually sparse except in the outer part of the core. Towards the outer part of the core bryozoa decrease in abundance and the unbedded calcilutite becomes increasingly crinoidal and sometimes has rudimentary bedding. No clear boundary exists between the core and the overlying thin bedded crinoid-stem calcarenites and calcirudites which contain occasional spirifers and bryozoans and dip radially off the cores. The amount of quaquaversal depositional dip is often difficult to determine exactly because of tectonic disturbance but dips of up to 15^{o} are common

Plate 6. The Cockleshell Limestone, west of Yarnbury (SE 075659).
An unbedded bryozoan calcilutite knoll core overlying
well bedded crinoid-ossicle calcarenites.

Plate 7. The Cockleshell Limestone, southwest of Bare House (SE 003665)
near Yarnbury.

An unbedded bryozoan calcilutite knoll core flanked (on right)
by crinoid-stem calcirudites showing depositional dips.

and dips of up to 30^{o} are occasionally seen as in the thin bedded crinoidal limestone capping a knoll to the south west of Bare House (Plate 7).

Although Joysey (1955) apparently considered the knolls persist to the most southerly exposure of the Cockleshell Limestone in the Grassington area, Black (1950) had previously indicated a southern limit on his map. A southern limit can be seen towards which the knolls gradually decrease in size and eventually disappear (Plate 8, Fig. 17). To the south of the knolls the Cockleshell Limestone becomes less crinoidal and darker in colour before it disappears beneath the over-stepping Bowland Shale.

In Hebden Beck (SE 011668) 60cm of shale and nodular calcilutite are exposed in the upper part of the Cockleshell Limestone. It contains a fauna of Gigantoproductus and clisiophyllids.

Plate 8. The Cockleshell Limestone, west of Yarnbury (SE 015659).

The southerly decrease in knoll size before their final disappearance is shown well by the three bioherms in the photograph.

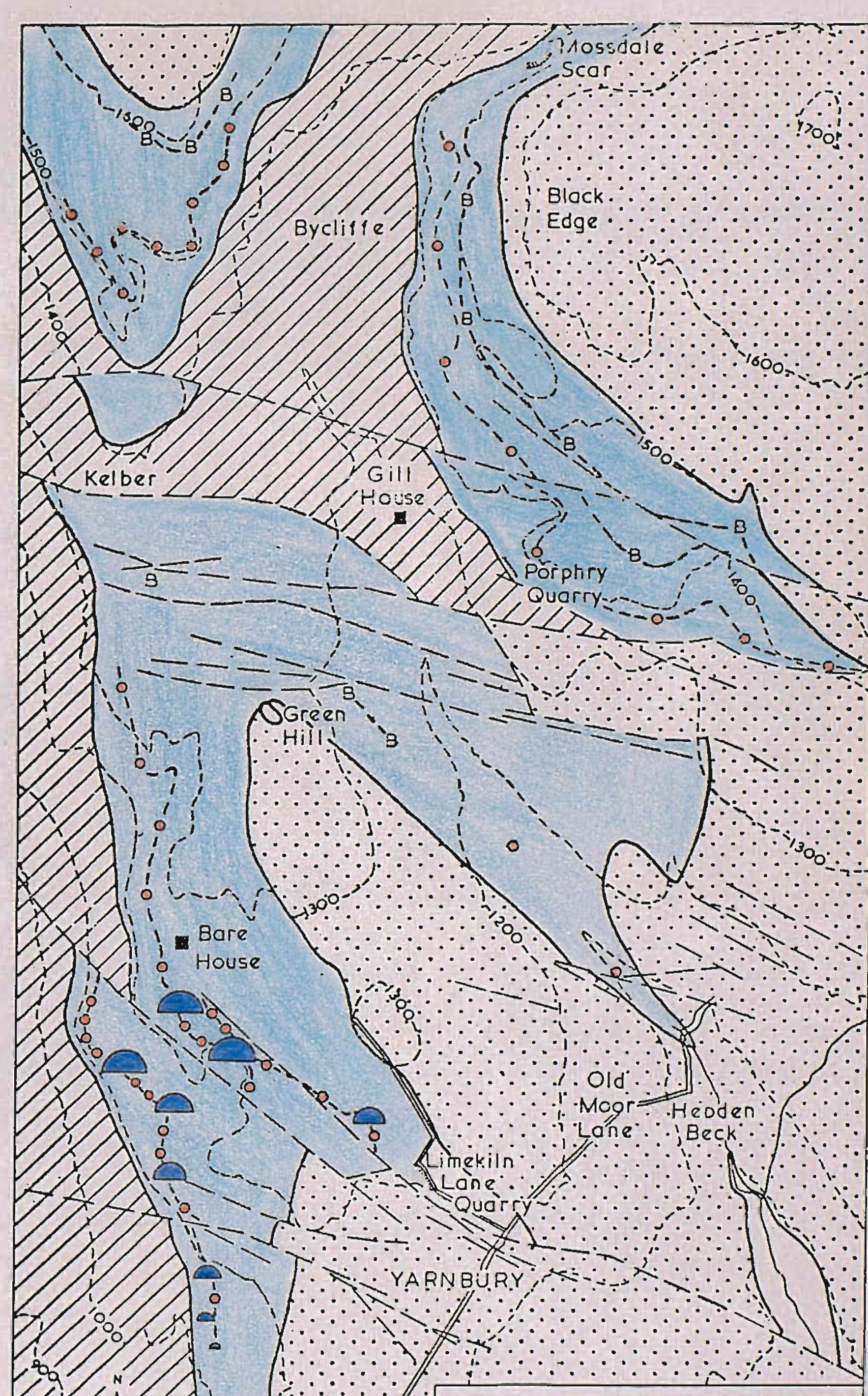


Fig. 17. Map of Middle Limestone in area north of Grassington.

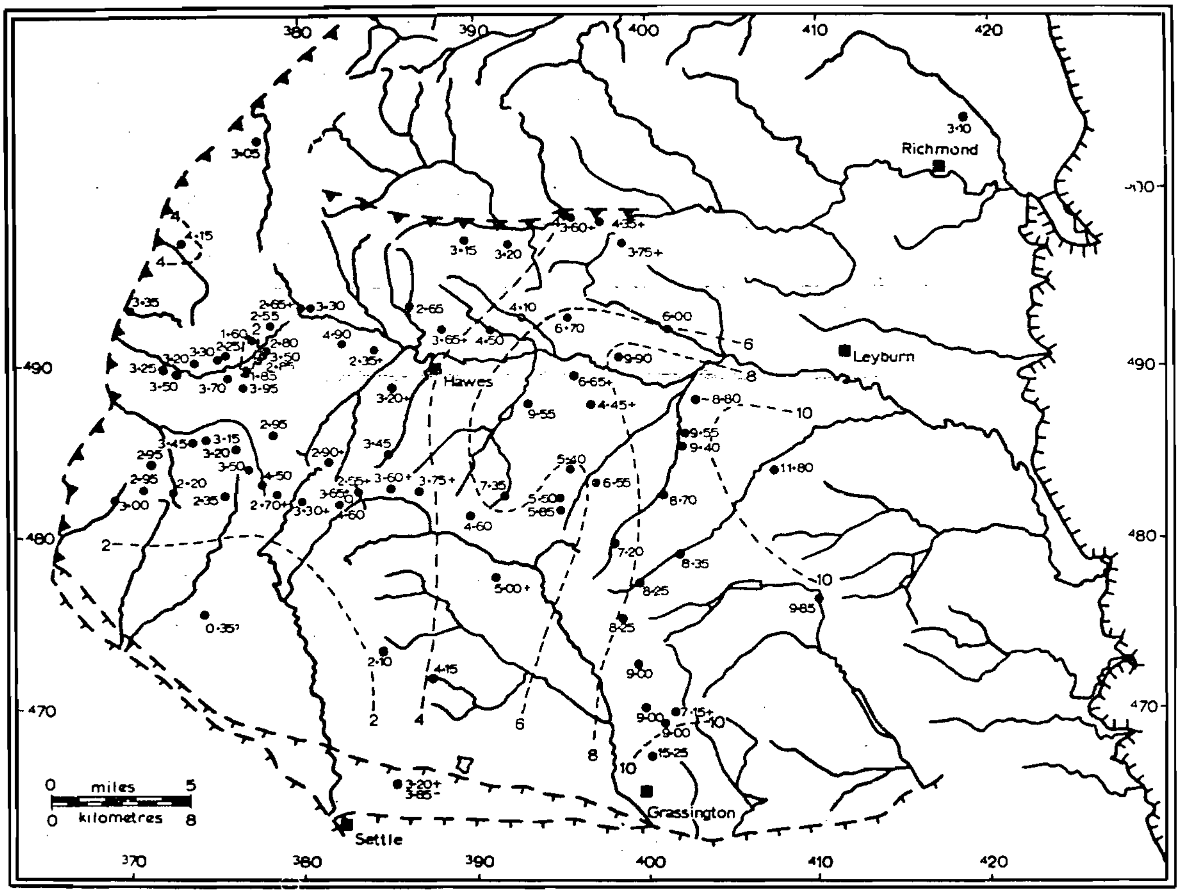


Fig. 18. Isopach map of Cockleshell Limestone.

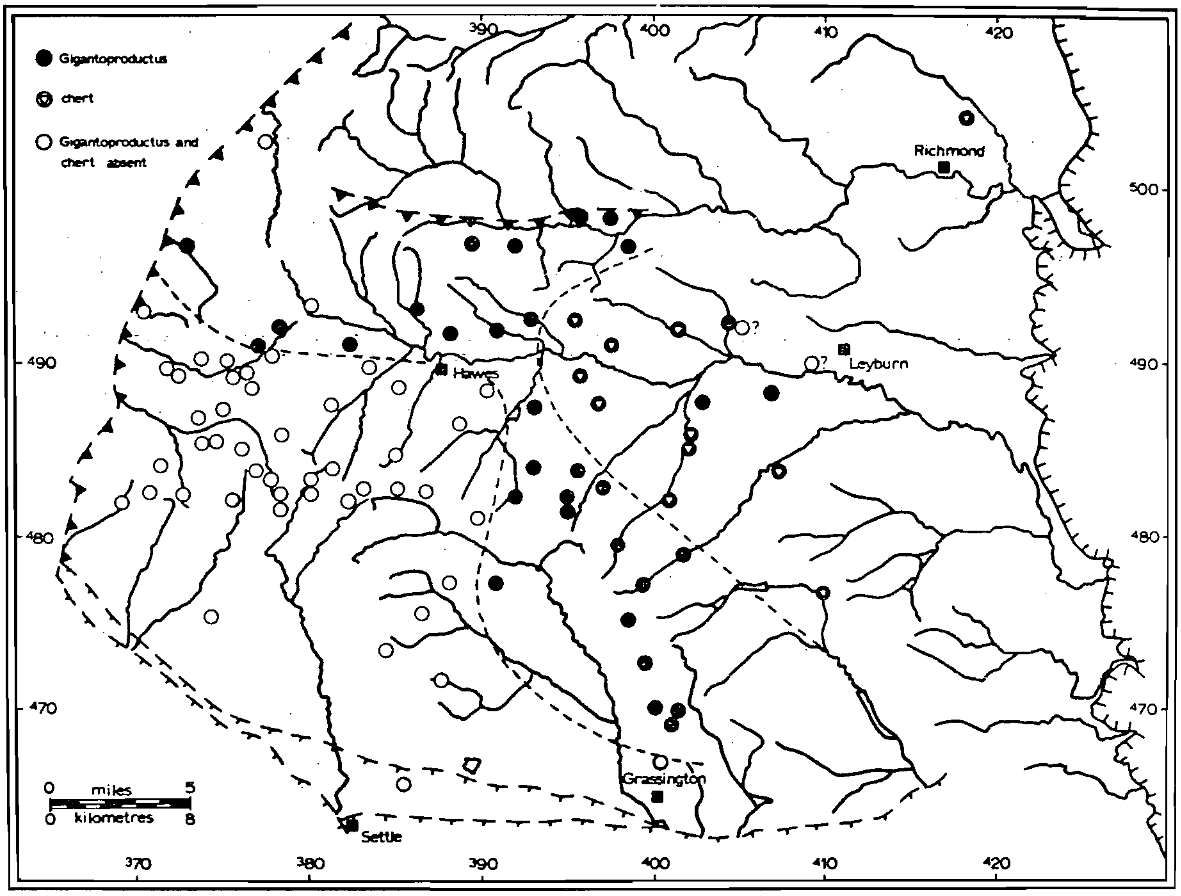


Fig. 19. Map showing distribution of <u>Gigantoproductus</u> and chert in Cockleshell Limestone.

THE UPPER PARTING.

SUMMARY.

The Upper Parting, like the Lower Parting is thickest northwest of the Askrigg Block. It rests on the Cockleshell Limestone and thins southeastwards. In the southwestern part of the Barnard Castle Trough the Upper Parting consists of 18m of deltaic micaceous sandstones and shales. The sandstones reach only the northern edge of the Askrigg Block but shale persists farther south where it becomes calcareous. In the south and east the shale also fails and the Upper Parting is absent.

On the Askrigg Block the calcareous shale contains scattered crinoid-debris and a fauna of brachiopods, including small spirifers, small productids and occasionally *Gigantoproductus*, and sometimes trepostome and fenestellid bryozoa. Thin, impersistent, usually argillaceous calcilutites sometimes occur within the shale.

THE UPPER PARTING.

DETAILS.

Wensleydale.

In this area the Upper Parting is a calcareous shale with sparse crinoid debris and a fauna of small brachiopods, dominantly spirifers and productids, and a few bryozoans. It is nearly 2m thick in the northwest but thins to the southeast failing completely in the east.

On the north side of Wensleydale in Tarn Gill (SD 807929), the most westerly exposure of the Upper Parting, 50cm of calcareous shale crops out beneath the Scar Limestone above a gap of 2.5m. Eastwards the Upper Parting is fully exposed in Fossdale Gill (SD 861930), Sar Gill (SD 908918) and Whitfield Gill (SD 930923) where it is 1.5m, 1.3m and 1.9m thick respectively. It consists of calcareous shale at all three localities but in Sar Gill and in Whitfield Gill a thin, dark to medium grey, argillaceous calcilutite with scattered crinoid ossicles is seen 10cm beneath the top of the shale. Although the Upper Parting is thick in Whitfield Gill, from Arn Gill (SD 953923) eastwards it is absent and the Scar Limestone rests directly on the Cockleshell Limestone.

On the south side of Wensleydale the Upper Parting is well developed in the northwest. Near the head of the dale in Hollin Gill (SD 823913) it is a calcareous shale 1.6m thick and to the east of Cragfold Sike (SD 839906) a gap of 1.5m at this horizon indicates the presence of a slightly thinner shale. Along the east side of Widdale Fell the thickness of the Upper Parting is unknown as large gaps occur at this level. East of Widdale Fell in Gaudy House Sike (SD 855887) on the north flank of Ten End a gap of 80cm between exposures of the Cockleshell and Scar Limestones probably represents the thickness of the Upper Parting shale but farther east in Horton Gill (SD 903883) on the northeast slopes of Wether Fell, the upper 40cm of calcareous shale is exposed above a gap of 1.55m. South of these outcrops in Bank Gill (SD 853850) at the head of Sleddale and in Middle Tongue Gill (SD 920824) at the head of Cragdale gaps of 1.65m and 70cm are probably developed at least partly in shale but at Burnett Force (SD 942873) on the east side of Raydale, even though a 50cm gap is seen, the shale is thought to be absent as on the north flank of Addleborough in Scar Top Sike (SD 958888) and in Gill Beck (SD 966876). At the head of Bishopdale in Raffen Gill (SD 951814), Back Gill (SD 951822) and Foss Gill (SD 956838) the shale is 30cm, 25cm and 20cm respectively but opposite, in Myers Garth Gill (SD 970830) on the southeast side of the dale, it is absent. The Upper Parting is also absent east and southeast of Bishopdale. This is proved by the outcrops at Walden Beck (SD 980796), Ashes Farm (SE 008821), Scar Folds (SE 020849), Long Ing Wood (SE 020849, and Morpeth Scar (SE 029877) in Waldendale and at Slape Gill (SE 001778), Ridge Gill (SE 022790) and Great Gill (SE 073840) in Coverdale where the Scar Limestone rests directly on the Cockleshell Limestone.

Swaledale.

On the north side of Swaledale the thickness of the Upper Parting is unknown. In Smarber Gill (SD 972980) 1.4m of shale is visible but gaps above and below prevent determination of its full thickness. Beneath the shale small isolated outcrops of calcilutite are seen. They may be part of the Cockleshell Limestone but it is more likely that they belong to the Upper Parting because the gaps between the outcrops are probably in shale. A possible maximum thickness of 6.75m for the Upper Parting is given by the distance separating large outcrops clearly identifiable as Cockleshell and Scar Limestone. In Staney Gill (SD 959986) to the east the Upper Parting is less than 6.3m thick. The medium to thick bedded, dark grey calcilutites 1.1m thick with scattered crinoid ossicles, exposed 3.85m above beds belonging to the Cockleshell Limestone, probably belong to the Upper Parting.

On the south side of Swaledale in Birks Gill (SD 985969) a calcareous shale 50cm thick resting on a thin muddy calcilutite with Lithostrotion and separated by a 40cm gap from an overlying muddy calcilutite 90cm thick with a fauna of Gigantoproductus, small productids and fenestellid bryozoa are the only beds of the Upper Parting exposed. Large gaps, probably in shale, separate these beds from the Cockleshell Limestone beneath and Scar Limestone above and show the thickness of the Upper Parting to be not greater than 4.7m. In Routin Gill (SD 919961) the Upper Parting is 3.5m thick. Shales, poorly exposed, form most of the Parting but in the lower part loose calcilutite blocks may indicate the presence of limestone. Farther east in Noon Gill (SD 893975) 1.25m of shale with a thin muddy crinoid-ossicle calcarenite in the centre are exposed beneath the Scar Limestone. Below the shale 25cm of calcilutite is exposed separated from the Cockleshell Limestone by a 75cm gap. The Upper Parting, therefore, has a thickness of not more than 2.25m.

Northeast of Swaledale the Upper Parting is exposed in Long Acres Quarry (NZ 181043) where it is 1.4m thick. A lower calcareous shale 30cm thick is separated from an upper shale 80cm thick by 30cm of calcilutite with Gigantoproductus.

Garsdale and the northwest.

The Upper Parting reaches its maximum thickness in this region. Its greatest thickness is seen in the Birkett Railway Cutting (NY 774029) to the north of the Askrigg Block where 18m of clastic sediments separate the Cockleshell and Scar Limestone. Here, the Lower Parting consists of shales with very thin and nodular ironstones overlain by micaceous sandstones with shales in their upper part. Many of the sandstones are ripple cross-laminated. A thin coal is present in the upper part.

To the south these beds thin rapidly and the sandstones fail. In Needlehouse Gill (SD 733971), just on the Block, the Lower Parting has thinned to 8.8m. The lowest 2m are calcareous shales with crinoid debris, Gigantoproductus and thin beds of muddy crinoidal calcarenite. A medium bedded, red-weathering, crinoidal calcarenite separates these beds from overlying silty shales. A 30cm micaceous sandstone 1.2m above the base of the silty shales is the only representative of the sandstones so well developed farther north. Shale overlies the sandstone and forms the rest of the Upper Parting. The sandstone fails completely to the south and in Penny Farm Gill (SD 702932) 3.5m of shale with a very thin nodular ironstone band 65cm above the base constitutes the Upper Parting.

In Garsdale the Upper Parting is exposed completely in Ay Gill (SD 756903), Garth Gill (SD 771910), the River Clough (SD 782922), Ingheads Railway Cutting (SD 777906) and partial sections are seen in Thrush Gill (SD 745900), Ray Gill (SD 768897) and Blea Gill (SD 758893). It consists entirely of calcareous shale, except in Garth Gill (SD 771910) and the River Clough (SD 782922) where, in addition, a thin bedded calcilutite occurs in the middle of the shale. In Garth Gill it is a thin nodular calcilutite but it thickens eastwards and in the River Clough 40cm of shaly crinoidal calcilutite with a fauna of Lithostrotion, Gigantoproductus and other small brachiopods is seen. The Upper Parting is thickest at the head of the dale, about 3m thick in the River Clough and thins westwards. It reaches a minimum thickness of 1m on the south side of the dale in Blea Gill but over most of the area it is between 1.5m and 2m.

Dentdale and the southwest.

In this region the Upper Parting is a calcareous shale with impersistent thin beds of calcilutite and contains a fauna of small brachiopods, dominantly productids and spirifers and scattered to sparse crinoid debris. It is thickest in the north but thins southwards and fails completely in the southernmost ground.

On the north side of Dentdale the Upper Parting is only fully exposed in Stock Beck (SD 734870), the most westerly outcrop. Here it is 1.8m thick and consists of calcareous shale with two thin beds of dark grey calcilutite in the upper part containing Lithostrotion. Eastwards, in Aye Gill (SD 741872) and Spice Gill (SD 746874) gaps of 1.15m and 1.65m separate the highest and lowest beds of the Cockleshell

Limestone and Scar Limestone exposed respectively but in Cowgill Beck (SD 770886), 15cm of calcareous shale outcrops beneath the Scar Limestone above a gap of 1.05m. Farther east in Arten Gill (SD 785859) a gap of 85cm is seen at the level of the Upper Parting but in Long Gill (SD 779833) at Dent Head the Upper Parting is fully exposed and consists of 85cm of calcareous shale.

Around the north slopes of Whernside on the south side of Dentdale the Upper Parting is exposed only in Hazel Bottom Gill (SD 770889) where 1.25m of calcareous shale is seen. In How Gill (SD 744855) and Stock Beck (SD 736854) gaps of 2.05m and 1.8m occur respectively. At Deepdale Head in Coombe Gill (SD 726825) calcareous shale 1.05m thick crops out poorly and in Gastack Beck (SD 709827) 1.1m of calcareous shale is seen above a gap of 55cm. On the west side of Deepdale in Broken Gill (SD 716841) only the lowest 30cm and uppermost 65cm of calcareous shale are exposed, separated by a gap of 65cm.

On the east flank of Whernside in Force Gill (SD 758821) a gap of 55cm between exposures of the Cockleshell and Scar Limestones probably indicates the presence of shale. Gaps at this horizon are also seen in the outcrops around Gearstones to the east, 1m in Long Gill (SD 803835) and 1.1m in Lat Gill (SD 802819) but it seems likely that if shale is present it represents only part of this gap.

South of these outcrops the Upper Parting is absent and in Mere Gill (SD 745753), on the west slope of Ingleborough, and in Ease Gill (SD 692820), on the south side of Crag Hill, the Scar Limestone rests directly on the Cockleshell Limestone.

Wharfedale.

The only exposure of the Upper Parting in the area is in Deepdale Gill (SD 898811) where it consists of a lower and upper calcareous shale 35cm and 25cm thick with Gigantoproductus separated by a dark grey calcilutite 30cm thick. To the west in Tur Gill (SD 825822) and Grainings Gill (SD 828324) gaps of 30cm and 90cm respectively at this level may indicate the presence of shale. South of Langstrothdale the outcrops in Halton Gill (SD 882793), Littondale and Crooke Gill (SD 845735), Penyghent, show the Lower Parting absent. In Darnbrook Beck (SD 878717), on Fountains Fell, a gap of 30cm is seen between outcrops of the Cockleshell and Scar Limestone but it is almost certainly in the base of the Scar Limestone not in shale belonging to the Upper Parting. Farther south at Gorbeck (SD 858657) the Upper Parting is also absent.

The Upper Parting is not present east of the River Wharfe. Its absence is demonstrated best in Park Gill Beck (SD 987753) and in sections north of Grassington.

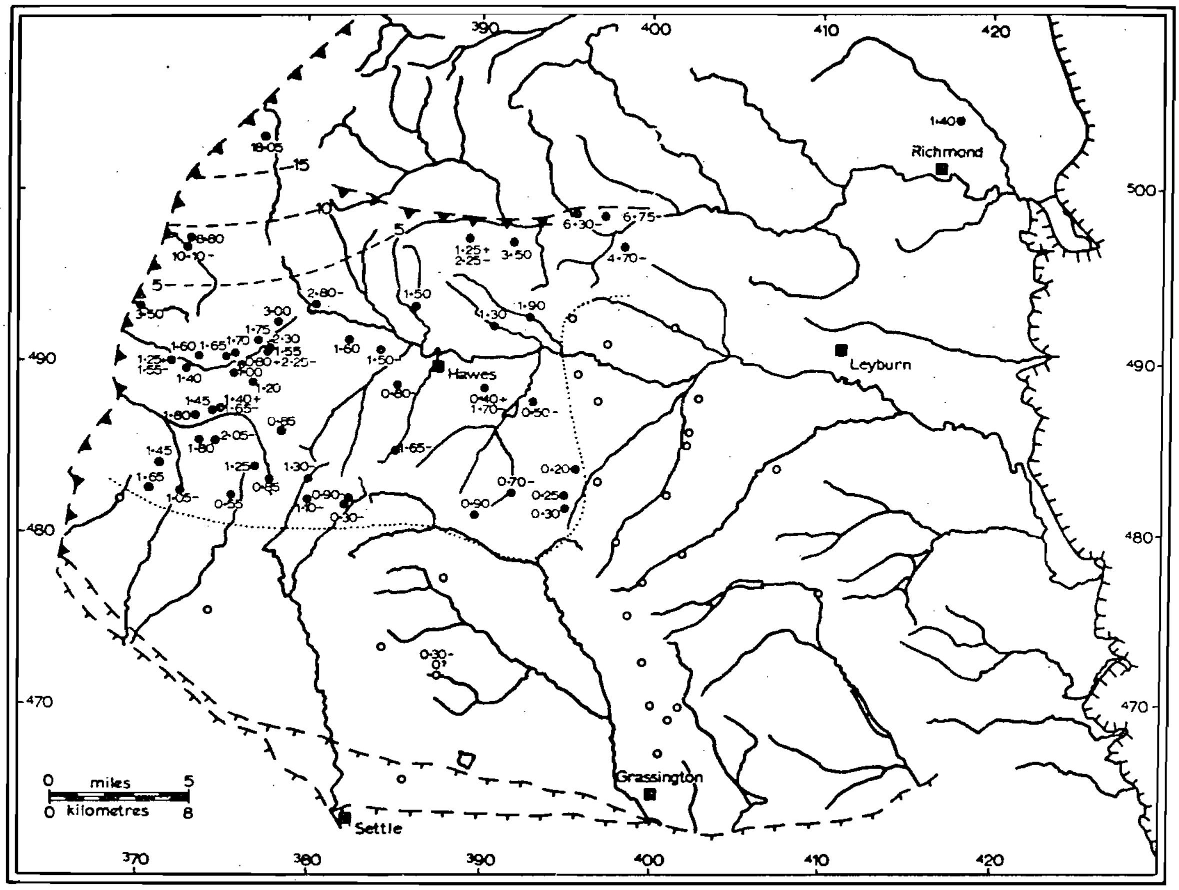


Fig. 20. Isopach map of Upper Parting.

THE SCAR LIMESTONE.

SUMMARY.

The Scar Limestone overlies the Upper Parting in the north but in the south and east, where the Upper Parting is absent, it rests directly on the Cockleshell Limestone. It varies in thickness from 1m in the southwest to over 30m in the east and southeast. Over most of the area it is a crinoid-ossicle calcarenite but, where thickest, becomes coarsely crinoidal with bioherms. The bioherms are similar to those in the Cockleshell Limestone and consist of mounds of bryozoan calcilutite up to 4metres high capped and flanked by crinoid-stem calcarenites and calcirudites.

The lower part of the Scar Limestone contains Gigantoproductus in the north and east and becomes cherty in the northeast with numerous chert nodules. The nodules are frequently situated in the concavity of gigantoproductid valves most of which are in their growth position. A similar relationship is seen where the Cockleshell Limestone is cherty. It appears that decaying gigantoproductid organic matter provided a locally favourable environment for silica precipitation.

In the southeast, the lowest beds contain Orbitremites which is abundant in the beds overlying bioherms in the Cockleshell Limestone. At the most southerly outcrop north of Grassington these beds pass into a brachiopod biostrome dominated by small productids and spirifers.

Over the northwest and central western parts of the Askrigg Block algae are numerous in the upper part of the Scar Limestone. They occur as oncolites in an horizon just beneath the top of the Limestone which is bioturbated and pyritic.

THE SCAR LIMESTONE.

DETAILS.

Wensleydale.

On the north side of Wensleydale the Scar Limestone is fully exposed in Tarn Gill (SD 807929), Fossdale Gill (SD 861930), Sar Gill (SD 908918), Whitfield Gill (SD 930923), and Arn Gill (SD 953923). East of Arn Gill only partial sections are seen, though some are nearly complete, the best being at Disher Force (SD 981904), in Beldon Beck (SE 013913), Apedale Beck (SE 043922) and Barney Beck (SE 049919).

From the head of Wensleydale westwards to Whitfield Gill the Scar Limestone overlies shale of the Upper Parting. It consists of three thick beds of medium to dark grey limestone which thicken from 1.65m and 1.5m in Tarn Gill and Fossdale Gill respectively to 2.1m in Sar Gill and 2.25m in Whitfield Gill. The lowest bed, a crinoidal calcilutite to sparse crinoid-ossicle calcarenite, is 35cm to 65cm thick. It contains Lithostrotion in its upper part in Sar Gill and in Whitfield Gill has a fauna of Gigantoproductus. The central and thickest bed of the Scar Limestone directly overlies the lowest bed except in Whitfield Gill where they are separated by a thin shale. It is a crinoid-ossicle calcarenite 65cm to 1.2m thick with numerous algae in the light brown to dark yellowish-orange weathering, iron-oxide stained, upper 45cm to 50cm. The algae occur as round, subround or rounded irregular oncolites, generally less than 5cm but up to 10cm in diameter, with concentric, often mammilated laminations. The thin laminations weather differentially into proud standing light brown to dark yellowish-orange iron-oxide stained zones which alternate with medium to light grey areas. The oncolites are often formed around a nucleus, usually a crinoid ossicle or shell fragment. The overlying and uppermost bed is also a crinoid-ossicle calcarenite, 40cm to 50cm thick, but is not algal.

East of Whitfield Gill the Scar Limestone thickens rapidly, shows no tripartite division and rests directly on the Cockleshell Limestone. In Arn Gill (SD 953923) it is 6.05m thick. Its base is marked by a change in lithology from the crinoidal calcilutites of the Cockleshell Limestone to crinoid-ossicle calcarenites. The lowest bed, a packed crinoid-ossicle calcarenite 1.35m thick with Gigantoproductus in its upper part, is succeeded by two medium bedded, sparsely crinoidal calcarenites with Gigantoproductus. The overlying bed is a crinoidal calcilutite 1.1m thick which, in addition to Gigantoproductus, also contains nodular chert. Chert first appears in the Scar Limestone east of Whitfield Gill and persists eastwards. It is associated with Gigantoproductus and nodules are commonly sited in the concavity of their valves which are usually in the position of growth. The upper beds of the Scar Limestone in Arn Gill are medium to thick bedded, medium grey, crinoid-ossicle calcarenites which weather light brown to dark yellowish-orange. An horizon of oncolites 50cm thick is present just beneath the top.

At Disher Force (SD 981904) to the east the lowest part of the Scar Limestone is a coarse crinoid-stem calcarenite 2.35m thick with numerous Gigantoproductus and nodular chert. It is overlain by at least 2.55m of crinoid-ossicle calcarenites. In Beldon Beck (SD 013913) the lower part with Gigantoproductus and chert is finer, a calcilutite with at least 2.5m thick with scattered crinoid-ossicles and Lithostrotion. It is overlain by at least 2.55m of medium to very thick bedded crinoid-ossicle calcarenites. Barney Beck exposes a similar section, a calcilutite at least 1.5m thick with scattered crinoid-ossicles, Gigantoproductus and nodular chert overlain by at least 2.2m of platy weathering, crinoid-ossicle calcarenites. However, just east of Barney Beck, a mound of unbedded, pale grey, variably crinoidal calcilutite with trepostome and fenestellid bryozoa, spirifers and productids is seen above the calcarenite and swells the thickness of the Scar Limestone to at least 11.45m. The calcilutite is resistant to erosion and forms a small hillock 6m high although only 4m of bryozoan calcilutite are exposed at the top. (Plate 9.) Unfortunately a gap of 3.75m occurs between the uppermost calcarenite and the lowest outcrop of bryozoan calcilutite which is similar in lithology to the knoll cores in the Cockleshell Limestone north of Grassington. The coarsely crinoidal capping beds are absent and have probably been removed by present day erosion but the beds flanking the unexposed knolls forming Hogra Hill (SE 053918) and the hillock to the north (SE 053926) are seen at (SE 056917). Farther east in Wensley Beck (SE 092898) the Scar Limestone is poorly exposed and consists, at least in part, of calcarenites.

The Scar Limestone also contains knoll limestone on the south side of Wensleydale on the west side of Penhill. At Morpeth Scar (SE 029877), the best section, it attains a thickness of 31m. The base of the Scar Limestone is marked by an abrupt change in lithology from the crinoidal calcilutites of the Cockleshell Limestone to crinoid-ossicle calcarenites. The lowest 4.25m of the Scar Limestone are unparted,

Plate 9. The Scar Limestone, Barney Beck (SE 049919), near Redmire. An unbedded bryozoan calcilutite knoll core overlying well-bedded crinoid-ossicle calcarenites. Another knoll can be seen in the distance on the right.

medium grey, crinoid-ossicle calcarenites. Gigantoproductus is numerous throughout and chert nodules, commonly sited in the concavity of Gigantoproductus valves, are abundant in all but the lowest 1.2m where they are absent. A few Lithostrotion colonies are also present. Medium to light grey, thick to very thick bedded, crinoid-ossicle calcarenites 11m thick overlie these beds, succeeded by mounds of bryozoan calcilutite overlain and flanked by crinoid-ossicle and -stem calcarenites and calcirudites. Present day erosion has exquisitely exposed a mound of medium to light grey, variably crinoidal calcilutite 3.8m thick with abundant trepostome bryozoa, overlain by 12m of coarse crinoidal limestone. The crinoidal limestone which caps and flanks the mound is variably crinoidal but consists dominantly of light grey, coarse crinoid-ossicle and -stem calcarenites and calcirudites. They show depositional dips off the mound of up to 15° and form the upper beds of the Scar Limestone.

In the area between Morpeth Scar (SE 029873) and Long Ing Wood (SE 022860) many exposures of the upper part of the Scar Limestone are seen. Here, as farther north, the upper part is coarsely crinoidal consisting of crinoid-ossicle and -stem calcarenites and calcirudites showing depositional dips. The best exposures are in the vicinity, and just north, of Knarlton Knot (SE 026868). Knarlton Knot is a small hillock composed of quaquaversally dipping crinoid-stem calcirudites probably cored by bryozoan calcilutite not yet exposed by erosion.

The exposure at Long Ing Wood (SE 022860) is similar to that at Morpeth Scar except that the upper part of the Scar Limestone is thinner and no bryozoan calcilutite mounds are seen. The lowest beds are poorly bedded, medium grey calcarenites 3.25m thick with numerous Gigantoproductus and scattered colonies of Lithostrotion which are concentrated at the top. Chert nodules are abundant except in the upper 80cm. Thick to very thick bedded crinoid-ossicle calcarenites 10.5m thick overlie these beds and are themselves overlain by 5m of variably bedded, light grey crinoid-stem calcirudites showing depositional dips. Though not exposed, the close proximity of mounds to this outcrop is indicated by the depositional dips.

Along the north side of Penhill the Scar Limestone is poorly exposed but in a section near Chantry (SE 055880) it contains a calcareous shale, at least 25cm thick but neither its base nor the beds beneath are exposed. The shale is overlain by 8.5m of thick to very thick bedded medium grey crinoid-ossicle calcarenites, the upper beds of the Scar Limestone. They are separated from the Five Yard Limestone by 1.8m of calcareous shale.

The Scar Limestone thins in all directions away from Penhill but to the southeast in lower Coverdale it is still thick. Though knoll limestones are not seen, coarsely crinoidal limestones, often associated with knoll development, form much of the Limestone. The thin calcareous shale seen within the Scar Limestone near Chantry on the north side of Penhill is also present in Caldbergh Gill (SE 091831). Here it is 20cm thick and underlain by at least 9.5m of thick to very thick bedded, medium grey crinoid-ossicle calcarenites. Lithostrotion occurs near the base of the section but the base of the Scar Limestone is not exposed. The shale is overlain by 16.15m of thick to very thick bedded coarse crinoid-ossicle and -stem calcarenites and calcirudites but the upper part belongs to the Five Yard Limestone and has a fauna of Gigantoproductus. The junction between the Scar and Five Yard Limestones was not located as the section is inaccessible.

Farther up Coverdale at West Scrafton the Scar Limestone is fully exposed in Great Gill (SE 073840). The lowest 1.5m are thick bedded, dark to medium grey crinoidal calcarenites with numerous Gigantoproductus, abundant chert nodules and scattered Lithostrotion and overlie crinoidal calcilutites of the Cockleshell Limestone. They are overlain by 22.95m of thick to very thick bedded, medium to light grey, coarse crinoid-ossicle and -stem calcarenites and calcirudites with scattered chert nodules in places and rare Lithostrotion. The top of the Scar Limestone is bioturbated and overlain directly by crinoid-stem calcirudites showing depositional dips belonging to the Five Yard Limestone.

From 24.45m in Great Gill the Scar Limestone thins to 6.25m in Ridge Gill (SE 022780) farther up Coverdale. Here it consists of thick to very thick bedded crinoid-ossicle and -stem calcarenites. The lower 1.4m is dark to medium grey with Gigantoproductus, in contrast to the paler medium to light grey overlying beds. At the head of Coverdale in Slape Gill (SE 011778) the Scar Limestone is composed of medium grey, medium to thick bedded crinoid-ossicle calcarenites 2.9m thick.

In Waldendale the Scar Limestone also thins towards the head of the dale. At Scar Folds (SE 020849), south of Penhill, the succession is similar to that seen at Long Ing Wood (SE 022860). Here 3.8m of coarse crinoid-ossicle and -stem calcarenites with numerous Gigantoproductus, chert nodules, occasional Lithostrotion and sparse clisiophyllids are overlain by at least 6.7m of thick to very thick bedded, variably crinoidal calcarenites with occasional Lithostrotion. Farther up the dale the Scar Limestone thins to 2.7m at Ashes Farm (SE 008821) and 2.9m in Walden Beck (SD 980796). At both localities it is a thick to very thick bedded, medium grey crinoid-ossicle calcarenite.

At the head of Bishopdale the Scar Limestone is a medium to very thick bedded, medium grey crinoid-ossicle calcarenite. It is 2.5m thick on the east side of Bishopdale in Myers Garth Gill(SD 970820) and overlies the Cockleshell Limestone but on the west side of the dale it overlies the Upper Parting shale and is 2.85m thick in Foss Gill (SD 956838) and Back Gill (SD 951822) and 2.4m in Raffen Gill (SD 951814). The lowest bed in Back Gill and Foss Gill contains Gigantoproductus.

On the east slopes of Addleborough in Gill Beck (SD 966876) the Scar Limestone, a calcarenite 1.5m thick, also contains Gigantoproductus. It is overlain by thick bedded crinoid-ossicle calcarenites 2.2m thick. Gigantoproductus disappears to the west and is absent from the Scar Limestone, a calcarenite at least 2m thick, in Scar Top Sike (SD 958888) and at Burnett Force (SD 942873).

At the head of Cragdale in Middle Tongue Gill (SD 920824) the Scar Limestone is a thick bedded calcarenite at least 1.4m thick. On the west side of Raydale, in Horton Gill (SD 963883) it is 2.05m thick. The lowest bed contains a fauna of Lithostrotion and small brachiopods in its upper part as in Sar Gill (SD 908918) to the north.

West of Raydale algae appear. In the northern outcrops the Scar Limestone consists of four beds, two lower medium bedded crinoidal calcilutites or sparse calcarenites, a central thick calcarenite with algae in the upper part and an upper thick calcarenite. It is well exposed in Gaudy House Sike (SD 855887), on the northern slope of Ten End, and in Cragfold Sike (SD 839906) and Hollin Gill (SD 823913), on the north end of Widdale Fell, where it is 1.6m, 1.95m and 1.8m thick respectively. South of these outcrops the Scar Limestone is poorly exposed. The thick calcarenite with algae in the upper part is seen on Widdale Fell (SD 823888) and in Lings Beck (SD 802866) but the best section is in Bank Gill (SD 853850) at the head of Sleddale where the Scar Limestone, at least 1.25m thick, consists of a lower crinoidal calcilutite overlain by a thick calcarenite with algae in the upper 40cm. At all these localities the algae occur as oncolites and are similar to those seen on the north side of Wensleydale.

Swaledale and the northeast.

The only complete exposure of the Scar Limestone in this area is in Routin Gill (SD 919969) where it is 3m thick. The lowest beds, medium to dark grey crinoid-ossicle calcarenites 15cm and 60cm thick, are overlain by 75cm of crinoidal calcilutite with Gigantoproductus in the upper part. The upper beds are thick bedded, medium grey calcarenites.

West of Routin Gill the Scar Limestone thins and in Noon Gill (SD 893975) it is not more than 1.4m thick. Only the upper 95cm is exposed but algae, not seen to the east, are present in the lowest bed exposed. They occur as oncolites, generally less than 5cm in diameter, and are similar to those seen at other localities in the north and west.

The Scar Limestone thickens eastward and the lower part which contains abundant *Gigantoproductus* becomes very cherty. In Birks Gill (SD 985969) it is at least 5.05m thick, though the base is not seen, and consists of 2.45m of unparted, dark grey crinoidal calcilutites with numerous *Gigantoproductus* and abundant nodular chert, overlain by medium grey, medium to thick bedded crinoid-ossicle calcarenites 2.6m thick.

Opposite, on the north side of Swaledale, the sections in Staney Gill (SD 959986) and Smarber Gill (SD 972980) show similar but thicker successions, 5.6m and 9.15m respectively, although neither the base nor top of the Limestone is exposed. In Staney Gill the Scar Limestone consists of 3.1m of poorly bedded, dark to medium grey crinoid-ossicle calcarenites with *Gigantoproductus* and chert, overlain by 2.5m of thick to very thick bedded, platy weathering, light grey crinoid-ossicle and -stem calcarenites. In Smarber Gill the thick bedded crinoid-ossicle calcarenites with abundant *Gigantoproductus* and chert are underlain by 55cm of dark grey calcilutite with *Gigantoproductus* and overlain by 4.6m of thick to very thick bedded platy-weathering calcarenites.

To the northwest in Long Acres Quarry (NZ 181043) the Scar Limestone, 6.6m thick, is similar. Two dark grey crinoidal calcilutites 15cm and 65cm thick separated by a thin calcareous shale overlie the shale of the Upper Parting. Another thin calcareous shale separates these beds from a crinoidal calcilutite 2.1m thick with numerous *Gigantoproductus* throughout and abundant chert nodules in the upper 1.2m. As at the other exposures where *Gigantoproductus* and chert occur together, many of the chert nodules are located in the concavity of

Plate 10. The Scar Limestone, Long Acres Quarry (NZ 181043), Gilling. Chert nodules preferentially situated in the concavity of gigantoproductid valves even where they are occasionally overturned.

Gigantoproductus valves most of which are in their position of growth. (Plate 10.) These beds are overlain by at least 3.55m of medium to light grey crinoid-ossicle calcarenites.

Garsdale and the northwest.

To the north of the Askrigg Block, in Birkett Railway Cutting (NY 774029) the Scar Limestone consists of thick bedded calcilutites with scattered crinoid ossicles. It is 4m thick and contains Gigantoproductus at its base. On the Askrigg Block to the south it is thinner. In Needlehouse Gill (SD 733971) and in the River Rawthey (SD 729966) it is 2.9m thick and thick to very thick bedded, passing from calcilutite with scattered crinoid ossicles at the base to crinoid-ossicle calcarenites above. Gigantoproductus occurs in the lower part, as in the Birkett Railway Cutting, but, in addition, oncolites are present in the central part of the Limestone. The top of the Scar Limestone is highly bioturbated and pyritic. Farther south the Limestone thins to 2m in Penny Farm Gill (SD 702932). As in the River Rawthey it consists of a lower calcilutite with scattered crinoid ossicles and Gigantoproductus, a central calcarenite with algae in the upper part and an upper calcarenite with a highly bioturbated, pyritic, red-weathering top.

At most outcrops in Garsdale the Scar Limestone shows a similar tripartite division but Gigantoproductus occurs only at the head of the dale in the River Clough (SD 782922). The lowest bed, a crinoidal calcilutite, is overlain by a thicker calcarenite with an orange-brown weathering upper part 30cm to 40cm thick containing oncolites. The upper bed is a calcarenite with a highly burrowed, red-weathering, pyritic top. Total variation in thickness of the Scar Limestone is less than 1m. It is thinnest in the southwest, 1.35m in Aye Gill (SD 730896), and thickest in Ray Gill (SD 768897), 2.30m, but variations seen are local rather than regional.

On the north side of Garsdale the tripartite division is well shown in Thrush Gill (SD 745900) and Grinning Gill (SD 762904). In Greenside Gill (SD 783901) and in the River Clough (SD 782922) two beds are present beneath the algal bed. In the River Clough they vary in thickness from 40cm and 50cm to 10cm each whilst the algal bed, 1.1m to 2.1m thick, compensates for this variation giving the Scar Limestone a constant overall thickness. Two very thin shales separate the 50cm to 10cm thick bed from the beds above and beneath. In Garth Gill (SD 771910) where only one crinoidal calcilutite is present beneath the algal bed, a single thin shale is seen.

On the southern side of Garsdale the tripartite division is seen in Ingheads Gill (SD 776905), Ray Gill (SD 768897) and Aye Gill (SD 730896) but in the railway cutting above Ingheads (SD 777906) the Limestone shows no well developed bedding. This is probably because the exposure is much more recent than those in the gills and weathering has not yet picked out the bedding planes. In Pegs Gill (SD 723899) a medium bedded, highly bioturbated, muddy calcarenite occurs in addition at the top of the Limestone.

Dentdale and the southwest.

In this area the Scar Limestone is thin and varies locally from 95cm to 2.15m. With the exception of the basal part, which is a dark grey crinoidal calcilutite where it overlies the Upper Parting shale, the Limestone is a medium grey crinoid-ossicle calcarenite.

Throughout Dentdale and Deepdale the Scar Limestone is algal in part. The algae form numerous oncolites, usually less than 10cm in diameter, in a single horizon 25cm to 30cm thick at the top of a thick calcarenite (Plate 11.) The algal horizon, especially the lower part, weathers yellowish-orange to yellowish-brown. In Stock Beck (SD 734870) and Aye Gill (SD 741872), on the north side of Dentdale, and in How Gill (SD 744855) and Stock Beck (SD 736854), on the south side of the dale, it consists of three beds, the central bed being thickest with oncolites in the upper part. In Arten Gill (SD 785859), on the north side of Dentdale, two beds occur beneath the thick algal bed but in Long Gill (SD 779833) at the head of the dale, in Hazel Bottom Gill (SD 770839) on the north slope of Whernside and in Gastack Beck (SD 709827) and Broken Gill (SD 716841) in Deepdale, the thick algal bed forms the lowest bed of the Scar Limestone and rests directly on the Upper Parting shale. In Cowgill Beck (SD 770886) and Arten Gill (SD 785859) in northern Dentdale, in Hazel Bottom Gill (SD 770839) and Great Blake Beck (SD 762851) on the north slopes of Whernside and in Gastack Beck (SD 709827) and Broken Gill (SD 716841) in Deepdale, the algal bed is the highest bed exposed. The bed which overlies the algal bed at the localities mentioned previously is absent in Gastack Beck and Broken Gill, but may be present, though not exposed, at the other localities. In Gastack Beck and Broken Gill the top of the algal bed is bioturbated, pyritic and weathers red, features seen only at the top of the Scar Limestone directly beneath the overlying shale.

South of Dentdale the Scar Limestone is exposed in Force Gill (SD 758821) on the east slopes of Whernside and in Long Gill (SD 803835)

Plate 11. The Scar Limestone, Cowgill Beck (SD 770886), Dentdale. Large irregular oncolites in the orange-brown weathering algal horizon in the upper part of the Scar Limestone.

and Lat Gill (SD 802819), near Gearstones. The algal bed is well exposed but the beds immediately beneath do not outcrop. A thick crinoid-ossicle calcarenite with a bioturbated, pyritic, red-weathering top overlies the algal bed in Force Gill and Lat Gill but in Long Gill it is absent and the top of the algal bed is bioturbated, pyritic and weathers red.

Farther south the algae disappear and are absent in Ease Gill (SD 692820) and on Ingleborough where the Scar Limestone directly overlies the Cockleshell Limestone. In Ease Gill the Limestone is 1.1m thick and consists of two thick bedded calcarenites. It is exposed poorly on Ingleborough but in Mere Gill (SD 745753) it is represented by a crinoid-ossicle calcarenite 1.25m thick.

Wharfedale.

In northern Wharfedale the tripartite division, characteristic of the Scar Limestone over much of the northwest Askrigg Block, is seen. The uppermost bed is not exposed in Tur Gill (SD 825823) but in Grainings Gill (SD 828324) and Deepdale Gill (SD 898811), where a lower and upper thick calcarenite are separated by a thicker calcarenite with oncolites in the upper part, the Limestone thickens from 1.6m to 1.9m respectively. To the south the algae disappear and the Scar Limestone, which loses its tripartite division, rests directly on the Cockleshell Limestone.

In upper Littondale the Scar Limestone cannot be differentiated from the Cockleshell Limestone. In Halton Gill (SD 882773) it consists of medium grey crinoid-ossicle calcarenites but to the south, on the northern slopes of Plover Hill, knoll limestones are developed. The knolls are seen best at (SD 870787) and (SD 853761) and consist of medium grey crinoidal calcilutite cores with trepostome and fenestellid bryozoa, capped and flanked by medium to light grey coarse crinoid-stem calcarenites and calcirudites. The core material is poorly exposed unlike the capping and flanking calcirudites and calcarenites which contain corals including clisiophyllids, zaphrentids and Lithostrotion, brachiopods including Gigantoproductus, small productids and spirifers, and bryozoa and scattered chert nodules. The exact thickness of the Scar Limestone is unknown but where thickest it probably is about 12m to 15m.

It thins to the south in Darnbrook Beck (SD 878817) where 1.5m of medium grey crinoid-stem calcirudites are separated by a gap of 30cm from the Cockleshell Limestone. The gap is almost certainly in crinoid-stem calcirudites belonging to the Scar Limestone. In Crooke Gill (SD 845733) and at Gorbeck (SD 858657) the Scar Limestone consists of thick bedded, medium grey, crinoid-ossicle calcarenites 2.85m and 1.45m thick respectively.

On the east side of Wharfedale in Park Gill Beck (SD 787753) the Scar Limestone is 3.65m thick. It consists of a lower 50cm crinoid-ossicle calcarenite followed by two calcilutites 45cm and 70cm thick with Gigantoproductus then 2m of crinoid-ossicle calcarenites. Here, as at the exposures in Walden Beck (SD 980796) and Myers Garth Gill (SD 970820), thin limestones are present just above, between the Scar Limestone and the Five Yard Limestone.

To the south the Scar Limestone thickens rapidly and in Dowber Gill (SD 993728) it is 13.2m thick. The thin limestones seen above the Scar Limestone to the north are probably included in this thickness because a thin shale, 20cm thick, now not exposed, was recorded in Providence Mine 1.1m beneath the top of the section measured here (Ingleborough Memoir, 1890). At this locality the Limestone is a medium grey, medium to thick bedded crinoid-ossicle calcarenite with

Gigantoproductus, occasionally infilled by chert nodules, common in the lowest 8.45m. South of Dowber Gill the thickening continues and in the area around Bycliffe about 33m of Limestone is seen above the Cockleshell Limestone. All this limestone is decribed here as Scar Limestone but the upper part may belong to the Five Yard Limestone (p.190). A good section in this area is seen at Mossdale Scar (SE 016697). Here the Cockleshell Limestone is overlain by 10.6m of medium to very thick bedded crinoid-ossicle calcarenites. The lower beds are medium to light grey but become medium to dark grey upwards. They are succeeded by 2.25m of medium bedded crinoidal calcilutites, calcarenites and shales with calcilutite nodules. They contain corals, including Diphyphyllum and clisiophyllids, and Gigantoproductus. Above 2.35m of thick to very thick bedded, medium grey crinoidal calcilutites with Gigantoproductus in the lower part are separated by 40cm of shaly weathering crinoidal calcilutite from 13m of thick to very thick bedded, platy weathering, crinoid-ossicle and -stem calcarenites and calcirudites with chert nodules in the lower part.

South of Mossdale Scar the calcarenites at the base of the Scar Limestone contain a blastoid fauna. Both Orbitremites derbiensis (Sowerby) and Codaster acutus (McCoy) have been recorded (Joysey, 1955) but whereas Orbitremites is common and abundant locally, Codaster is rare.

Orbitremites is found on both sides of Bycliffe but it is most common in the west where the blastoid bearing calcarenites outcrop along 1500' contour and are well exposed in the small quarry (SD 003692) beside the old lime kiln 800m north of Kelber Gate. Orbitremites is

Plate 12. The Scar Limestone, southeast of Bare House (SE 005667) near Yarnbury.

Orbitremites derbiensis in thin bedded crinoid-stem calcirudites capping the calcilutite knoll cores in the Cocklesnell Limestone.

most abundant farther south in the upper part of the crinoid-stem calcarenites and calcirudites which overlie the knolls in the Cockleshell Limestone south of Bare House. They first appear with crinoid debris in the upper part of the knoll limestones but become numerous only in the overlying thin bedded calcarenites and calcirudites. The blastoids are confined to certain beds only a few centimetres thick which are lithologically indistinguishable from the intervening barren beds. They occur in light to very light grey crinoid-stem calcarenites and calcirudites with an associated fauna of trepostome bryozoa and small spirifers. Whereas fragments of crinoid stems, brachia and pinnules are common, calyces are extremely rare.

In the region immediately south of the Yarnbury Faults Orbitremites appears to be distributed through about 10m of crinoidal limestones capping the knolls. However, measurement by Abney Level is undoubtedly inaccurate between exposures as both depositional and tectonic dips occur. This apparent thickness is probably excessive as elsewhere the blastoids are confined to a maximum of 3 metres of crinoidal limestone. To the south, even though knolls persist for some distance, Orbitremites decrease in abundance and eventually disappear. Only a single blastoid is recorded south of Rakes Fault (Joysey, 1955).

At the southernmost exposure of these beds, within a few metres of their disappearance beneath the overstepping Upper Bowland Shale, a shell biostrome with an abundant brachiopod fauna is seen. Its thickness is unknown for the tiny outcrop, which poorly exposes about 1m, is isolated. The exposure appears to be at the same horizon as the beds with blastoids; the most southerly specimen of Orbitremites being recorded 250m to the north (Joysey, 1955). The fauna recorded by Joysey

(1955) consists dominantly of spirifers and productids. Most shells are complete with both valves attached and appear in their position of growth.

The rest of the Scar Limestone consists of thick to very thick bedded crinoid-ossicle and -stem calcarenites which coarsen locally into lenses of crinoid-stem calcirudites. On weathering they develop a thin parting giving a false impression of being thin bedded. In the area north of Bare House (SD 005669) the calcarenites 15m to 18m above the base of the Scar Limestone contain trepostome bryozoa. Bryozoa are abundant on the west side of Bycliffe as far north as Capplestone Gate (SE 000700) and on the east side of Bycliffe to just south of Mossdale Scar (SE 016697) but farther north they are absent. Gigantoproductus and Lithostrotion, usually confined to certain beds, are seen beneath the bryozoan calcarenite and Gigantoproductus is numerous in the beds 1m to 4m beneath. South of Bare House (SE 005669) both Gigantoproductus and the abundant bryozoa disappear.

Sparse chert nodules are seen throughout the Scar Limestone but they are most common, sometimes occuring in bands, in the beds above the bryozoan calcarenites. They are seen best in the gully (SE 021673) 1.25km south east of Gill House. The crinoid debris within the nodules has escaped silicification and on weathered surfaces has been dissolved leaving chert molds.

Around Bycliffe the Scar Limestone is about 33m thick but in the vicinity of Bare House (SE 005669) only about 20m are seen beneath the unconformable Grassington Grit. Although the Grassington Grit cuts down southwards there is evidence of depositional thinning of the Scar Limestone. (Moore, pers. comm.) considers that Sudeticeras cf adeps recorded from Limekiln Lane Quarry (SE 013662) by Joysey (1955), indicates a P_2b age and therefore the Five Yard or possibly the Three Yard Limestone. If the identification is correct, the Scar Limestone must thin towards its most southerly outcrops north of Grassington allowing at least the overlying Five Yard Limestone to be preserved beneath the unconformable Grassington Grit.

Green Hill (SE 008677), a small hillock about 60m long, 25m wide and 4.5m high, is worthy of special mention (Plate 13.) It is visible from a long distance because, besides being elevated, its green, partly grass-covered slopes contrast markedly with the brownish heather moorland surrounding it to the east, west and south. On closer inspection the vegetation can be seen to reflect the geology; the hillock consists of limestone blocks whilst the surrounding area is Grassington Grit which is exposed in several small disused quarries around the hillock. Clearly, either the limestone overlies the Grassington Grit as it would appear from field relations (though no limestone normally occurs at this stratigraphic level) or a prominence in the upper part of the Scar Limestone has been exposed after erosion of overlying Grit.

The Geological Survey explained Green Hill by two intersecting faults (Old series 1" Geological Map) but now there is no evidence in the field to infer that Green Hill is a small horst of Middle Limestone.

Black (1950) considered Green Hill a knoll on the upper surface of the Middle Limestone (i.e. Scar Limestone) whose unconformable cover of Grassington Grit is now mostly removed by erosion. He noted that the hillock consisted of grey, medium grained limestone which was bedded, at least at the surface of the knoll.

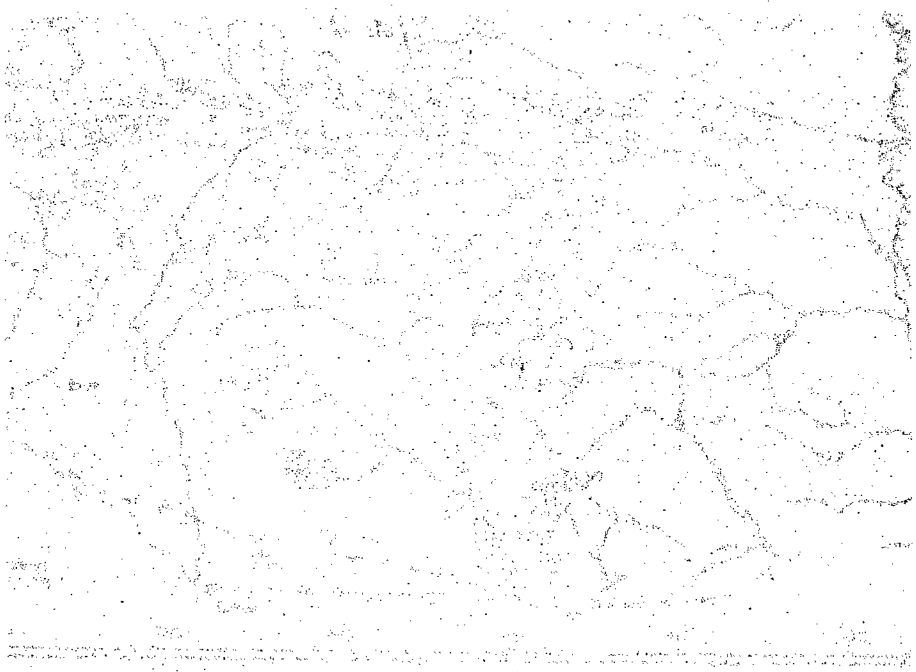
There are several reasons for disputing Black's interpretation. At Green Hill none of the limestone can reasonably be shown to be in situ. The limestone consists of blocks which are generally haphazardly orientated. Black states, "At the northern end the 18° dip corresponds almost exactly with the surface of the knoll, but elsewhere the dip is confused and large slabs of limestone lie at all angles as though disturbed by wave action". The crude form of quaquaversal dip noted by Black in places on Green Hill would be expected if the hillock consisted of blocks of limestone as the stable configuration for these would be with their largest planesparallel to the surface of the hillock (i.e. with their centre of gravity as low as possible). Green Hill occurs at the same level as the Scar Limestone and is much higher stratigraphically than the knoll limestones which are in the Cockleshell Limestone. Besides, the limestones are not bryozoan calcilutites or crinoid-stem calcirudites typical of the knolls but instead consist of blocks of various lithologies including calcarenites and calcilutites.

Joysey (1955) also disputed Black's conclusion. He noted that the surface over which the Grassington Grit transgressed was not plane and considered Green Hill to be "a residual mass carved from bedded rock in the upper part of the Middle Limestone, the blocks having been displaced during the present denudation".

The haphazard orientation of the limestone blocks (recorded by both Black, 1950 and Joysey, 1955) their variation in lithology and the absence of limestone in situ is crucial in any interpretation of Green Hill. These features , the elongate shape of the hillock and abundance

Plate 13. Green Hill (SE 008677) - Previously interpreted as an upfaulted block, a limestone knoll and an upstanding erosional remnant of Middle Limestone (i.e. Scar Limestone) is interpreted here as a mass of glacially transported limestone debris. The limestone blocks vary greatly in lithology and attitude and are not in situ. They rest on stratigraphically higher Grassington Grit which crops out around the hillock on three sides. Small outcrops of the Grit are visible in the disused quarries in the foreground from which the walling stones were extracted.

of glacial erratics in the area lead the author to conclude that Green Hill is a mass of glacially transported limestone debris deposited on the Grassington Grit.



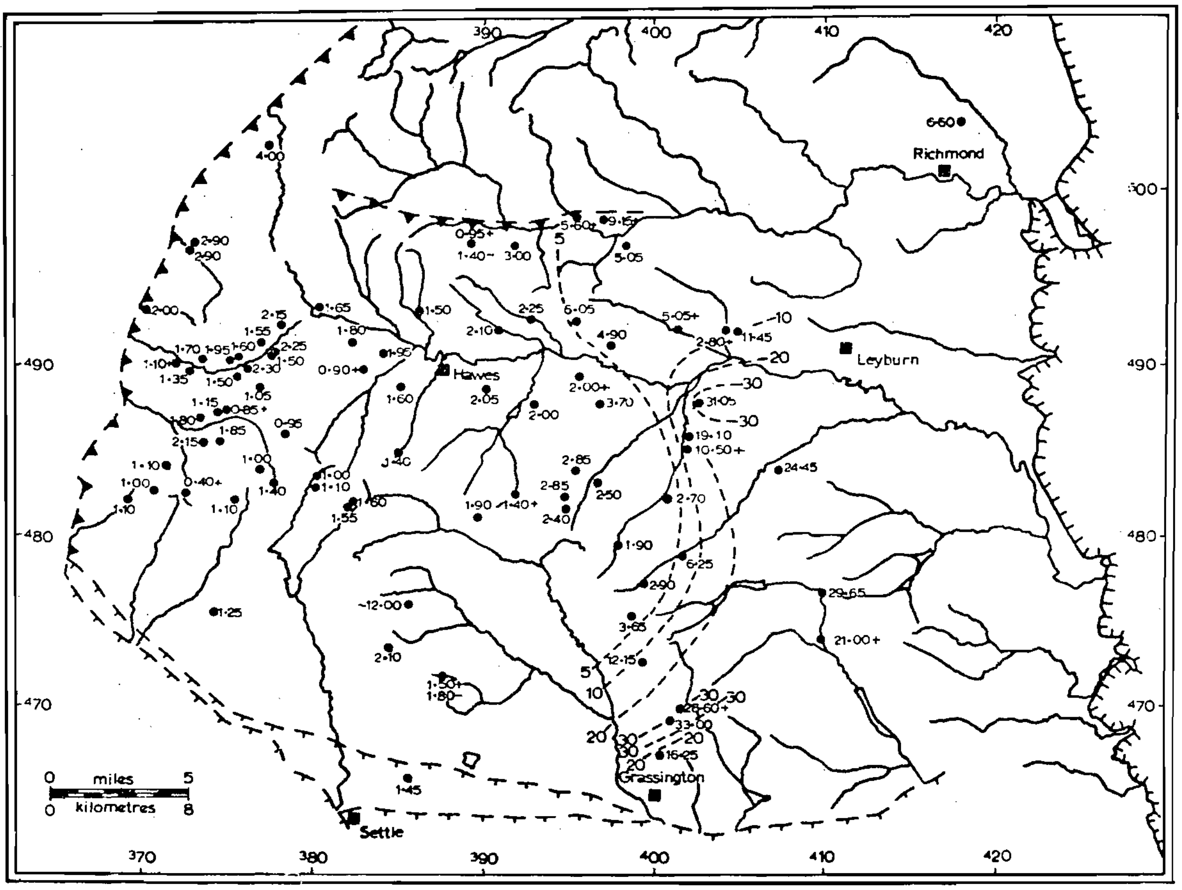


Fig. 21. Isopach map of Scar Limestone.

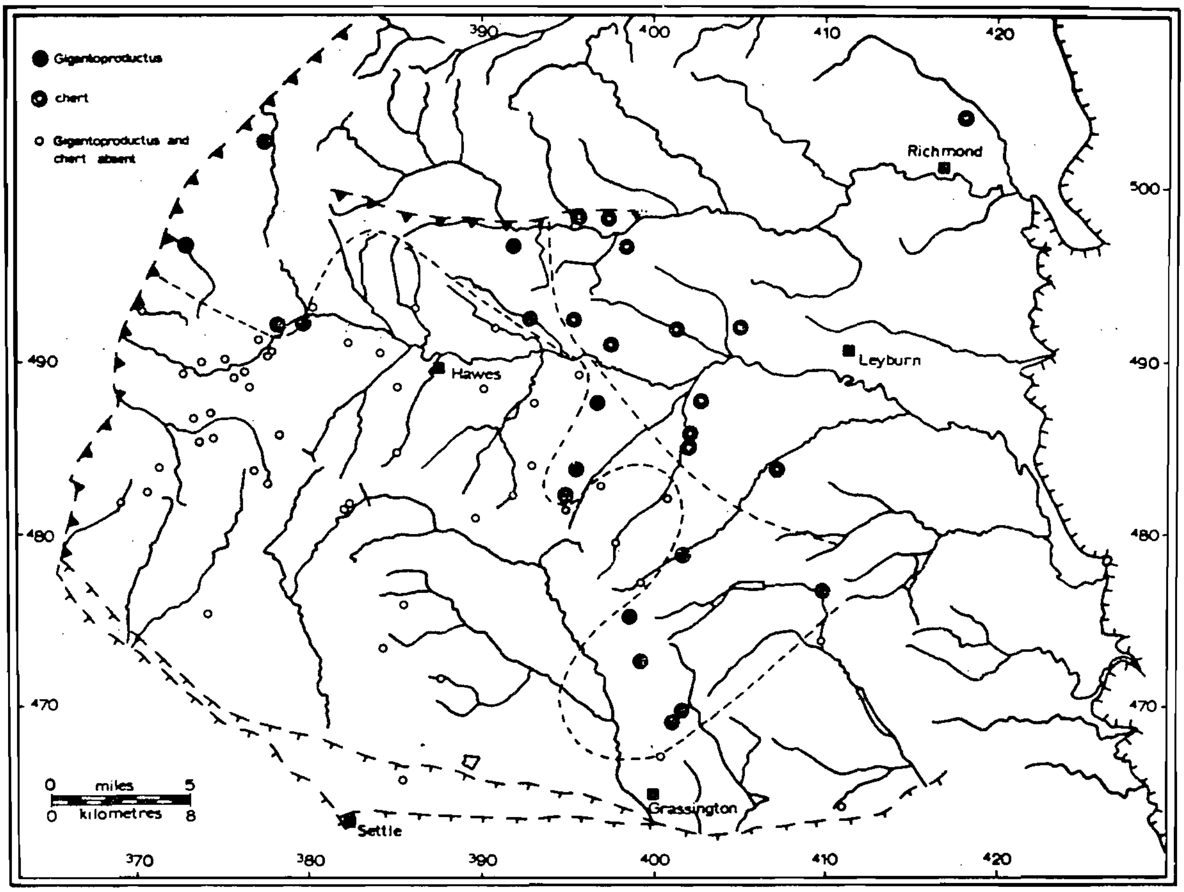


Fig. 22. Map showing distribution of <u>Gigantoproductus</u> and chert in Scar Limestone.

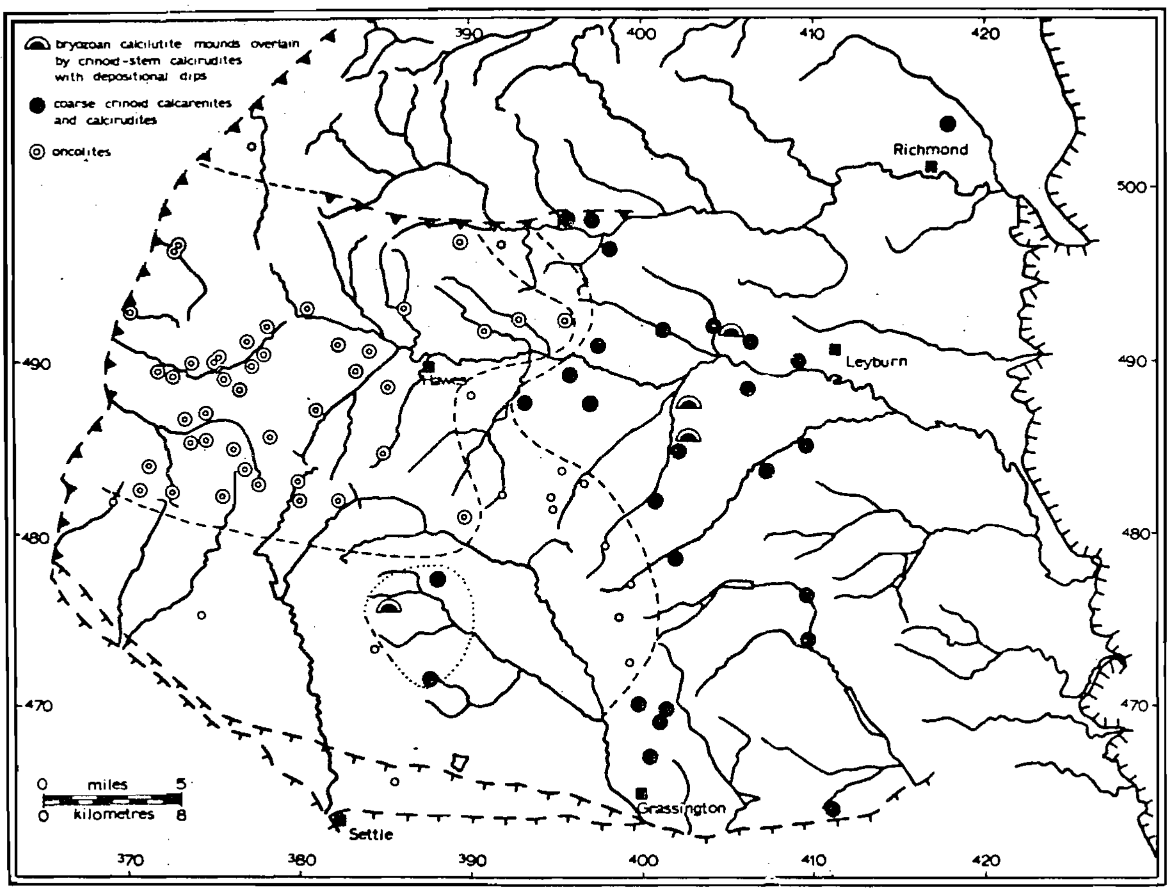


Fig. 23. Map showing distribution of bryozoan calcilutite mounds, coarse crinoid-stem calcarenites and calcirudites and oncolites in Scar Limestone.

THE MIDDLE LIMESTONE.

Nidderdale and the southeast.

In this area the Middle Limestone is exposed only in inliers at Limley and Lofthouse in Nidderdale and to the south in the Skyreholme and Greenhow areas.

In the Limley inlier a good, though incomplete, section is seen in the banks of the River Nidd and above in the Limley Railway Cutting (SE 099764). The succession is similar in lithology and thickness to the sections seen to the north of Grassington with which correlation can be made (Fig. 24.)

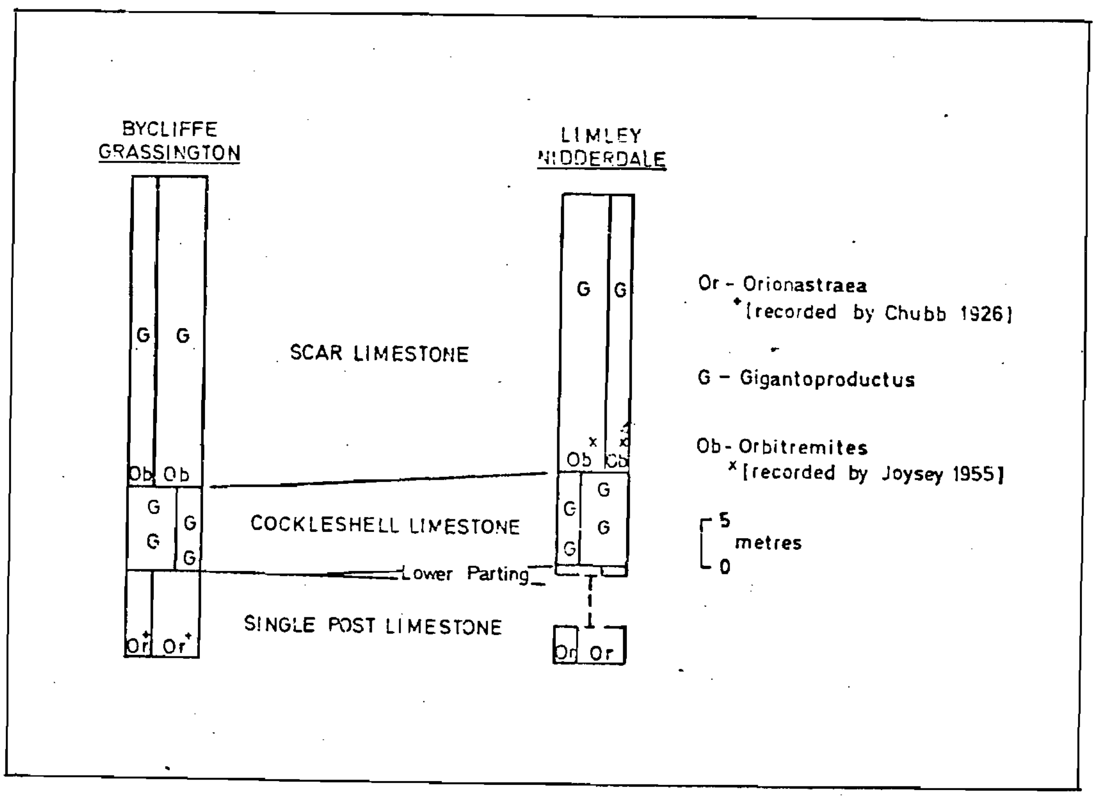


Fig. 24. Lithostratigraphic correlation of the Middle Limestone at Grassington and in Nidderdale.

In the core of the Limley anticline 4.15m of medium to dark grey, thick bedded, sparse crinoid-ossicle calcarenites overlying a thin shale are exposed in the right bank of the River Nidd. Scattered colonies of Orionastraea are seen in their position of growth along a single horizon, 75cm above the base of the limestone. Tonks (1925) recorded a thin sheet of Orionastraea phillipsi (McCoy) 1/4" (6mm) thick directly overlying the shale and a bed of corals 1'3" (30cm) above. The bed of corals, from which Tonks recorded Diphyphyllum aff. gracile (McCoy), Diphyphyllum cf. lateseptatum (McCoy), Productus, Alveolites sp., cf. latissimus (Sowerby) and Seminula gillingensis, (Davidson), appears to be the coral biostrome at the base of the Single Post Limestone. The beds above belong to the Single Post Limestone and are separated by a 5.5m gap from the next outcrop in the left bank of the River Nidd where a pink mottled pale grey calcilutite at least 90cm thick is seen; the bioturbated calcilutite the top of the Lower Parting. Above, thick to very thick bedded, sparse crinoid-ossicle calcarenites 9.85m thick with abundant Gigantoproductus and chert nodules in all but the lowest 2.75m form the Cockleshell Limestone. The upper part of the Cockleshell Limestone is also exposed in the Limley Railway Cutting at the southern entrance to the tunnel. The Cockleshell Limestone is overlain directly by the Scar Limestone which is best exposed in the railway cutting but also crops out on the left bank of the River Nidd. In the railway cutting the lowest 19.55m are very thick bedded, medium grey crinoid-ossicle and -stem calcarenites and calcirudites with scattered chert nodules. Bather (1913) recorded Orbitremites derbiensis (Sowerby) from a locality near Manchester Pot

Holes and, though he described the horizon as the Great Limestone, it was later correlated with the Middle Limestone by Tonks (1925). Versey (1923) also recorded Orbitremites in 'Lumley' (Limley) Quarry and more recently Joysey (1955) found Orbitremites derbiensis (Sowerby) in the railway cutting at the southern approach to the tunnel. Joysey correlated this horizon with the Orbitremites bearing beds north of Grassington which occur at a similar level. These beds are overlain by 1m of crinoid-ossicle and -stem calcarenite with abundant Gigantoproductus, then a shaly nodular calcilutite 40cm thick, followed by 1.2m of coarse crinoid-ossicle calcarenites and 4m of crinoid-stem calcirudites.

The upper beds of the Middle Limestone are also exposed in the Lofthouse inlier below Lofthouse Foot Bridge (SE 101735) and in Howstean Gorge (SE 093735). They are coarse crinoid-ossicle and -stem calcarenites and calcirudites at least 21m thick in Howstean Gorge.

South of Nidderdale the Black Hill Limestone, which crops out on the north limb of the Skyreholme anticline, is correlated with the Middle Limestone (Black & Bond, 1952) though Anderson (1928) had previously incorrectly correlated it with the Gayle Limestone (Fig.25.) It is exposed in Trollers Gill at the New Dam (SE 072625) but the members of the Middle Limestone cannot be recognised. The Black Hill Limestone overlies calcareous shale but the exact horizon correlated with the base of the Middle Limestone is unknown because the coral biostrome is absent. Using outcrops to the north and northwest as evidence, it seems likely that the Limestone IVc is fused to its base so the base of the Middle Limestone is probably a short distance above the base of the Black Hill Limestone.

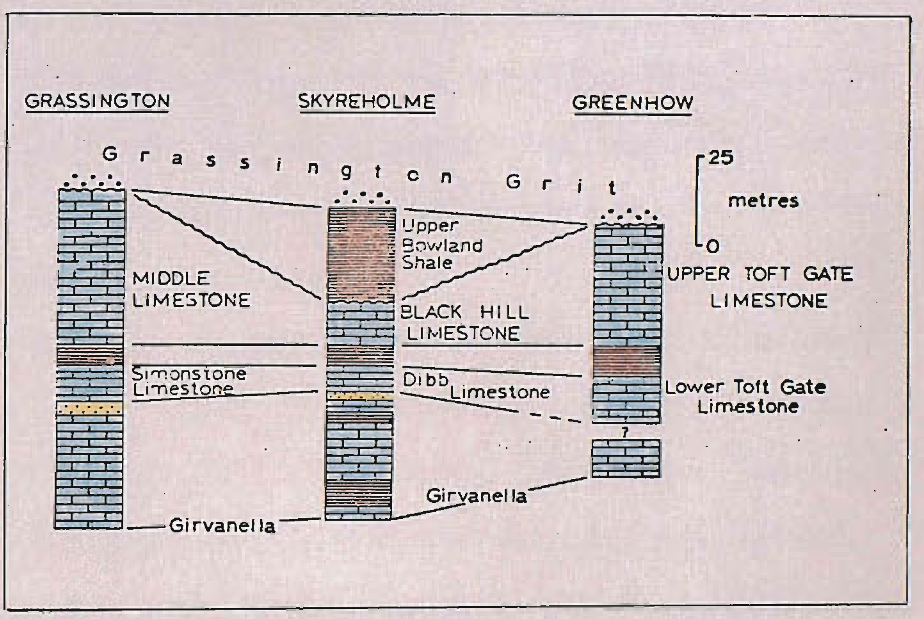


Fig. 25. Lithostratigraphic correlation of the Middle Limestone at Grassington with the Black Hill Limestone at Skyreholme and the Upper Toft Gate Limestone at Greenhow (after Dunham & Stubblefield, 1945; Black & Bond, 1952).

The lowest bed overlying the calcareous shale, a dolomitised crinoid-stem calcirudite 45cm thick, is overlain by 45cm of chertified crinoid-stem calcirudites with chert nodules. A 40cm thick crinoidal calcirudite with productids showing beautiful geopetal structures overlies these beds and in turn is overlain by thin bedded calcilutites and calcareous shales 25cm thick. These are followed by 3.4m of medium to very thick bedded crinoid-stem calcirudites with tabular and nodular chert. Above, 65cm of thin to medium bedded crinoid-stem calcirudites, with crinoid stems, preferentially oriented north-south, and productids, including Gigantoproductus at the top, are overlain by 33cm of shale with a 3cm calcilutite in the upper part. The shale is overlain by 10cm of crinoidal calcarenite and calcirudite with clisiophyllids in the upper part but corals, including Diphyphyllum and Dibunophyllum, are more abundant in the overlying calcilutite 18cm thick which is overlain by 30cm of decalcified crinoid-ossicle calcarenite. The overlying beds are not exposed.

In the Greenhow area east of Trollers Gill the limestone in and around Toft Gate Quarry (SE 133646) was mapped by Chubb & Hudson (1925) as Middle Limestone. Later Hudson (1938) stated, "There is no doubt that the Orionastraea beds of Toft Gate are the Simonstone Limestone", since Orionastraea indivisa (Hudson) was accepted by him as an indicator of that Limestone. In 1945 Dunham & Stubblefield mapped the Greenhow Mining area and published sections measured in the Cockhill and Gillfields Adit. They recorded a specimen of Orionastraea, in thin bedded limestones and shales 15m up in crinoidal limestones, identified by Smith as Orionastraea placenta (McCoy) (= Orionastraea rete Hudson) but by Hudson as Orionastraea garwoodi probably var. pristina Hudson). It is interesting to note that the type locality for Orionastraea garwoodi var pristina is in the basal part of the Middle Limestone in Nidderdale 12km to the north but it must be remembered that it has also been recorded from the Simonstone Limestone of Wensleydale. Dunham & Stubblefield (1945) named the crinoidal limestone above the thin bedded limestone and shales the Upper Toft Gate Limestone and correlated it with the Middle Limestone in the Grassington Moor mining area to the west (Fig. 25). They also noted a faunal similarity between the base of the Upper Toft Gate Limestone and the limestones at Toft Gate Quarry

(SE 133646). This, and the proximity of the limestone to the Grassington Grit, suggests that the limestone at Toft Gate Quarry is the Upper Toft Gate Limestone and can therefore be correlated with the Middle Limestone. This is a gross correlation; the base and top of the Middle Limestone at Grassington probably do not correlate precisely with the base and top of the Upper Toft Gate Limestone.

The best section of the Upper Toft Gate Limestone is in the Cockhill Adit (SE 113647) and was recorded by Dunham & Stubblefield (1945). Here it consists of 111 feet (33.8m) of crinoidal limestone with five thin shale partings separating lower medium grained limestone from the upper 34 feet (10.4m) of very coarsely crinoidal limestone, overlain by 20 feet (6m) of crinoidal limestones and shales. The basal post yielded trepostome bryozoa, similar to those at Toft Gate Quarry, (SE 113646) and brachiopods. They recorded a similar but incomplete section in Gillfields Adit (SE 116649); 90 feet (27.4m) of Upper Toft Gate Limestone was seen beneath the Grassington Grit. The upper 27 feet (8.2m) is coarsely crinoidal and separated by a shale parting from 53 feet (16.1m) of dark grey, partly dolomitised, crinoidal limestone beneath.

The small surface exposures in the area around Toft Gate at Toft Gate Quarry (SE 133646) and at a small quarry to the southwest (SE 131644) expose about 9m of thick to very thick bedded crinoid-ossicle and -stem calcarenites and calcirudites with a fauna of trepostome bryozoa and small brachiopods.

FIGURED SECTIONS OF THE MIDDLE LIMESTONE.

1.	Long Acres Quarry	NZ 181043	27.	Aye Gill	SD 741872
2.	Smarber Gill.	SD 972980	28.	Spice Gill	SD 746874
3.	Staney Gill.	SD 959986	29.	Cowgill Beck	SD 770886
4.	Birks Gill Crag Sike	SD 985969 SD 984968	30.	Arten Gill	SD 785859
5.	Routin Gill.	SD 919969	31.	Long Gill	SD 779833
6.	Noon Gill.	SD 893975	32.	Hazel Bottom Gill	SD 770839
7.	Birkett Railway Cutting	NY 774029	33.	Great Blake Beck	SD 762851
8.	Needlehouse Gill	SD 733971	34.	How Gill	SD 744855
9.	River Rawthey	SD 729966	35.	Stock Beck	SD 736854
10.	Penny Farm Gill	SD 702932	36.	Coombe Gill	SD 726825
11.	Thrush Gill	SD 745900	37.	Gastack Beck	SD 709827
12.	Greenside Gill	SD 753901	38.	Broken Gill	SD 716841
13.	Ay Gill	SD 756903	39.	Ease Gill	SD 692820
14.	Grinning Gill	SD 762904	40.	Force Gill	SD 758821
15.	Garth Gill	SD 771910	41.	Gate Cote Gill	SD 783816
16.	River Clough	SD782922	42.	Hazel Gill	SD 785821
17.	Cote Gill	SD 780918	43.	Long Gill	SD 803835
18.	Smout Gill	SD 779908	44.	Lat Gill	SD 802819
19.	Ingheads Railway Cutting	SD 777906	45.	Mere Gill	SD 745753
20.	Ingheads Gill	SD 776905	46.	Ure Force	SD 801932
21.	Assey Gill	SD 772902	47.	Tarn Gill	SD 807929
22.	Ray Gill	SD 768897	48.	Fossdale Gill	SD 861938
23.	Blea Gill	SD 758893	49.	Coal Gill	SD 881917
24.	Aye Gill	SD 730896	50.	Sar Gill	SD 908918
25.	Pegs Gill	SD 723899	51.	Whitfield Gill	SD 930923
26.	Stock Beck	SD 734870	52.	Arn Gill	SD 953923

53. Disher Force	SD 981904	79. Gaudy House Sike	SD 855887
54. Beldon Beck	SE 013913	80. Long Sike	SD 817842
55. Apedale Beck	SE 043922	81. Lings Beck	SD 802866
56. Barney Beck	SE 049919	82. Widdale Side	SD 823888
57. Wensley Beck	SE 092893	83. Cragfold Sike	SD 839906
58. Chantry	SE 055880	84. Hollin Gill	SD 823913
59. Caldbergh Gill	SE 091851	85. Tur Gill	SD 825822
60. Great Gill	SE 073840	86. Grainings Gill	SD 828324
61. Ridge Gill	SE 022790	87. Far End Gill	SD 833825
62. Slape Gill	SE 001778	88. Swarth Gill	SD 848828
63. Morpeth Scar	SE 029877	89. Hazel Bank Gill	SD 865826
64. Long Ing Wood	SE 022869	90. Deepdale Gill	SD 898811
65. Scar Folds	SE 020849	91. Bowther Gill	SD 906772
66. Ashes Farm	SE 008821	92. Halton Gill	SD 882773
67. Walden Beck	SD 980796	93. Crooke Gill	SD 845733
68. Myers Garth Gill	SD 970820	94. Darnbrook Beck	SD 878717
69. Foss Gill	SD 956838	95. Gorbeck	SD 858657
70. Back Gill	SD 951822	96. Park Gill Beck	SD 987753
71. Raffen Gill	SD 951814	97. Dowber Gill	SD 993728
72. Gill Beck	SD 966876	98. Mossdale Scar	SE 016697
73. Scar Top Sike	SD 958888	99. Bycliffe	SE 013694
74. Burnett Force	SD 942873	100. Bare House	SE 005669
75. Shaw Gate Gill	SD 926844	101. Limley Railway Cutting	SE 099764
76. Middle Tongue Gill	SD 920824	102. Cockhill Adit	SE 113647
77. Horton Gill	SD 903883	103. Trollers Gill	SE 072625
78. Bank Gill	SD 853850		

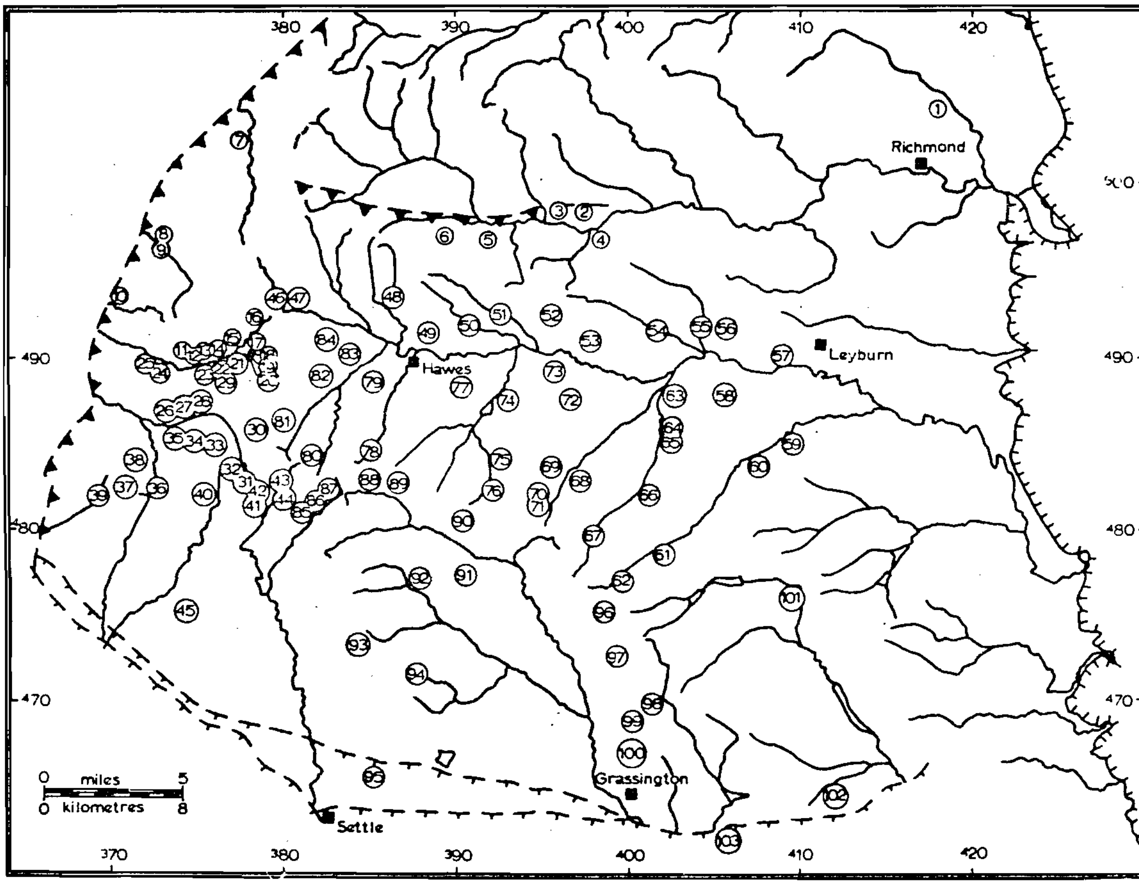


Fig. 26. Map showing location of figured sections of Middle Limestone.

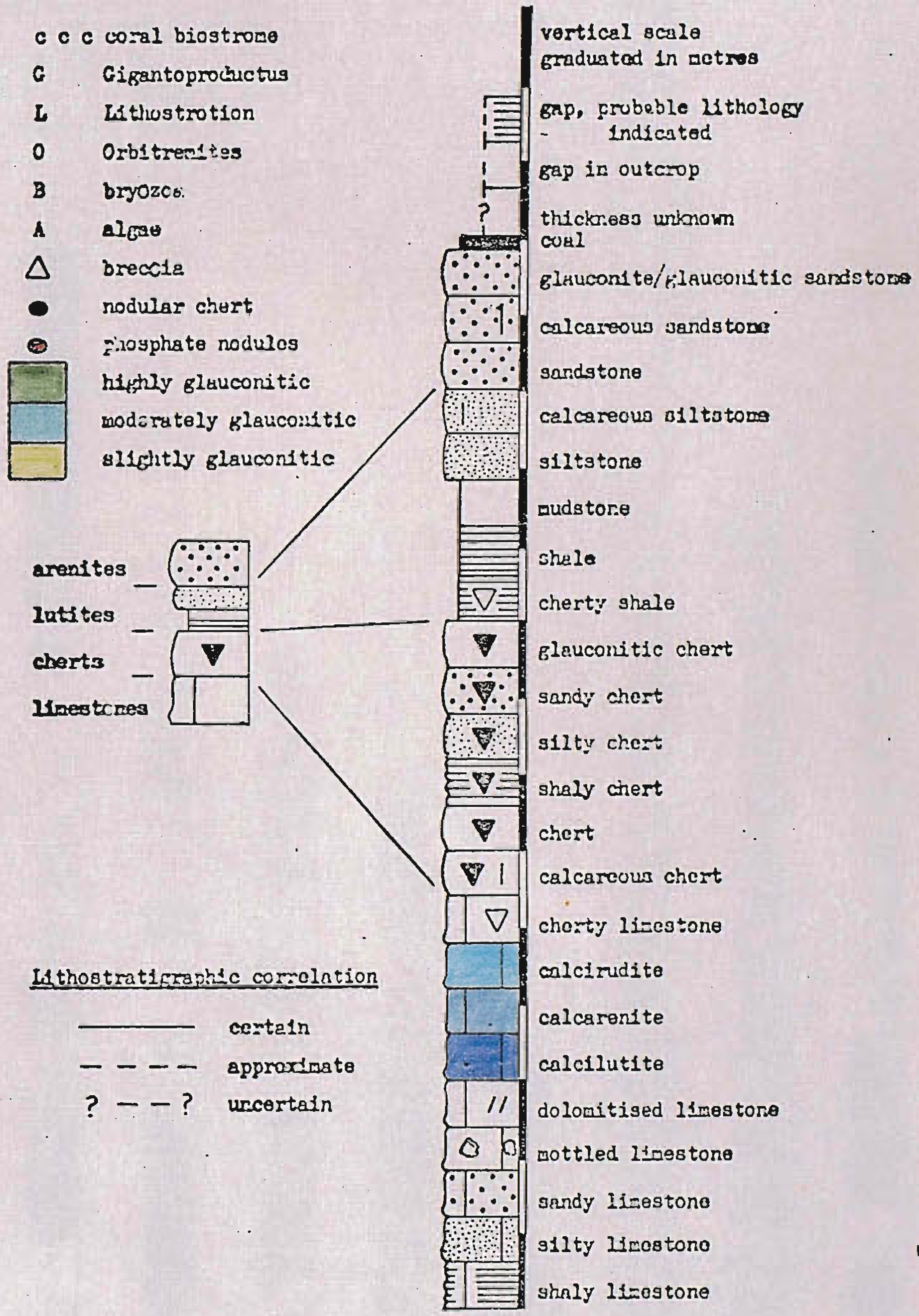


Fig. 27. Key to symbols used in the figured sections.

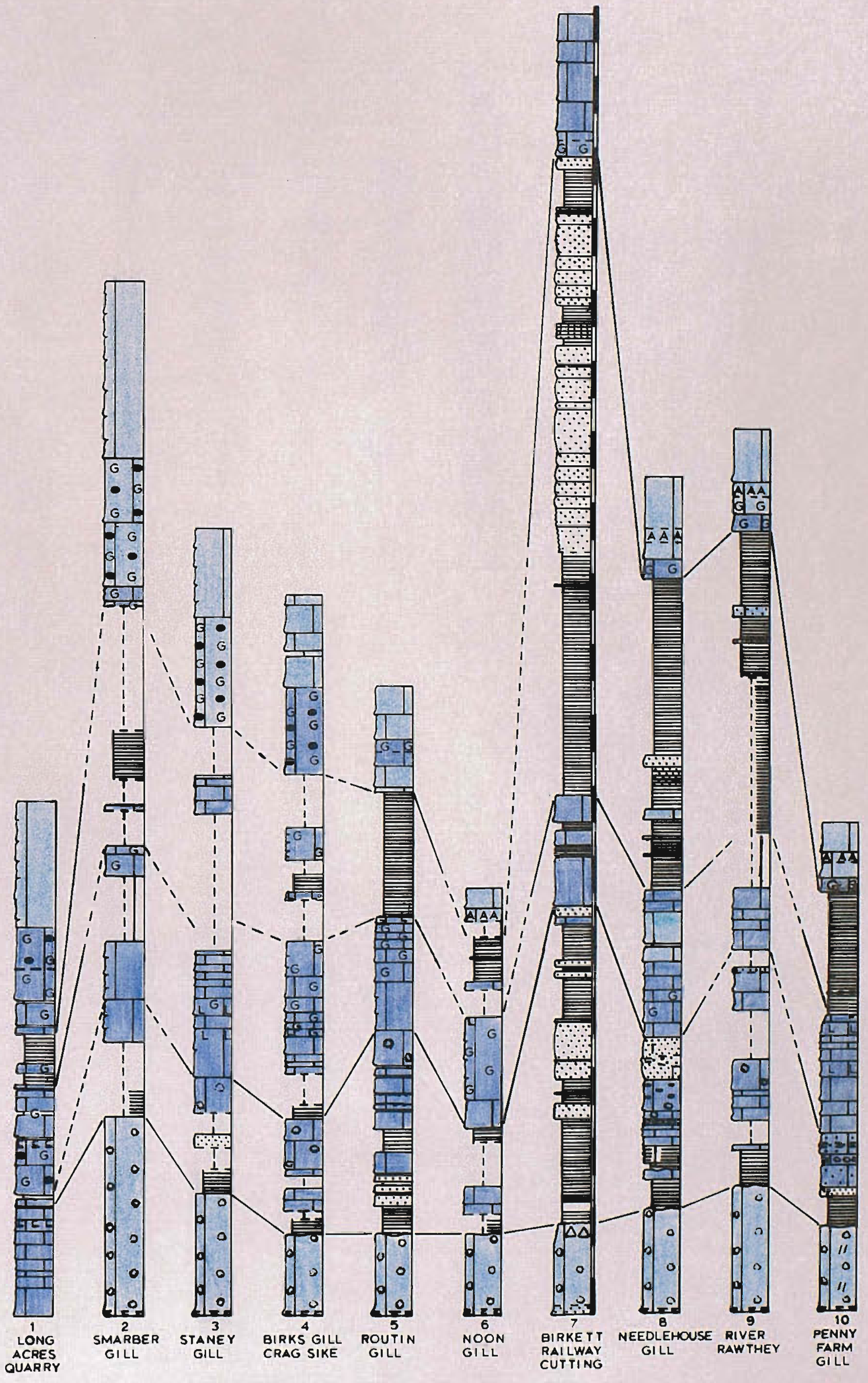

1
LONG
ACRES
QUARRY
2
SMARBER
GILL
3
STANEY
GILL
4
BIRKS GILL
CRAG SIKE
5
ROUTIN
GILL
6
NOON
GILL
7
BIRKETT
RAILWAY
CUTTING
8
NEEDLEHOUSE
GILL
9
RIVER
RAWTHEY
10
PENNY
FARM
GILL

Fig. 28.

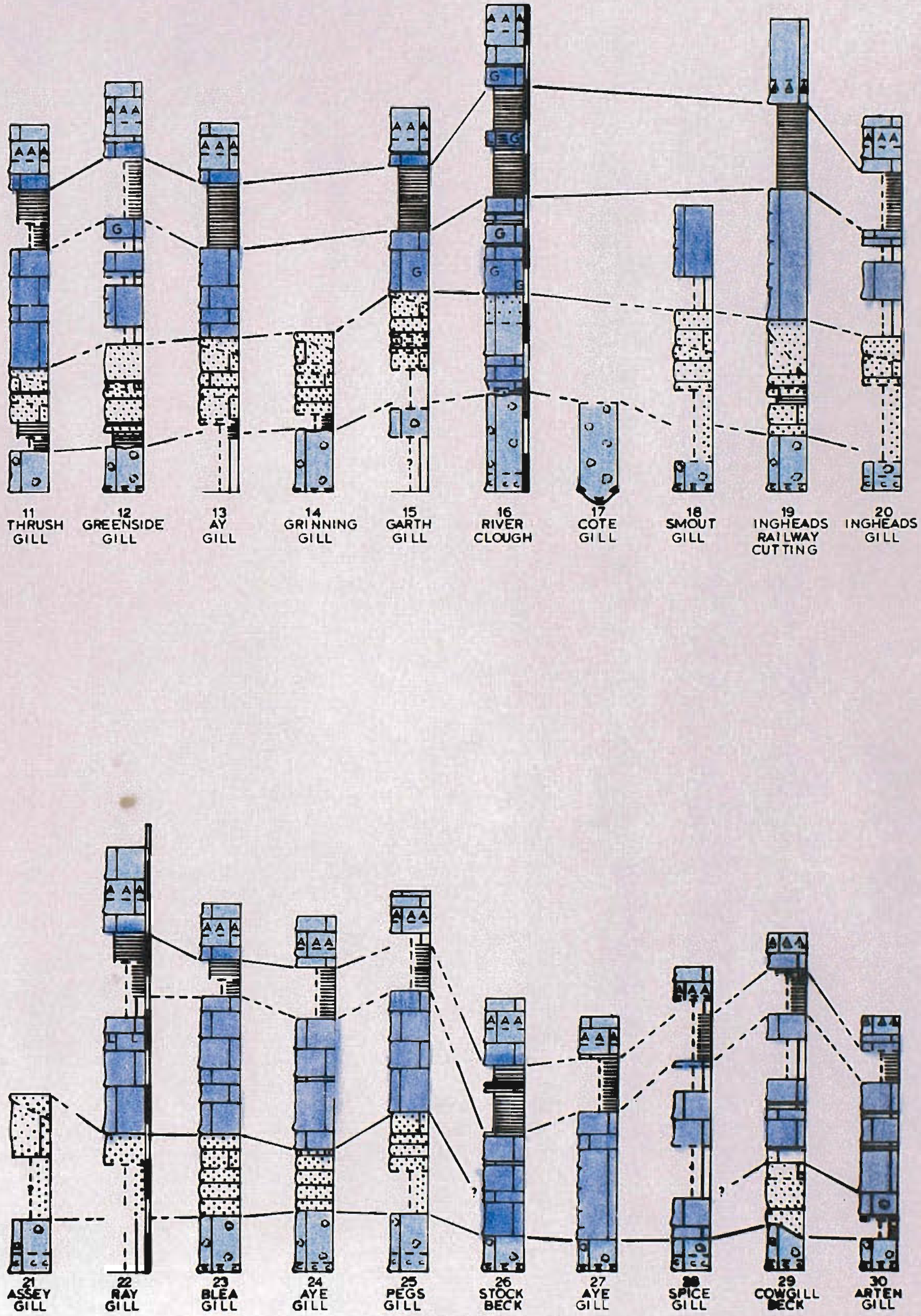
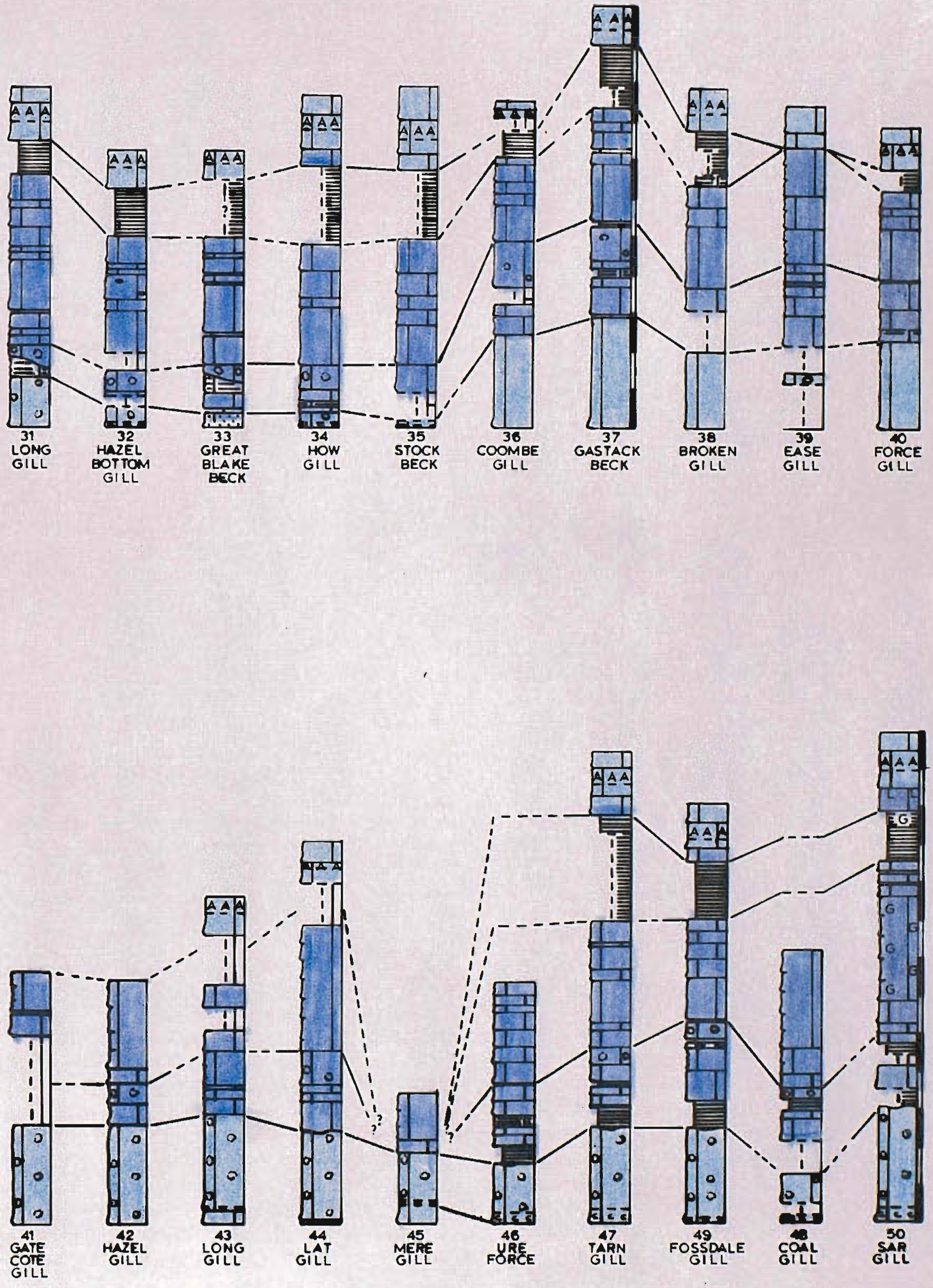
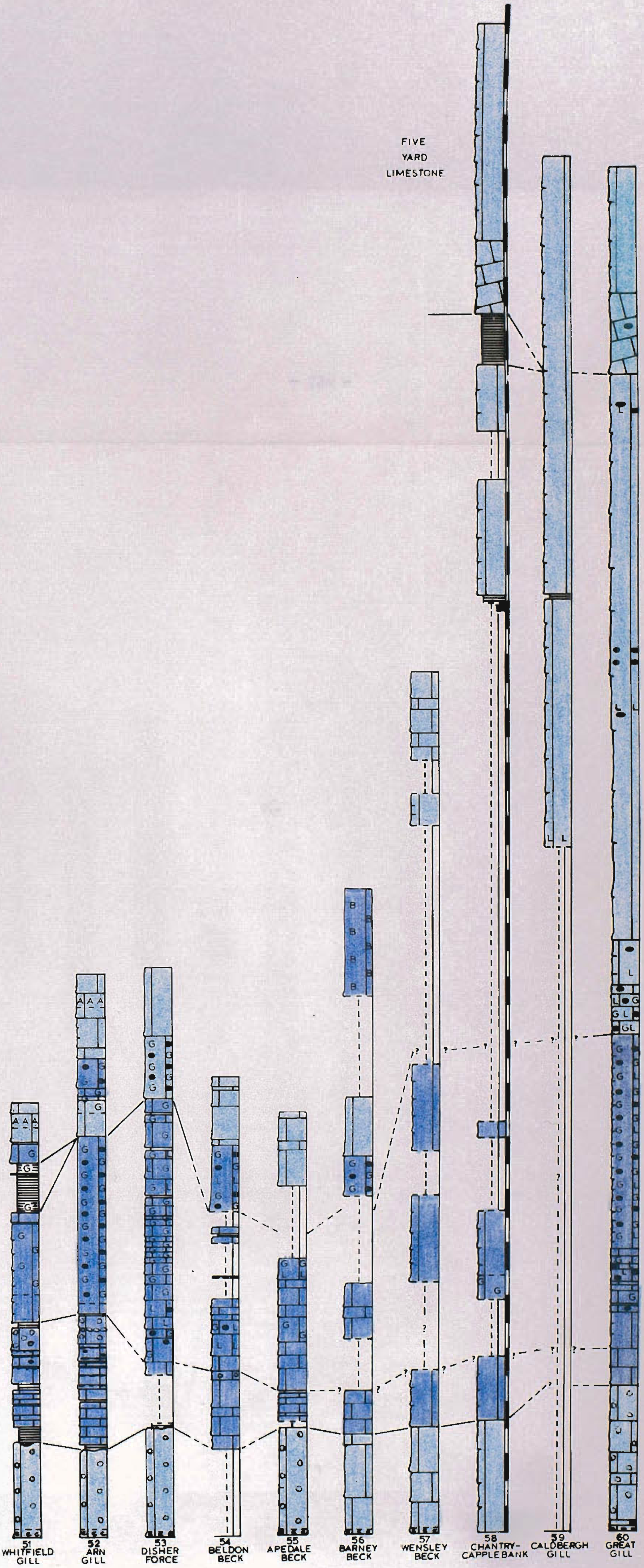

11 THRUSH GILL
12 GREENSIDE GILL
13 AY GILL
14 GRINNING GILL
15 GARTH GILL
16 RIVER CLOUGH
17 COTE GILL
18 SMOUT GILL
19 INGHEADS RAILWAY CUTTING
20 INGHEADS GILL
21 ASSEY GILL
22 RAY GILL
23 BLEA GILL
24 AYE GILL
25 PEGS GILL
26 STOCK BECK
27 AYE GILL
28 SPICE GILL
29 COWGILL BECK
30 ARTEN GILL

Fig. 29.



31 LONG GILL
32 HAZEL BOTTOM GILL
33 GREAT BLAKE BECK
34 HOW GILL
35 STOCK BECK
36 COOMBE GILL
37 GASTACK BECK
38 BROKEN GILL
39 EASE GILL
40 FORCE GILL
41 GATE COTE GILL
42 HAZEL GILL
43 LONG GILL
44 LAT GILL
45 MERE GILL
46 URE FORCE
47 TARN GILL
49 FOSSDALE GILL
48 COAL GILL
50 SAR GILL

Fig. 30.



FIVE
YARD
LIMESTONE
51
WHITFIELD
GILL
52
ARN
GILL
53
DISHER
FORCE
54
BELDON
BECK
55
APEDALE
BECK
56
BARNEY
BECK
57
WENSLEY
BECK
58
CHANTRY-
CAPPLE BANK
59
CALDBERGH
GILL
60
GREAT
GILL

Fig. 31.

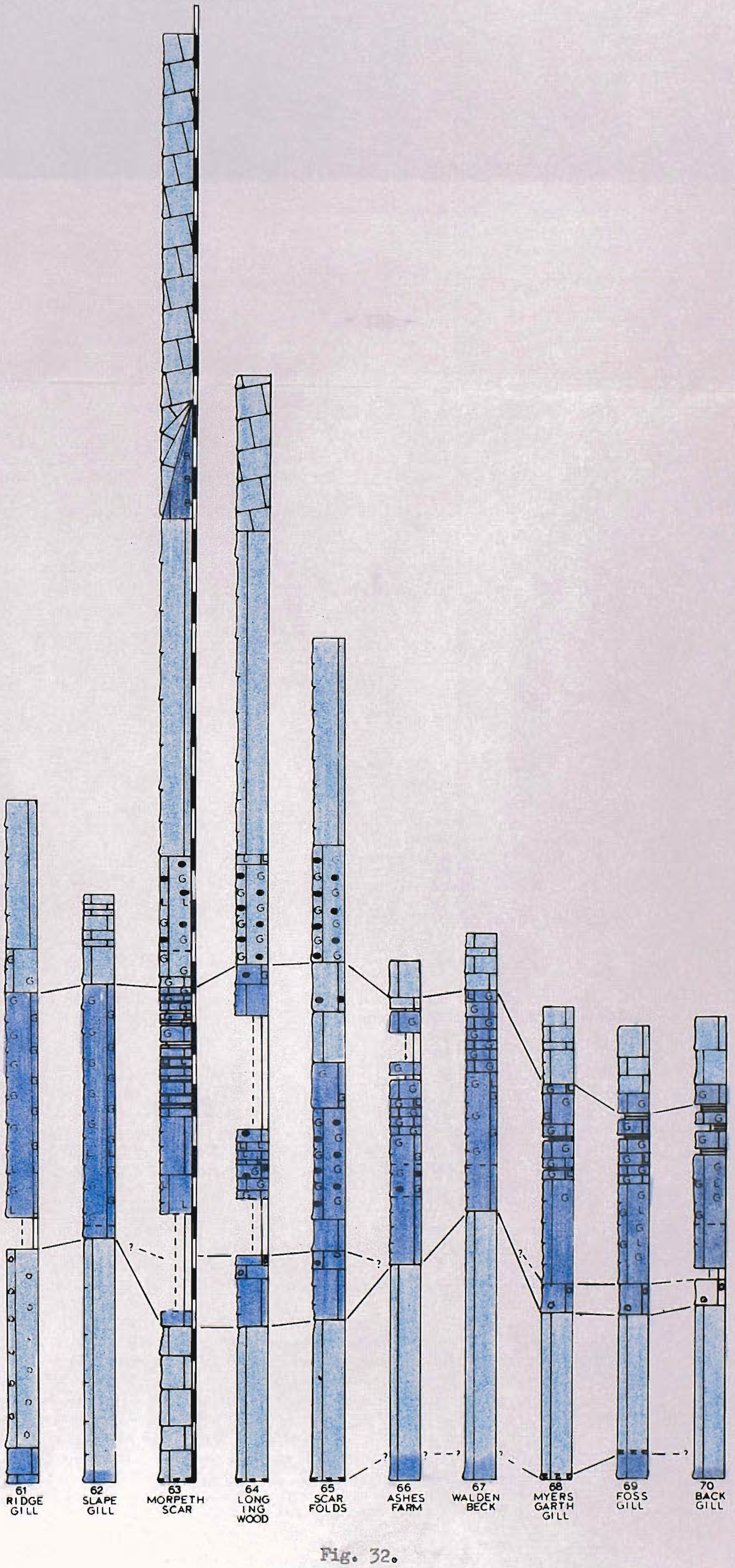

61
RIDGE
GILL
62
SLAPE
GILL
63
MORPETH
SCAR
64
LONG
ING
WOOD
65
SCAR
FOLDS
66
ASHES
FARM
67
WALDEN
BECK
68
MYERS
GARTH
GILL
69
FOSS
GILL
70
BACK
GILL

Fig. 32.

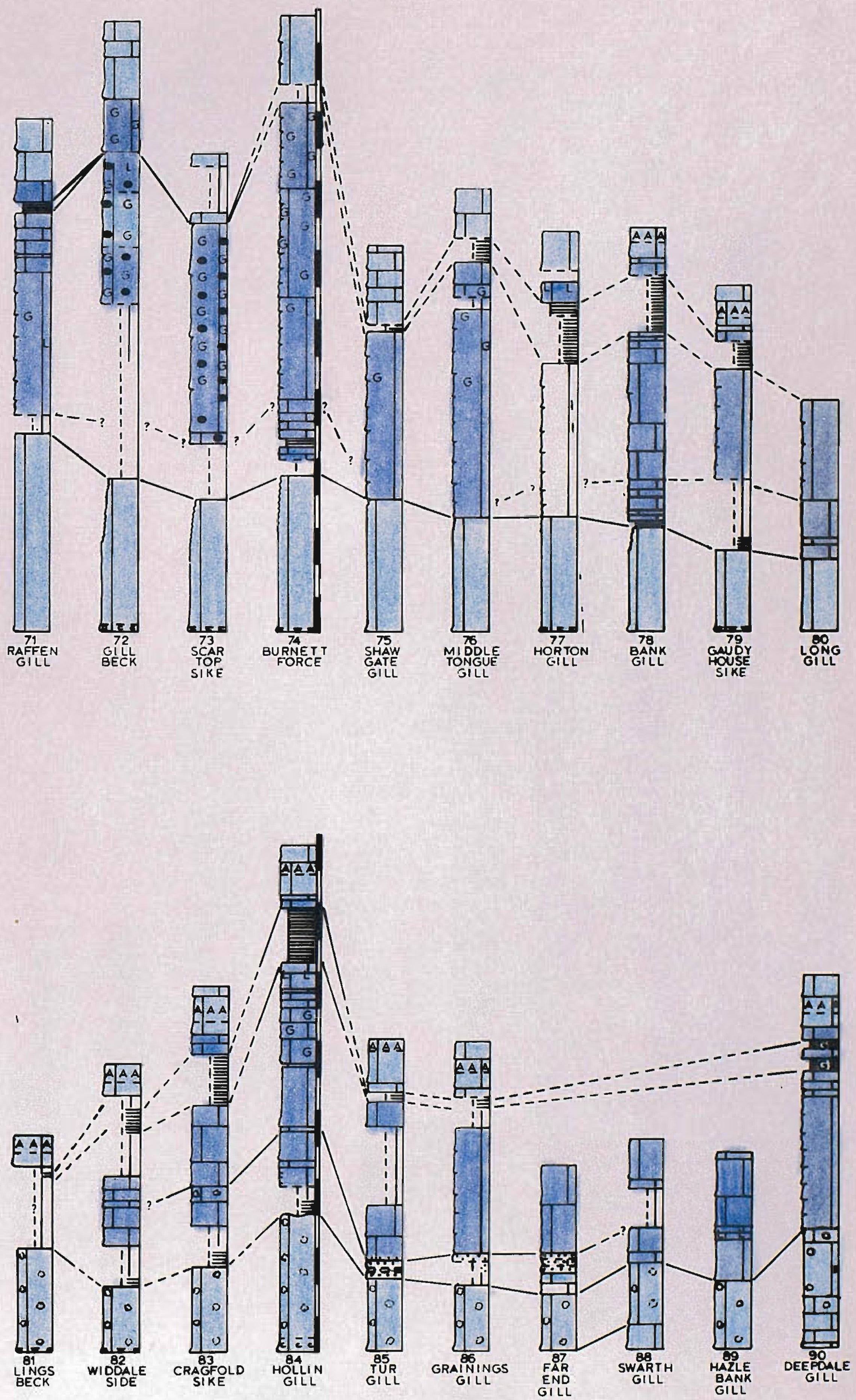
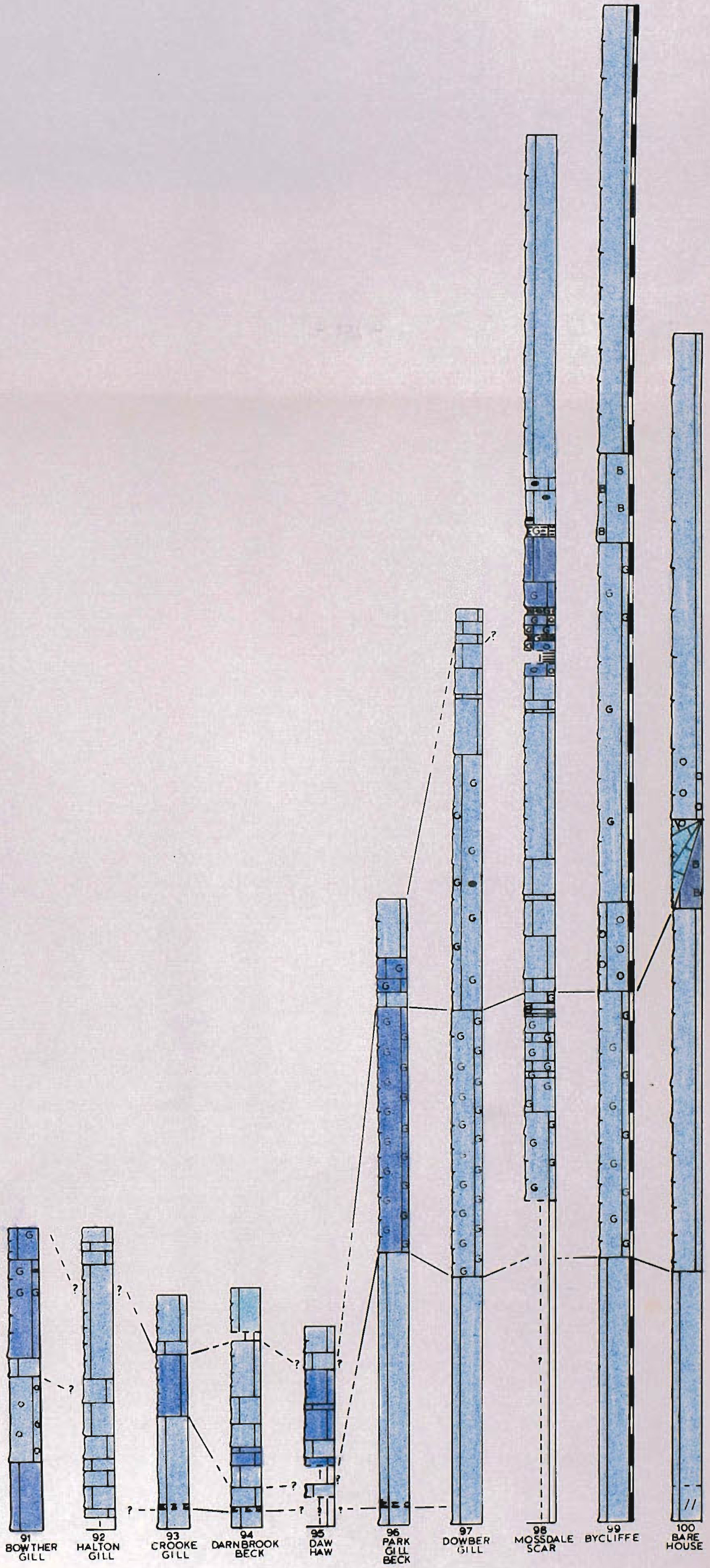

71 RAFFEN GILL
72 GILL BECK
73 SCAR TOP SIKE
74 BURNETT FORCE
75 SHAW GATE GILL
76 MIDDLE TONGUE GILL
77 HORTON GILL
78 BANK GILL
79 GAUDY HOUSE SIKE
80 LONG GILL
81 LINGS BECK
82 WIDDALE SIDE
83 CRAGFOLD SIKE
84 HOLLIN GILL
85 TUR GILL
86 GRAININGS GILL
87 FAR END GILL
88 SWARTH GILL
89 HAZLE BANK GILL
90 DEEPDALE GILL

Fig. 33.



91 BOWTHER GILL
92 HALTON GILL
93 CROOKE GILL
94 DARNBROOK BECK
95 DAW HAW
96 PARK GILL BECK
97 DOWBER GILL
98 MOSSDALE SCAR
99 BYCLIFFE
100 BARE HOUSE

Fig. 34.

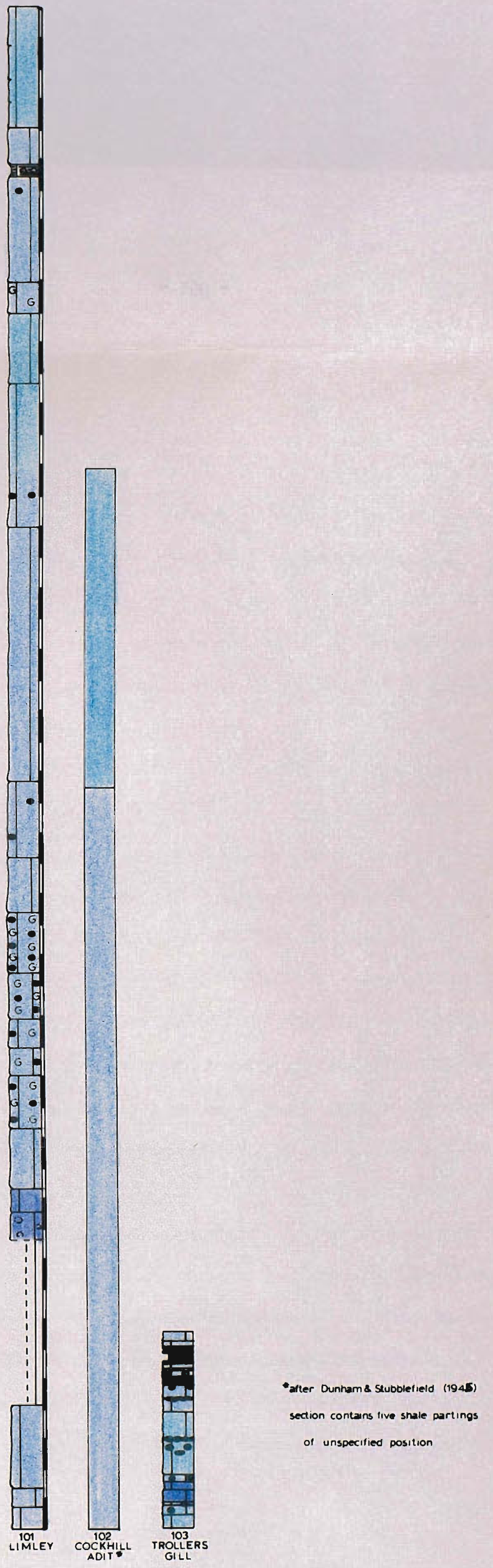

101
LIMLEY
102
COCKHILL
ADIT*
103
TROLLERS
GILL
*after Dunham & Stubblefield (1945)
section contains five shale partings
of unspecified position

Fig. 35.

THE SINGLE POST LIMESTONE

DISCUSSION.

The Single Post Limestone contains a marine fauna of crinoids, brachiopods, corals, foraminifera, bryozoa, pelecypods and gastropods indicative of normal salinity. It overlies a sequence of clastic deltaic sediments in which temporary marine incursions are recorded by thin limestones. Like the other major limestones of the Yoredale Group it records a more prolonged, although still temporary, establishment of a marine environment.

The change from deltaic to marine conditions during which the Single Post Limestone accumulated is first marked by accumulation of Limestone IVc which also contains a marine fauna. The delta-top sediments with thin but extensive seatearths and coals became inundated by the sea, calcareous organisms colonised the area and carbonate accumulation commenced over most of the Askrigg Block. Carbonate accumulation was halted later over the northwestern part of the Block by temporary re-establishment of deltaic conditions and deposition of a thin sheet of sand which failed to reach the southern part of the Block. The sand must have been deposited in very shallow water as it contains seatearths (gannisters). The presence of seatearths (gannisters and fireclays) and coal in the deltaic sediments below Limestone IVc and gannisters in the deltaics above, often within one or two metres of the Limestone, and the absence of any marked discontinuity in the sequence, suggests that Limestone IVc probably accumulated in water only a few metres deep. Indeed, at some localities Limestone IVc directly overlies coal.

In the north, where the Single Post Limestone overlies sandstone, the onset of carbonate accumulation is marked by a change from deltaic to marine conditions but in the south, where the Single Post Limestone overlies Limestone IVc, marine conditions were already established (Fig.36)

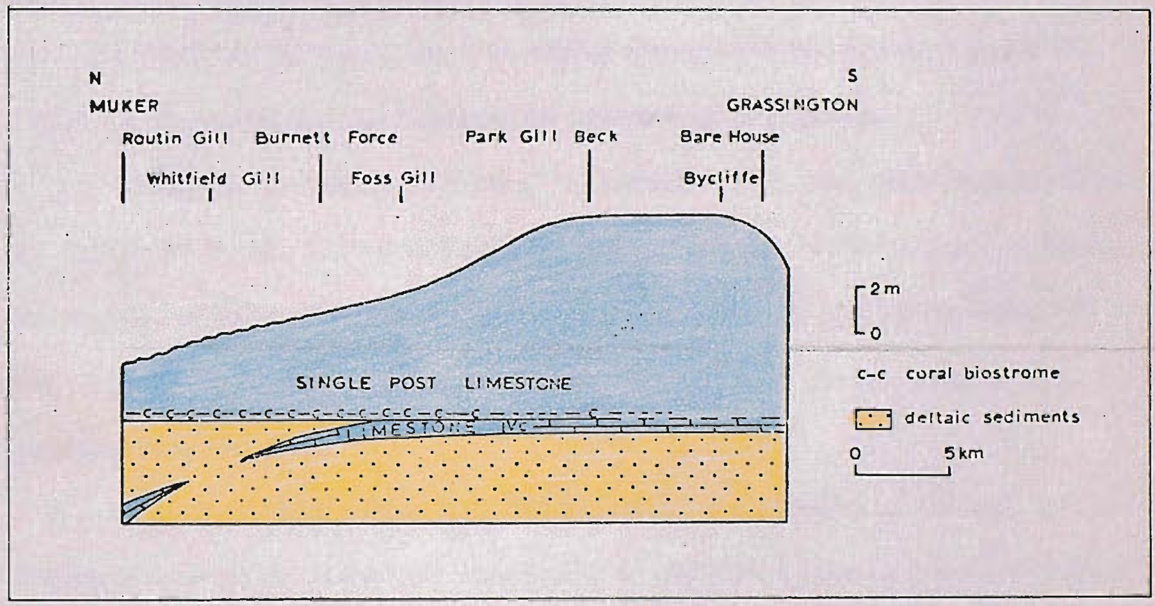


Fig.36. The relationship between the Single Post Limestone and Limestone IVc on the Askrigg Block.

The initial phase of accumulation of the Single Post Limestone is marked by colonisation of the sediment surface by corals, dominantly <u>Lithostrotionidae</u>, over much of the Askrigg Block. They colonised all the northern part where the underlying sediment was sand except a small area on the north flank of Whernside but in the south, where the underlying sediment was a bioclastic carbonate mud, only patchy colonisation occurred (Fig.14).

The mud-free, fine quartz sand substrate was sufficiently stable over nearly all the northern part of the Askrigg Block to allow establishment of coral polyps although scattered grains of quartz sand in the coral biostrome show that at least some sand was redistributed. Only exceptionally does the coral biostrome contain more than 5% sand as in Sar Gill (SD 908918).

Currents may have redistributed the sand but evidence of current activity is absent. Bioturbation cannot be discounted as a mechanism of sand redistribution but the abrupt top of the sandstone beneath and the absence of identifiable bioturbation structures in the biostrome indicate bioturbation was not intense. An environment of dense coral growth would be an unfavourable habitat for burrowing organisms.

Failure to locate the coral biostrome above the sandstone pavement in Thrush Gill (SD 745900), Garsdale, was probably due to a combination of patchy or poor coral development and poor quality and small size of the outcrop rather than absence of the biostrome as it is seen at all neighbouring outcrops.

In Great Blake Beck (SD 762851) and Stock Beck (SD 736854) on northern Whernside the coral biostrome is definitely absent even though a sand substrate is present. At both these outcrops the Single Post Limestone contains abundant sand, passing from a calcareous sandstone at the base into a sandy limestone above. Redistribution of the sand substrate by currents can be proved in Great Blake Beck because the gradational contact between the sandstone pavement and the Single Post Limestone is cross-laminated. The sea floor was probably locally high and the sediments susceptible to current activity. The disappearance of Limestone IVc in this region and the extreme thinning of the Single Post Limestone to 40cm in Great Blake Beck, its minimum thickness on the Askrigg Block, is supporting evidence. The absence of corals at the base of the Single Post Limestone in this area is due, therefore, to instability of the substrate; the coral polyps could not establish themselves on mobile sediment.

In contrast to the profuse coral development on the sand pavement in the north, corals colonised the carbonate-mud substrate in the south only patchily. There is nothing to suggest the surface was lithified and formed a hardground and no change in lithology occurs at this horizon. The common absence of an identifiable bedding plane or parting between Limestone IVc and the Single Post Limestone indicates no great break in carbonate accumulation. It appears that the pavement of carbonate mud on which the Single Post Limestone accumulated was not lithified. Bioclasts, dominantly crinoid ossicles and brachiopod fragments, are numerous enough at most outcrops to have offered potential sites for polyp establishment and growth but colonisation would be impeded if the surface was unstable. Although evidence of current activity is lacking the sediment may have been bioturbated. Carbonate mud in suspension or carbonate mud, and possibly mucilaginous films, coating grains may have inhibited coral development. The patchy colonisation probably occurred during an hiatus in carbonate accumulation.

The almost total colonisation of the sand substrate but only patchy colonisation of the carbonate-mud substrate cannot be coincidental. The corals besides being more numerous on the sand substrate are also larger, show greater diversity of genera and species and generally form a thicker biostrome. It seems, therefore, that suitability of the substrate for coral colonisation was of great importance in determining their distribution. Wells (1956) when referring to modern scleractinian corals noted, "Coral planulae can settle only on firm substrates such as bed rock, other corals, shells and skeletal parts of other sedentary organisms, loose blocks and smaller particles down to a few millimetres in size. In general fine sand, silt or mud bottoms are inimical to coral development unless there are scattered larger, clean particles and sedimentation is slow".

Development of the coral biostrome is thought to have been rapid and more or less penecontemporaneous. As the biostrome rests on sandstone with seatearths (gannisters) in the north, deposited in very shallow-water deltaic conditions, the corals must have been early colonisers after marine conditions were established. They presumably colonised the substrate in very shallow water conditions. In the south where marine conditions were already established the sea was probably deeper. However, water depth cannot fully account for the patchy distribution of corals in the south because the change from almost ubiquitous coral development on the sand substrate to patchy colonisation of the carbonate-mud substrate is abrupt and coincides with the junction between the two.

All the coral colonies in the biostrome are in their position of growth, none are overturned and there are no signs of marked turbulence Saccaminopsis carteri (Brady), although distributed patchily, and small brachiopods, notably Sinuatella sinuata (De Koninck), are common at the base of the Single Post Limestone but especially between the coral colonies. The sheltered environment seems to have been a particularly favourable habitat. Although brachiopods have been considered relatively unimportant in modern carbonate sediments dense populations occur in cryptic shallow water tropical habitats such as reef crevices and underneath foliose corals (Jackson et al, 1971).

The corals die out suddenly after a period of apparently vigorous growth but there is no change in sediment type and reasons for their death can only be postulated. They may have been overwhelmed by carbonate mud, the production of which would increase when marine conditions were fully established and calcareous organisms became abundant after initial colonisation. An increase in bioturbation may have made the substrate unstable and unsuitable for polyp attachment and growth but other factors such as increasing water depth or failure to compete with other organisms are possible causes.

After a period of carbonate accumulation Orionastraea sporadically colonised the sediment surface in the southeast. At outcrop the sparse colonies are seen along a single horizon and it seems probable, although proof is absent, that they can be correlated lithostratigraphically. Conditions for polyp establishment and growth were suitable only for a short period, possibly during a temporary reduction in the rate of carbonate accumulation, but no change in lithology is seen.

Besides occurring in the Single Post Limestone, Orionastraea is found also in the Simonstone Limestone, Hardraw Scar Limestone and in the thin limestones between the Simonstone and Middle Limestones on the Askrigg Block. It has been used traditionally as a 'zone fossil'. Hudson (1929) placed the limestones of the Yoredale Group containing Orionastraea into two 'subzones', a lower one characterised by Orionastraea indivisa (Hudson) and its variants and Orionastraea prerete (Hudson) and an upper 'zone' characterised by Orionastraea garwoodi (Hudson). He considered the upper 'subzone' was, "in the main ", equivalent to the Middle Limestone of Wensleydale and the limestones of the other areas correlated with it. He divided this 'subzone' into a lower part containing Orionastraea rete (Hudson) and rare Orionastraea garwoodi var. pristina (Hudson) and an upper part characterised by Orionastraea garwoodi (Hudson). Hudson (1929) considered Orionastraea garwoodi var. pristina (Hudson) an earlier form than Orionastraea garwoodi (Hudson) noting that the former variety is seen only in the Middle Limestone (i.e. the Single Post Limestone) of Upper Wharfedale and Nidderdale. From this he concluded that the base of the Middle Limestone in Upper Wharfedale and Nidderdale is stratigraphically lower than the base of the same Limestone in Wensleydale which contains Orionastraea garwoodi (Hudson). To explain this Hudson (1929) postulated coalescence of the thin limestones below the Middle Limestone in Wensleydale with the Middle Limestone in Upper Wharfedale and Nidderdale. Certainly, Limestone IVc beneath the Middle Limestone (Single Post Limestone) in Wensleydale has fused with the Middle Limestone in the areas Hudson mentions but his statement that Orionastraea in the Middle Limestone of Upper Wharfedale and Nidderdale is at a lower stratigraphic level than Orionastraea in the coral biostrome at the base of the Middle Limestone of Wensleydale is not correct. In Park Gill Beck (SD 987753), Wharfedale Orionastraea occurs 60cm above the coral biostrome at the base of the Single Post Limestone. The exact position of the base of the Single Post Limestone is unknown farther south because the coral biostrome is absent but the occurrence of Orionastraea at a similar level in Whernside Pasture and Providence Mine (Chubb, 1926) with respect to the base of Limestone IVc and the similarity in limestone thickness indicates that it also occurs above the base of the Single Post Limestone.

In Nidderdale Orionastraea occurs both beneath and above the coral biostrome at the base of the Single Post Limestone. Tonks (1925) recorded Orionastraea ¼in. (6mm) thick at the base of the limestone exposed at Limley beneath an horizon with Diphyphyllum and other corals here correlated with the coral biostrome at the base of the Single Post Limestone. Neither of these were recorded by Wilson (1960) nor during the present study but sparse scattered colonies of Orionastraea along a single horizon were recorded 75cm above the base of the Limestone (37cm above the base of the Single Post Limestone).

Carbonate accumulation persisted until uplift of at least the northwest part of the Askrigg Block (p.175). Although post-depositional removal of the upper part of the Single Post Limestone can be proved in the northwest (p.176) the Limestone was thickest in the southeast and thinnest in the northwest immediately after accumulation. This is confirmed by the correlation between limestone thickness and size and abundance of crinoid debris (p.415) where the upper part of the Single Post Limestone has not been removed. The regional variations in thickness cannot be accounted for by differential compaction (p.356). In the southeast, not only are crinoid ossicles more abundant, but they are larger and frequently preserved articulated as crinoid stems unlike the crinoid debris in the northwest which is less abundant, smaller sized and more fragmented. The relationship between crinoid size, degree of preservation and limestone thickness and the presence of a micrite matrix shows that thickness variations result dominantly from differences in rates of biogenic carbonate production rather than current activity. The environment for biogenic carbonate production, as indicated by the profuse development of large crinoids, was most favourable in the southeast. Rapid accumulation of carbonate is indicated by preservation of crinoid debris often as lengths of stem, presumably due to rapid burial before complete decay of the binding organic matter. Indeed some of the fragmentary bioclastic debris seen to the northwest may have been derived from the thicker accumulations in the southeast. Although rate of biogenic carbonate production is considered the main cause of thickness variations other factors may also have been important. Carbonate accumulation may have persisted in the southeast after cessation in the northwest for uplift of the northwest immediately post-dates the Single Post Limestone (p.175). This, however, does not account for the differences in crinoid populations. Water depth may have been important. It seems probable that the sea was deepest in the south and shallowest in the north for marine conditions were established in the south prior to accumulation of the Single Post Limestone. This cannot have been a major factor, however, as the Single Post Limestone is thin in the southwest. The thicker carbonate accumulation in the southeast may have been aided by a rate of subsidence faster than elsewhere on the Block. The upward movement of the northwest part of the Askrigg Block immediately post-dating accumulation of the Single Post Limestone (p.175) may have been compensated by a downward movement of the southeastern part of the Block. Whilst several of the above factors may have operated the thickness variation of the Single Post Limestone is explained best in terms of varying rates of biogenic carbonate production in response to environment.

The surface of the Single Post Limestone is abrupt and planar in the south and east but in the northwest it is irregular, pitted, commonly iron-oxide stained and corroded. The irregularity is not a result of erosion of unlithified sediment by currents because carbonate mud has not been winnowed from the top of the Limestone, there is no residual concentration of coarse bioclastic debris and intraclasts are absent both in and above the Limestone. The question arises whether the surface of the Single Post Limestone was a hardground. Bathurst (1971) defines hardgrounds as "beds of limestone which show unmistakable evidence of having existed as hardened sea floors, as rock surfaces, at the sediment-sea water interfaces" lithfied in either a submarine or subaerial environment. However, the term hardground is often used in a more restricted sense in the literature to refer to only submarine cemented sea floors. "A bed of limestone is regarded as a hardground if its upper surface has been bored, corroded or eroded (by abrasion) if encrusting or other sessile organisms are attached to the surface or if pebbles derived from the bed occur in the overlying sediment", (Bathurst, 1971). Common, although not strictly diagnostic, are crusts or impregnations of glauconite, phosphate, iron and manganese salts. The irregular, corroded and iron-stained surface of the Single Post Limestone in the northwest is not bored, lacks an encrusting or attached sessile fauna, does not appear abraded and pebbles derived from the limestone are not found in the overlying beds; subaerial corrosion rather than marine erosion seems likely, resulting in formation of an emersion surface.

When freshwater falls on the surface of newly exposed carbonate sediment dissolution occurs. During percolation through the sediment-pore system it becomes rapidly saturated with $CaCO_3$ but this process involves an important amount of dissolution (Weyl, 1959). Once the water is inside the sediment and moving slowly downwards concentration gradients between particles of different solubilities cause diffusion and further dissolution. Cementation will be slight as the pore water is moving and the rate of precipitation is slow by comparison with the rate of dissolution so there will be a net loss of $CaCO_3$. The surface of the rocks will develop a corrosional topography, the inside of the rock, irregularly and lightly cemented, will evolve a secondary porosity. Dissolution of the limestone is increased by further rainfall, the release of CO_2 and organic acids from organic decay and cooling brought about by changes in weather (Dunham, 1969). Recent carbonate sands, mixtures of aragonite, high Mg calcite and low Mg calcite, have undergone two processes, cementation and large scale dissolution (Bathurst, 1971). These processes have been recorded in many places. for example in the oolitic facies of the Pleistocene Miami Limestone of Florida, where a corrosional topography is accompanied by calcite cementation and dissolution of aragonite ooids with development of not only oomouldic porosity but also vugs with diameters up to several centimetres (Stanley, 1966; Robinson, 1967). Similar vugs are recorded beneath subaerially exposed surfaces in Virgillian Strata, Pennsylvanian of Southern New Mexico (Wilson, 1967). Selective leaching of certain components of the carbonate sediment is dependent upon their solubility but once cavities are formed enlargement by further dissolution is common.

Vugs, now infilled with coarsely crystalline ferroan calcite, are seen beneath the corroded surface of the Single Post Limestone. Their development only below the emersion surface, particularly just beneath, suggests that they are related. The calcite infilled vugs were first recorded by the Geological Survey in the Mallerstang Memoir (1891), "It (the Single Post Limestone) has moreover a peculiar spotty appearance owing to the dissemination through it of a number of small calcite crystals .....(it) is marked by the presence of many small irregular calcite spots of doubtful origin." Moore (1955) noted they were usually iron-stained and that their origin was unknown. The coarsely crystalline ferroan calcite is space filling cement and fills voids. The vugs are clearly secondary, not primary sedimentary features as they truncate fossils (Plate 47). They are thought to have formed by dissolution of carbonate by percolation of rainwater through the sediment during subaerial exposure. Dissolution presumably took place where solution channels passed through the limestone, formed initially by solution of the most soluble component and then solution enlargement of the cavity.

Although centimetre sized vugs now filled with ferroan calcite represent only a small proportion of the Single Post Limestone (usually less than 1%) dissolution on a smaller scale may have been volumetrically more important. Beneath the emersion surface the limestone is colour mottled unlike elsewhere on the Askrigg Block. Colour mottling is common in limestones of the Yoredale Group as a result of bioturbation but the type of mottling in the Single Post Limestone, which is exceptionally vivid in places, has not been noted by the author in any other Yoredale Limestones on the Askrigg Block. In the past the Limestone, because of the mottling, has been referred to as a pseudobreccia (Hudson, 1929) but no explanation for the mottling has been proposed. The mottling is not a depositional feature nor a result of simple aggrading neomorphism.

The dark mottles in the Single Post Limestone, a neomorphosed biomicrite, have a non-ferroan microspar matrix whilst the surrounding lighter coloured areas have a matrix of coarser, dominantly ferroan microspar. Bioclasts are abundant and well preserved in the dark mottles but in the surrounding areas they are sparser and often corroded. The difference in limestone texture is thought to be due to leaching by rainwater during subaerial exposure; the dark patches being unleached carbonate whilst the lighter areas acted as channels for percolating rainwater and are leached. The presence of ferroan microspar in the channel areas suggests that they were not finally lithified until quite late (p.363) unlike the dark non-ferroan mottles.

Payton (1966) recorded mottling produced by differences in size of constituent calcite grains in the upper part of the Pennsylvanian upper Benthamy Falls Limestone of Kansas, though the dark mottles were coarser grained (calcite av. 20μ) than the finer 'groundmass' (calcite av. 10μ) the opposite to the Single Post Limestone (p.368). He did not suggest an origin for the mottles but interpreted the limestone as being deposited in shallow water mud-flats.

In Birkett Railway Cutting (NY 774029), north of the Askrigg Block, the breccia at the top of the Single Post Limestone is unique over the area studied. It was recorded first in the Mallerstang Memoir (1891) as a "nodular limestone rubble" and later, because of the rubbly appearance, Turner (1956) thought it to be '*Erythrospongia lithodes*' (Hudson) which he took as an indicator of the Single Post Limestone. Although Turner's identification of the Single Post Limestone is correct his method of correlation was invalid. Accepting that Turner considered '*Erythrospongia*' a siliceous sponge as described by Hudson, 1929 (not a bioturbation structure as suggested here) his misidentification of '*Erythrospongia*' in Birkett Railway Cutting makes any biostratigraphic correlation invalid.

Lithostratigraphic correlation of the breccia with the beds containing *'Erythrospongia'* to the south is also impossible because the breccia is at the top of the Single Post Limestone whereas the beds with *'Erythrospongia'* form the top of the Lower Parting.

The abrupt, irregular surface at the top of the Single Post Limestone seen to the south is absent at the top of the breccia although the limestone beneath the breccia is mottled and contains patches of coarsely crystalline calcite as beneath the emersion surface.

Blount and Moore (1969) gave criteria for the recognition of various types of carbonate breccia based on a study of Cretaceous breccias in the Chiantla Quadrangle, Guatemala. They differentiated between depositional and non-depositional types dividing the non-depositional types into evaporite breccias, solution collapse breccias, tectonic breccias, pseudobreccias and caliche breccias. The breccia in Birkett Railway Cutting (p.49) cannot be depositional or tectonic because the clasts of carbonate in the upper part are unlike the limestone beneath yet the breccia grades down into non-brecciated limestone. The possibility that it is an evaporite-solution breccia is unlikely as there is no evidence of evaporites or dolomitisation. Neither is it a pseudobreccia because the clasts have distinct boundaries. Only two possibilities remain, either the breccia is the residual rubbly carbonate left on a subaerially exposed surface after dissolution of carbonate or it is a caliche. If the breccia is simply a residual limestone rubble on a subaerially exposed surface after carbonate dissolution then the clasts would be similar in lithology to the carbonate they were derived from. In Birkett Railway Cutting the clasts of the breccia contain only extremely rare bioclasts unlike the limestone beneath where bioclasts are abundant. The clasts also have a completely different fabric from the limestone beneath, are sometimes laminated concentrically and often contain calcite infilled fractures. These features and their petrography (p.366) suggest that the breccia is the result of calichification.

The best documented caliches are those of Pliocene to Holocene age which cover large parts of the High Plains of eastern New Mexico. They result from in situ soil forming processes taking place in a semi-arid climate with seasonal rainfall. Caliches consist typically of a thin leached soil with scattered calcareous nodules at the base beneath which is an irregular thin-bedded to massive, partly laminated and/or nodular zone composed only of slightly porous calcite with few remains of pre-existing sediment. This grades down into a massive, somewhat thicker, rubbly zone composed mainly of loosely aggregated, partly brecciated nodules and irregular fragments of carbonate in a powdery carbonate matrix. A transitional zone beneath passes down into unaltered country rock. Variability in caliche profiles partly reflect their maturity (Price, 1933; Hawley & Gile, 1966; Reeves, 1970) and partly stems from interrelated physical factors which include the nature of the parent material, the amount and chemical composition of infiltrating water, local climate, nature and density of plant cover and whether or not new sediment is being added as calichification proceeds (Smith, 1974). One or more of common caliche zones is absent from many profiles and laminated pisolitic structures are formed in latest stages of caliche formation (Reeves, 1970).

Although pisolitic caliches have been described frequently in the literature the absence of well developed pisoliths in the breccia presents no problems. Non-pisolitic caliches have been described by Smith (1974) who notes, "Perhaps the most common form of caliche in Upper Artesia shelf sediments (Permian) is non-pisolitic as it is in the more modern caliches". Smith (1974) notes that more of the original sediment is preserved in the non-pisolitic caliches and that most of the upper part of the profiles now comprise a dense cryptocrystalline aggregate of turbid carbonate grains interrupted by ghosts of former clasts. Although fibrous calcite is abundant in many caliches, the main component of the caliche in Birkett Railway Cutting is microspar (p.366) as in calcified limestones on many hills in Texas (Folk, 1969, quoted in Bathurst, 1971). The absence of quartz sand, a component of most caliches, reflects either a lack of exposed source material or no supply.

Provided no new sediment is added during formation of caliche, the nature of the many processes involved demands that the rate of buildup of the caliche diminishes with time; there must be a tendency toward self limitation in thickness. The widespread occurrence of Pliocene to Holocene caliches between 1m and 4m thick is probably a reflection of this tendency. Assuming that no material had been removed from the caliche in Birkett Railway Cutting, its thickness of only 60cm and the absence of abundant laminated and pisolitic structures suggests that calichification did not progress to its final stages. Soils at the top of fossil caliches are commonly not preserved (Smith, 1974) presumably because of erosion after resubmergence.

The presence of a caliche conclusively demonstrates that the sediments in which they formed were exposed subaerially (Smith, 1974). The caliche in Birkett Railway Cutting, like the corroded surface of the Single Post Limestone over the northwest part of the Askrigg Block, is iron-oxide stained. The area peripheral but adjacent to the emersion surface is also iron-oxide stained and weathers rubbly. Similar iron-oxide concentrations beneath subaerially exposed surfaces are recorded by Smith (1974) in Guadalupian rocks (Permian) of New Mexico and by Wilson (1967) in Virgillian Strata (Pennsylvanian) of the Sacramento Mountains.

The widespread development of an irregular, emersion surface in the northwest but only extremely localised formation of a poor caliche is probably a reflection of climate. Although the corroded surface, vugs and mottling suggest rainfall was adequate for caliche formation, the climate was probably not seasonally arid enough for widespread caliche development. The poor caliche seen in Birkett Railway Cutting probably formed in a locally favourable microenvironment where relief and possibly the water-table were most favourable. The rubbly weathering, iron-oxide-stained area peripheral to the irregular, corroded surface may represent incipient caliche formation.

Accumulation of the Single Post Limestone was terminated by subaerial exposure of the carbonate sediment over the northwest part of the Askrigg Block, a result of tectonic movement, eustatic change or both. Subaerial exposure is explained easily in terms of tectonic uplift of the northwest corner of the Askrigg Block above sea level. The Pennine Basin, subsiding at a faster rate than the Askrigg Block, must have exerted a downward drag on the southern edge of the Block. If the drag was greatest in the southeast then the relatively buoyant, though slowly subsiding Block would tilt southeastward about a NE-SW axis. This tilting may have produced uplift of the northwest and subaerial exposure of the recently accumulated sediment. If the tilt is considered uniform over the entire Block (an unlikely situation notably because of the non-monolithic character of the Block and drag effects at the Block edges) then speculation about the amount of tilt required to subaerial expose the area now covered by the erosion surface can be made for given water depths. At a water depth of 10m the tilt required is only about 0.1°. Unfortunately, absolute water depths during accumulation of the Single Post Limestone are unknown. Although evidence of high energy environments is absent the fauna indicates shallow water conditions. If eustatic change i.e. marine regression, caused the subaerial exposure then the sea must have been shallowest in the northwest. There is some evidence to support this (p.160) but the sediments in the northwest record no signs of shallowing conditions even in the area peripheral to the erosion surface where the upper part of the limestone presumably has not been removed.

A tectonic explanation is preferred because of absence of change in sediment type of the top of the Limestone and the occurrence of similar movements later (p.415). The amount of limestone removed during subaerial exposure in the northwest was probably small, only one or two metres. This estimate is based on the relationship between abundance and size of crinoid debris and limestone thickness (p.415) and the marked thinning to the northwest that is seen where the emersion surface is absent. In Dentdale where the Single Post Limestone is exceptionally thin it is possible that a greater thickness was removed. However, because it is very sandy and uniquely cross-laminated here, this probably reflects thin carbonate accumulation rather than considerable post-depositional removal. If the sediment surface after deposition is assumed to be more or less planar within the confines of small outcrops then post-depositional removal of at least 75cm can be proved (p.65).

Dickite is recorded infilling cavities and along stylolites in the Single Post Limestone over the northwestern part of the Askrigg Block. It is often associated with cavity-filling ferroan calcite cement but etching and embayment of the ferroan calcite, where adjacent to dickite, shows they are not related genetically; the dickite is authigenic and post-dates the ferroan calcite cement. Dickite is recorded infilling cavities in Pennsylvanian Limestones of Kansas where it is most common in the mottled biomicrite facies and is associated with a ferroan carbonate cement, in this case ferroan dolomite (Hayes, 1967; Schroeder & Hayes, 1968; Mossler, 1971). Hayes (1967) originally suggested the dickite and ferroan dolomite were related genetically but this view was later changed (Schroeder & Hayes, 1968) for the change from large volumes of alkaline solutions of negative Eh to acidic solutions necessary for dickite crystallisation could not be explained. Most dickite occurrences are associated with hydrothermal activity. Schroeder & Hayes (1968) demonstrated a relationship between the areal distribution of dickite in Pennsylvanian Limestones of Kansas and Tertiary igneous intrusions and suggested dickite formed from heated ground waters. However, occurrences of dickite are recorded which bear no apparent relationship to hydrothermal solutions (Bayliss et al, 1965) , as in the Single Post Limestone. The origin of dickite in the Single Post Limestone is unknown though it is interesting to note that in the Pennsylvanian Limestones of Kansas and the Single Post Limestone, dickite is most common in mottled biomicrites.

THE LOWER PARTING.

DISCUSSION.

The base of the Lower Parting is recognised easily over most of the Askrigg Block because it overlies the abrupt top of the usually distinctive Single Post Limestone. Its top is defined by the base of the Cockleshell Limestone. Over the southern part of the Askrigg Block the Lower Parting is absent and the Cockleshell Limestone rests directly on the Single Post Limestone (Fig. 15).

Accumulation of the Lower Parting did not commence until resubmergence of the subaerially exposed Single Post Limestone, probably a result of tectonic subsidence rather than eustatic rise (p. 175). Hollows in the irregular, corroded top of the Single Post Limestone, which presumably had become at least partly lithified during subaerial exposure, were infilled by sediment, usually terrigenous or carbonate mud but sometimes quartz sand. Evidence of scouring prior to deposition is absent, the hollows are simply infilled and no debris from the Single Post Limestone is seen in the overlying beds. There is never any lithological transition between the Single Post Limestone and the overlying beds.

In the southern part of the Barnard Castle Trough the Lower Parting consists of thin shales and calcilutites in the east but in the west it is thick and composed of deltaic sandstones and shales with occasional thin marine limestones. The Lower Parting thins southwards across the Askrigg Block where marine rather than deltaic sediments predominate. The thick deltaic sandstones seen in the northwest reach only the western part of the north edge of the Askrigg Block where calcilutites become prominent. The shales become calcareous and contain a sparse marine fauna on the Block but as the Lower Parting thins calcilutites form more of the succession and the shales eventually fail. Farther south the calcilutites also thin and fail so that over the southern part of the Askrigg Block the Lower Parting is absent. Absence of the Lower Parting here is real and not a result of lateral passage into the Cockleshell Limestone because at the most southerly exposures the mottled calcilutite, seen at the top of the Parting in the north, rests directly on the Single Post Limestone. The reason for its absence is not known although subsidence of the northwest part of the Askrigg Block, which resubmerged the subaerially exposed Single Post Limestone allowing accumulation of the Lower Parting. may have been a rotational movement causing a compensating uplift of the southern part of the Block. This may have prevented accumulation of the Lower Parting but there is no evidence to suggest that the southern part of the Block was subaerially exposed.

Thick, well developed sandstones in the Lower Parting occur in two areas, in the southwest part of the Barnard Castle Trough and on the west of the Askrigg Block in Garsdale. Between these areas the sparse outcrops from Garsdale (SD 745900) northwards to Needlehouse Gill (SD 733971) contain much less sand but from Needlehouse Gill northwards to Birkett Railway Cutting (NY 774029) exposure is very poor and the presence or absence of sand in the Lower Parting is unknown. The distribution and thickness of sandstone indicate two sand bodies with different directions of supply (Fig.16). The sand in the Birkett Railway Cutting reaches only the western part of the north edge of the Askrigg

Block and had a northnorthwesterly source. It is micaceous, sometimes parallel or ripple cross-laminated and belongs to a suite of deltaic sediments (p.401). The sand in Garsdale has a west to northwesterly derivation. Its northern limit lies in the poorly exposed ground between Needlehouse Gill (SD 733971) and Birkett Railway Cutting (NY 774029). The sandstone is occasionally cross-laminated, calcareous, has a sparse fauna of brachiopods and is marine differing markedly from the deltaic sandstones to the north.

The deltaic sand reached only the north edge of the Askrigg Block and is unlikely to have been the source of the westnorthwesterly derived sand in Garsdale. Unlike the deltaic sandstones which grade distally into siltstones and shales, the sandstones in Garsdale pass into limestones with interbedded shales absent or only poorly developed. Quartz sand must have been the dominant type of sediment supplied to Garsdale; terrigenous mud was quantitatively unimportant. If the sand had been derived from the deltaic sediments which contain abundant terrigenous mud and silt in addition to sand, then the sandstones in Garsdale would be associated with, or grade distally into, finer clastic sediments before finally passing into carbonates.

The location of marine sandstones in the Lower Parting on the northwest part of the Askrigg Block, the area of maximum uplift post-dating accumulation of the Single Post Limestone, is considered significant. It is thought that during subaerial exposure, the Single Post Limestone was completely removed in an area west of the Dent Fault, to the north-west of Garsdale, exposing the sandstone beneath. After resubmergence the exposed sand was redistributed by currents eastsoutheastwards into

Garsdale, an area where the Single Post Limestone had not been completely removed, to form the Lower Parting. Total removal of the Single Post Limestone is easily envisaged for it is only 40cm thick at some localities on the Askrigg Block (p.52). The area northwest of Garsdale where it is absent is not only the area of maximum post-Single Post Limestone uplift but is also anticlinal (the Howgill Fells anticline). This structure, like many other tectonic features in this region, probably had an extremely long history and may have been active at this time. The sandstones of the Lower Parting in Garsdale, like the sandstone directly beneath the Single Post Limestone, are not notably micaceous and contrast with the sandstones of the Lower Parting to the north which contain abundant mica.

North of Garsdale the sand content of the Lower Parting decreases gradually. Beneath the mottled calcilutite sand disappears between Penny Farm Gill (SD 702932) and Needlehouse Gill (SD 733971) but that above persists northwards at least to Needlehouse Gill. East of Garsdale the sand disappears more abruptly. Sandstones are well developed in Garth Gill (SD 771910) but in the River Clough (SD 782922), 1.5km to the northwest, only scattered grains of sand are seen in the upper limestones of the Lower Parting. The southern margin of the sand, although impossible to position accurately in the southwest because of poor outcrop, is abrupt in the southeast. Its boundary passes eastwards under Rise Hill to the south of Cowgill Beck (SD 770886) then northwest under the northwest flank of Widdale Fell to Garsdale Head. Outcrops northwest of this line all show well developed sandstones but sand is absent immediately to the southeast. The abrupt southeast margin of the sand probably represents the 'sand-front'. Further, the area immediately southeast of the sand, around Upper Dentdale, was a local 'high' (p.176) possibly halting advance of the sand.

Besides the main sand sheet in Garsdale, sand is also seen in Tur Gill (SD 825822), Grainings Gill (SD 828324) and Far End Gill (SD 833825), east of Cam Houses. Although good outcrops surrounding this area are sparse none contain sand. They show the sand at Cam Houses is a small isolated patch lying southeast of, and downcurrent from, the sand in Garsdale. It seems some sand broke free from the main sand body in Garsdale and was eventually deposited 8km to the southeast. The sand did not travel over a soft-sediment surface but over the surface of the Single Post Limestone which must have become at least partly lithified during subaerial exposure. During transportation by currents grains with similar hydraulic properties tend to travel en mass. Isolated patches of sand totally surrounded by carbonate are also recorded from the Three Yard Limestone (Moore, 1958).

The Lower Parting elsewhere consists of calcilutites with, over the northern part of the Block, interbedded shales. Although the main influxes of terrigenous mud are recorded by shales, a distal deposit of the delta to the north, a limited supply of mud was more or less continuous throughout accumulation of the lowest beds of the Lower Parting in the north as the calcilutites are muddy.

In an area including Routin Gill (SD 919969), Whitfield Gill (SD 930923) and Arn Gill (SD 953923), the Lower Parting contains chert as nodules and thin stringers. This is the first appearance of chert in quantity in the Middle Limestone although isolated nodules are seen in the Single Post Limestone in the southeast.

The uppermost calcilutites of the Lower Parting are characteristically but variably mottled. Mottling is very distinct at some localities but at others, generally in the south, it is faint or indistinct and recognition depends on the state of weathering of the outcrop. It shows best on water-polished surfaces and sometimes quite well on clean-weathered surfaces but on badly weathered faces and often on fresh-broken surfaces the mottling can be difficult to see. At some outcrops it is invisible on fresh-broken surfaces but can be recognised as vague, faint pinkish blotches on suitably weathered surfaces. The margins of the mottles vary from distinct through diffuse to indistinct. Where shales occur adjacent to the mottled calcilutites they often contain carbonate nodules similar to the mottles in the calcilutites.

Hudson (1929) first commented specifically on the uppermost of these beds and noted the nodules are 1/2" (1.3cm) to 5" (12.7cm) in diameter, red or dark grey, occur in both limestone and shale and the smaller nodules are cylindrical whereas the larger nodules are irregular and bulbous. The form of the nodules and the presence of spicules, sometimes siliceous but mostly pyrite or haematite, led Hudson to conclude that the nodules were siliceous sponges which he named '<u>Erythrospongia lithodes</u>'.

When considering the distribution of the sponge Hudson (1929) used previously published data but unfortunately misinterpreted several different descriptions thinking incorrectly that they referred to the horizon he described from Arn Gill (SD 953923), Wensleydale. Hudson thought the "small irregular spots of calcite of doubtful origin" recorded in the Mallerstang Memoir (1891) described '<u>Erythrospongia</u>' and stated that the reference to small calcite crystals in the introduction is, "an evident error of the writer". This description, however, refers to the small irregular patches of coarsely crystalline ferroan calcite in the Single Post Limestone. Similarly, he incorrectly correlated the bed of "spotted limestone" 8' thick at the base of the Middle Limestone in the River Clough (Mallerstang Memoir, 1891), the Single Post Limestone, with the nodular beds in Arn Gill. The middle of the limestones exposed on the northeast flank of Park Fell was also mis-correlated with the Middle Limestone of Wensleydale even though it had been previously correlated with the Simonstone Limestone (Ingleborough Memoir, 1890). Hudson's conclusion was based on recognition of a rubbly horizon bed as the '<u>Erythrospongia</u>' bed.

Variations in size, form and preservation of the mottles and nodules in the upper beds of the Lower Parting leads the writer to conclude that they are bioturbation structures not sponges as Hudson (1929) suggested. Both the mottles and the nodules are burrow infills The nodules in shale are always associated with an adjacent mottled calcilutite and result from infiltration of carbonate mud into open burrows in terrigenous mud or physical incorporation of carbonate mud into terrigenous mud during bioturbation. Many of the mottles and nodules are iron-stained, a feature frequently associated with burrow infills in limestones of the Yoredale Group which are muddy or beneath shales. The staining results from oxidation of fine disseminated pyrite.

To the northwest of the Askrigg Block deltaic conditions prevailed during accumulation of most of the Lower Parting. The thin coal near its base in Birkett Railway Cutting (NY 774029), the product of a swampy environment, indicates very shallow water conditions during accumulation of the lowest beds. Temporary establishment of marine conditions is recorded by two thin limestones in the upper beds.

On the Askrigg Block a marine environment became established. Throughout the Lower Parting there is an upward and southward increase in the carbonate mud : terrigenous mud ratio. Not only do shales decrease in thickness and frequency in these directions but they also become increasingly calcareous. The upward and southward change in colour of the calcilutites from dark brownish-grey in the north and grey in the south to paler grey also reflects this trend.

The macrofauna of the Lower Parting is sparse, especially in the north, consisting of brachiopods, dominantly productids including spinose types, and bellerophontids. In contrast to the Single Post Limestone beneath, corals are absent and crinoid debris is sparse, often rare. The poor macrofauna, especially the scarcity of crinoids which are usually abundant in carbonates of the Yoredale Group, shows the environment did not favour colonisation by abundant and diverse calcareous organisms. The appearance of intense bioturbation in the upper beds is not marked by any faunal change. It may have occurred during a decrease in the rate of carbonate accumulation or be related to other environmental factors such as changes in water depth.

THE COCKLESHELL LIMESTONE

DISCUSSION.

Accumulation of the Cockleshell Limestone followed deposition of the Lower Parting. Over the northern part of the Askrigg Block it overlies the Lower Parting but in the south, where the Lower Parting is absent, it rests directly on the Single Post Limestone. The top of the Cockleshell Limestone is defined by the base of the Upper Parting over the northern part of the Block but in the south and southeast the Upper Parting is absent and its top is marked by the base of the Scar Limestone.

The Cockleshell Limestone accumulated over the entire Askrigg Block. In the northwest and west it is a crinoidal calcilutite with thin interbedded shales but towards the southeast the shales disappear and the limestone becomes more crinoidal passing in the southeast into coarse crinoid-stem calcarenites and calcirudites. Increasing crinoid content is accompanied by an increase in limestone thickness, a relationship seen also in the Single Post and Scar Limestones. The greater abundance, larger size and less fragmented nature of crinoid debris in the southeast shows the environment there was more favourable for crinoid growth than elsewhere on the Block and carbonate accumulation was rapid. Good preservation of crinoid debris, lack of evidence of current accumulation and the association of coarse crinoid debris with bioherms indicate limestone thickness is controlled mainly by the rate of biogenic carbonate production.

Gigantoproductus, a characteristic faunal element of the Cockleshell Limestone, occurs over most of the area except in the south and central-west. It appears just above the base of the limestone. In the east where Gigantoproductus is accompanied by a profuse fauna including Lithostrotion and Clisiophyllids the beds become very cherty. The simultaneous appearance of an abundant fauna and chert suggest they are related. It is thought siliceous organisms were part of this fauna and their silica was redistributed during diagenesis to form both nodular and disseminated chert (p.378).

The formation of many chert nodules in the concavity of Gigantoproductus valves, which are usually in their position of growth, is related to decomposition of gigantoproductid organic matter after death. This would produce a locally favourable environment for silica precipitation (p.376).

In the southeast, north of Grassington, knolls are developed in the Cockleshell Limestone. They are discussed on p.354 and considered as bioherms (Cumings, 1932). The knolls first appear near the base of the Cockleshell Limestone and persist throughout the Limestone. The association of coarse crinoid debris with the knolls suggests that the coarse crinoidal limestones seen farther east may also be related to bioherm development. The gradual southerly decrease in size and final disappearance of the knolls in the southern-most ground at Grassington shows they do not persist right to the southern edge of the Askrigg Block.

THE UPPER PARTING.

DISCUSSION.

The Upper Parting on the Askrigg Block marks interruption of carbonate accumulation by influx of terrigenous mud in quantity. Its base is taken at the first appearance of well developed shale above the Cockleshell Limestone, its top at the base of the Scar Limestone.

To the northwest of the Askrigg Block in the Barnard Castle Trough, the Upper Parting, well exposed in Birkett Railway Cutting (NY 774029), is thick and consists of a coarsening upward sequence of deltaic shales and sandstones. The sandstones reach only the northwest corner of the Askrigg Block and are seen in Needlehouse Gill (SD 733971) and the River Rawthey (SD 729966). Here they are poorly developed in an essentially shale sequence only half as thick as the Upper Parting in Birkett Railway Cutting. The shale thins and becomes increasingly calcareous southeastwards failing in the south and east where the Upper Parting is absent. Thin limestones developed locally in the shale record periods of temporary reduction in accumulation of terrigenous mud.

On the Block the shale contains a marina fauna of brachiopods, dominantly productids including Gigantoproductus and spirifers, and variable quantities of crinoid, bryozoan and shell-debris. The presence of Gigantoproductus only in the basal and uppermost calcareous parts of the shale, adjacent to the underlying Cockleshell Limestone and overlying Scar Limestone, and in thin limestones within the shale suggests that Gigantoproductus tolerated a muddy environment providing it was sufficiently calcareous. It did not survive in less calcareous, muddy environments.

The similarity between the lithology of the thin limestones in the Upper Parting shale and the Cockleshell Limestone beneath, suggests that the Cockleshell Limestone may have continued accumulating in the south and east during deposition of the Upper Parting in the north. The Upper Parting in the north may therefore be equivalent to the upper part of the Cockleshell Limestone in the south and east. The only other possibility is that carbonate accumulation ceased during deposition of the Upper Parting. The change in carbonate lithology from calcilutites to calcarenites at the base of the Scar Limestone over much of the Askrigg Block shows the Upper Parting in the north does not pass laterally into the Scar Limestone in the south and east.

THE SCAR LIMESTONE.

DISCUSSION.

The base of the Scar Limestone is easily recognised where it overlies clastics of the Upper Parting but in the south and east, where the Upper Parting is absent and the Scar Limestone rests on the Cockleshell Limestone, its base is less easily identified. The change in lithology from crinoidal calcilutites of the Cockleshell Limestone to crinoidal calcarenites of the Scar Limestone enables recognition of the base of the Scar Limestone over much of the southern ground. However, in the southeast the Cockleshell Limestone becomes increasingly crinoidal and the base of the Scar Limestone is difficult and sometimes impossible to recognise. In the area north of Grassington where knolls are developed in the Cockleshell Limestone the coarsely crinoidal capping beds are similar in lithology to the overlying beds of the Scar Limestone. However, the occurrence of Orbitremites, correlated with Orbitremites recorded from the base of the Scar Limestone at Limley, Nidderdale (Joysey, 1955) enables recognition of the lowest beds.

The top of the Scar Limestone is easily identified in the north and west where the Limestone is thin and separated from the Five Yard Limestone by a thick clastic sequence but to the southeast the clastics thin, the Scar Limestone thickens and its top is less easily recognised. The shales and sandstones separating the Scar and Five Yard Limestones in the northwest thin southeastward, the sandstones failing first then the shales. As the shales thin they become increasingly calcareous and thin limestones appear within them. Farther southeast the thin limestones thicken, the shales separating them from the Scar Limestone fail and the limestones become attached to the top of the Scar Limestone. Where attached, the thin limestones are inseparable from, and included within, the Scar Limestone. The top of the Scar Limestone in the southeast is therefore stratigraphically higher than in the northwest. Carbonate accumulation, terminated in the northwest by influx of terrigenous mud, persisted in the southeast until accumulation of the Five Yard Limestone was complete.

Wilson (1960) considered the sediments overlying the Middle Limestone (i.e. Scar Limestone) in the area around Penhill belong to the Three Yard Cyclothem and that the Five Yard Cyclothem is absent. He suggested the Five Yard Cyclothem was never deposited in this area and that the Middle Limestone may have stood above water whilst the Five Yard Cyclothem accumulated elsewhere. Local increase in thickness of the Middle Limestone on Penhill and the presence of a gannisteroid sandstone and seatearth above the Middle Limestone in Caldbergh Gill (SE 092851) Coverdale, 6 kilometres to the east, were used to support his conclusion. The Five Yard Cyclothem, however, was deposited over this area and there is no lithological evidence to indicate that the Middle Limestone was subaerially exposed. The Five Yard Limestone lies close to the top of the Scar Limestone on Penhill and was included in the upper part of the Middle Limestone (Scar Limestone) by Wilson (1960). The shale separating the Scar and the Five Yard Limestones is poorly exposed but 1.5m of shale, probably with a total thickness of about 2m, is seen near Chantry (SE 054878) on the north side of Penhill. It separates thick bedded crinoidal calcarenites of the Scar Limestone from crinoid-stem calcarenites and calcirudites with depositional dips belonging to the Five Yard

Limestone. The upper beds at Morpeth Scar (SE 029877) and the bryozoan calcarenite at Long Ing Wood (SE 022869) recorded as Middle Limestone by Wilson belong to the Five Yard Limestone. Farther southeast the shale fails completely and the Five Yard Limestone rests directly on the Scar Limestone. This is seen in Great Gill (SE 075840) and Caldbergh Gill (SE 090851), Coverdale. The gannisteroid sandstone and seatearth recorded by Wilson (1960) in Caldbergh Gill above the Middle Limestone are therefore above the Five Yard Limestone.

In the area north of Grassington recognition of the top of the Scar Limestone is not only complicated by thinning of the shale separating the Scar and Five Yard Limestones but also by thickening of the Limestones and stratigraphic lowering of the intra-E_1 unconformity. Black (1950) and Joysey (1955) considered the limestone immediately beneath the Grassington Grit south of Bycliffe was the Middle Limestone. However, the record of Sudeticeras cf adeps (E.W.J. Moore) from Limekiln Lane Quarry (SE 013662) in limestone just beneath the Grassington Grit (Joysey, 1955) is taken by Moore (pers. comm.) to indicate a P_2b age, the Five Yard or possibly the Three Yard Limestone. A thin shale of unknown thickness underlies the limestone and may separate the Five Yard Limestone from the Scar Limestone.

Thin shales also occur in the Scar Limestone. In the east a thin shale is exposed in the Scar Limestone near Chantry (SE 054878) on Penhill and in Caldbergh Gill (SE 091851), Coverdale. The shales exposed at Mossdale Scar (SE 016697) north of Grassington and in Limley Railway Cutting (SE 099764), Nidderdale, may be equivalent to this shale. If this is so then the shale and at least part of the overlying limestone belong to the Scar Limestone. However, if the shales at Mossdale Scar and Limley Railway Cutting are the feather edge of the shales overlying the Scar Limestone, then both the shales and the overlying limestone are above the Scar Limestone. These beds are tentatively included in the Scar Limestone but it is thought that detailed mapping could prove them to overlie the Scar Limestone.

The great variation in thickness of the Scar Limestone over the Askrigg Block from between 1m and 4m in the west to 30m in the east and southeast, although partly due to a longer period of accumulation in the east and southeast (p.191) was controlled mainly by the rate of biogenic carbonate production. There is good correlation between limestone thickness and abundance, size and preservation of crinoid debris, as in the Single Post and Cockleshell Limestones. The limestone is thickest where biogenic carbonate production was greatest, its thickness reflecting essentially in, or near, situ accumulation of biogenic carbonate not current accumulations.

During accumulation of the lower part of the Scar Limestone Gigantoproductus inhabited the northern and eastern part of the Askrigg Block and the area to the north; a similar area occupied by Gigantoproductus in the Cockleshell Limestone. Where the Scar Limestone is thin in the northwest they are usually confined to the lowest bed but in the east and southeast where the Scar Limestone thickens they increase in abundance and occur throughout a greater thickness of limestone. Around Bycliffe and at Limley in Nidderdale Gigantoproductus is particularly abundant in a restricted horizon in the upper part of the Scar Limestone.

In the northeast and central east the beds with Gigantoproductus are cherty and contain an abundant, diverse fauna including Lithostrotion and Clisiophyllidae. The association of an abundant fauna with development of chert was also noted in the Cockleshell Limestone (p.187). It is thought favourable environmental conditions led not only to establishment of an abundant and varied calcareous fauna but also to profusion of siliceous organisms which contributed silica to the sediments. Diagenetic redistribution of this organic silica resulted in the formation of chert nodules (p.376).

After a period of colonisation Gigantoproductus disappear. Although the beds become more coarsely crinoidal failure to compete with a dense population of large crinoids cannot be the main reason for their disappearance because the beds without Gigantoproductus in the northwest are finer and less crinoidal than those with Gigantoproductus in the east and southeast.

In the southeast the lowest beds of the Scar Limestone contain Orbitremites. It is most abundant in the beds capping the uppermost knolls of the Cockleshell Limestone but is also seen to the north and east, though is absent in the south. Both its lateral and vertical distribution is small. The occurrence of Orbitremites in certain thin beds which are lithologically indistinguishable from the beds above and beneath suggests they were only abundant at certain times or they have been concentrated by current sorting.

North of Grassington the beds with Orbitremites pass southwards into a brachiopod biostrome. The brachiopods, still in or near their position of growth, lived just south of the knolls in the upper part of the Cockleshell Limestone.

In the area around Redmire and on the north side of Plover Hill accumulation of the lowest beds was followed by development of calcilutite mounds with trepostomatous and fenestellid bryozoa. After growth to a height up to a few metres the mounds became colonised by abundant crinoids which grew to a large size. Local thickening associated with development of these knolls, which are considered to be bioherms (p.354), is controlled dominantly by in situ accumulation of biogenic carbonate rather than by accumulation of organic debris by currents.

Disappearance of _Gigantoproductus_ in the lower part of the Scar Limestone is followed by appearance of abundant trepostome bryozoa in the area around Bycliffe. They occur throughout a small thickness of crinoidal calcarenites and do not appear to be associated with knoll cores.

In the northwest and central west where the Scar Limestone is thin algae are abundant in a well defined horizon at, or just beneath, the top of the limestone. They occur as oncolites, laminated structures that grew around a nucleus. Ginsburg (1960) considered the major controls on the final external form of algal growths are probably stability of the sediment surface on which growth starts and their strength of attachment to it. If the nucleus is fixed the algae grow upward and laterally into an asymmetric structure. If the nucleus can be overturned or the algal growth broken loose by wave action or organic activity, then lamination can develop on what was the underside. In this way forms with symmetric lamination can develop. The algae in the Scar Limestone belong to Logan et al (1964) stacked spheroids (ss). Many oncolites, especially the larger ones, show greater vertical than lateral growth, a feature which cannot be accounted for by post-depositional compaction, and are often irregular in shape (Plate 11). This asymmetry shows they were not continuously rolled around on the sea floor. Although perfect symmetry is rare, some of the smaller oncolites consist of laminae which are more or less concentric around a nucleus. In order for these symmetric coatings to have developed the nucleus must have been mobile. However, evidence of strong current activity is absent. The crinoid-ossicle calcarenites in which the oncolites occur have a micrite matrix. The layers in oncolites are defined by a couplet of laminae consisting of a dark, organic-rich lamina and a light carbonate-rich lamina (Milliman, 1974). Black (1933) offered three possible explanations for the laminae, rhythmic variations in filament growth with relation to sedimentation, alternation of algal species and sedimentary lamination of mineral particles. Ginsburg (1960) considered the first alternative most likely and subsequent studies have substantiated this (Milliman, 1974). In places algae persist to the top of the Scar Limestone but more commonly they disappear before carbonate accumulation ceased.

The intense bioturbation of the top of the Scar Limestone, even where it is directly overlain by carbonate, probably reflects a temporary reduction or halt in deposition after its accumulation. Where overlain by shale the bioturbated top is pyritic and weathers red.

THE UNDERSET LIMESTONE.

THE UNDERSET LIMESTONE.

SUMMARY.

The Underset Limestone is present over all the area studied except the southern part of the Askrigg Block. In the Barnard Castle Trough it is only 3.65m thick around Bowes but it thickens southwards to 10m in the vicinity of the Stockdale Fault and eastwards to nearly 20m northeast of Richmond. On the Askrigg Block a maximum thickness of 30m is seen at Bishopdale Head and it is more than 15m thick on Abbotside, Askrigg and Muker Commons, Wether Fell, in the region between Bishopdale and Cragdale and on the north slope of Whernside. Its thickness varies locally, the thicker developments occurring where bioherms swell the Limestone. The Limestone thins away from these areas but is rarely less than 5m thick except in the south where it eventually fails. Its absence over the southern part of the Askrigg Block results from non-accumulation except in the area just south of Angram and Scar House Reservoirs where its feather edge has been removed by intra-E_1 erosion.

The Underset Limestone rests on a pavement of sandstone in the central-southern and eastern parts of the Barnard Castle Trough but shale in the north and west. On the Askrigg Block it overlies sandstone over most of the northern, central and western areas except in the north-west where it rests on shale. To the south it sometimes rests on shale but over most of this region and in an area encompassing Penhill and part of Lower Coverdale chert overlies the shale and forms the pavement. The chert is medium to dark grey, laminated, fissile, variably calcareous and shaly and has a characteristic fauna of fenestellid bryozoa, small brachiopods and pelecypods. It is thickest at the heads of Nidderdale,

Coverdale, Waldendale and Bishopdale reaching a maximum of nearly 3m.

The lowest beds of the Underset Limestone are medium to very thick bedded, dark to medium grey crinoid-ossicle calcarenites with a fauna of small brachiopods, dominantly Eomarginifera. Where they overlie the sandstone they are often dolomitised.

A coral biostrome is developed in the lower part of the Limestone except in the eastern part of the Barnard Castle Trough and over the southern and eastern Askrigg Block. Over most of the area only a single coral bed is seen 20cm to 75cm thick and 50cm to 4.1m above the base of the Limestone but in upper Garsdale and parts of Mallerstang and over the northern central part of the Askrigg Block up to four coral beds are developed, separated by crinoid-ossicle calcarenites. The scattered corals seen between these coral beds at some localities show that a single but complex biostrome exists rather than several discrete biostromes.

In the Barnard Castle Trough the single coral bed consists almost entirely of Clisiophyllidae, dominantly Dibunophyllum bipartitum (McCoy), although Diphyphyllum fasciculatum (Fleming) becomes important in the vicinity of the Stockdale Fault. On the Askrigg Block Diphyphyllum is common. It rarely replaces Dibunophyllum as the dominant coral where there is a single coral bed but where the biostrome is complex it is often the dominant coral.

Where the coral biostrome is dominated by Clisiophyllidae the corals are associated with crinoid debris. The clisiophyllids frequently lie on their sides, have imperfect outer dissepimental zones and appear to have been rolled on the sea-floor. Where Diphyphyllum is common the coral biostrome has a calcilutite matrix with sparse crinoid debris and a fauna of small telotrematous brachiopods. In contrast to the Clisiophyllidae, Diphyphyllum occurs in its position of growth. The corals are frequently silicified and chert nodules are common in or near the biostrome.

Above the coral biostrome the Underset Limestone consists dominantly of medium to very thick bedded crinoid-ossicle calcarenites, with scattered chert nodules, abundant bryozoan debris and occasional Gigantoproductus. Locally the calcarenites coarsen and pass laterally into bioherms which swell the limestone thickness.

Bioherms occur over all except the southern and eastern areas on the Askrigg Block and are best developed over the central area. They are also present in the southeastern part of the Barnard Castle Trough. At most localities they appear as unbedded lenses of coarse crinoid-stem calcirudites capped and flanked by thin parted coarse crinoid-stem calcirudites with depositional dips of up to 15° but at others the thin parted coarse crinoid-stem calcirudites cap and flank bryozoan calcilutite mounds. The bioherms are discussed on p. 352.

Corals reappear in number in the upper part of the Underset Limestone and form a biostrome generally 15cm to 30cm thick, but up to 2.5m thick, in an area encompassing Crackpot, Summer Lodge and Carperby Moors and Askrigg Common. It has a fauna of Diphyphyllum fasciculatum (Fleming), Diphyphyllum ingens (Hill), Dibunophyllum bipartitum (McCoy) and Heterophyllia. Most of the corals are silicified and occur in a calcilutite matrix with associated small telotrematous brachiopods.

The upper part of the Underset Limestone is often cherty, especially where overlain by bedded chert, but on Satron Side and in

Great Sleddale most of the upper part of the Limestone is silicified. Here the upper beds are medium to dark grey calcilutites with bryozoa but only sparse to very sparse , small-sized crinoid debris. They contain abundant nodular and disseminated chert which in places is so abundant that only small patches of calcilutite are left surrounded by calcareous chert.

Over much of the area the Underset Limestone is overlain by bedded chert. In the north the chert is separated from the Limestone by 4m of shale but the shale thins to the south. It reaches the north-west part of the Askrigg Block where it is about 1m thick but fails to the southeast and is absent over the rest of the area. The bedded cherts above are variable in thickness. They reach a maximum of about 10m in the central parts of the southern Barnard Castle Trough but thin out and are absent in the northeast. Chert is widely distributed over the northern part of the Askrigg Block but from Garsdale and Wensleydale southwards it is developed only locally. The cherts are very thin to thick bedded, usually medium to dark grey and have a variable carbonate and clay content. Although some of the cherts are flinty with only a very minor carbonate component most are at least slightly calcareous, many are highly calcareous and some are argillaceous and shaly. The cherts often contain shales, usually as thin partings, and occasional calcilutites. Both are usually at least partly silicified. Diagenetic redistribution of silica is common in all the cherts but is most evident in the calcareous cherts and cherty calcilutites where highly siliceous, often flinty nodules, irregular areas or bands occur in a less siliceous matrix. The fauna of the cherts is variable and besides crinoid debris includes small brachiopods including spinose productids, bryozoa, sponge spicules and *Zoophycos*.

THE UNDERSET LIMESTONE.

The Underset Limestone on the Askrigg Block is recorded first in the literature as the Four Fathom Limestone (Sedgwick, 1835) the name introduced by Westgarth Forster (1809), and still used to-day, for the same limestone on the Alston Block. Phillips (1836) called it the Underset Limestone, a name adopted by the Geological Survey during mapping of the Askrigg Block (Ingleborough Memoir, 1890; Mallerstang Memoir, 1891). In the southern part of the Barnard Castle Trough it is usually referred to as the Underset Limestone (Mallerstang Memoir, 1891; Appleby Memoir, 1897; Miller and Turner, 1931; Wells, 1955) although Turner (1935) and Reading (1957) call it the Four Fathom Limestone.

Sedgwick (1835) noticed that the Underset Limestone varies locally, as well as regionally, in thickness and that the thicker developments occur when coarse crinoid debris is abundant. He also recognised development of chert in places above the Limestone which later became known as the Underset Chert (Mallerstang Memoir, 1891).

Sedgwick (1835) thought that on Ingleborough and Penyghent the Four Fathom (Underset) and Twelve Fathom (Main) Limestones were fused but Phillips (1836) recorded the Underset Limestone absent over the southern part of the Askrigg Block and realised that this resulted from non-deposition. This was commented on again by Dakyns in 1891 and 1892.

In the late 1800's Officers of the Geological Survey mapped much of the Askrigg Block and descriptions of the geology including the Underset Limestone are given in the Ingleborough Memoir (1890) and Mallerstang Memoir (1891). Later Tonks (1925) described the succession in Nidderdale but misidentified the Underset Limestone as the upper leaf of the Five Yard Limestone. Subsequently the Main Limestone at Coverhead was misidentified as the Underset Limestone by Chubb and Hudson (1925) and the true Underset Limestone referred to erroneously as the Three Yard Limestone. This correlation was later corrected by Hudson (1933) without explanation.

In 1931 Miller and Turner recorded the Underset Limestone in the area adjacent to the Dent Fault and mapping of the Stainmore Syncline (Reading, 1957), the Middleton Tyas-Sleightholme anticline (Wells, 1955), Wensleydale and adjacent areas (Moore, 1958), the western part of the Askrigg Block (Hicks, 1959), and Coverdale and adjacent areas (Wilson, 1960) documented the Limestone in these regions.

The coral biostrome in the lower part of the Underset Limestone, mentioned by many authors, was specifically commented on by Turner (1954) who showed its distribution over part of the Askrigg Block and Barnard Castle Trough.

THE UNDERSET LIMESTONE.

DETAILS.

To facilitate description of the Underset Limestone the area studied has been divided into six regions, Swaledale and the northeast, Garsdale and the northwest, Dentdale and the southwest, Wensleydale (and its tributary dales), Wharfedale (and its tributary dales) and Nidderdale and the southeast. These areas are shown in Fig. 37.

Swaledale and the northeast.

The Underset Limestone crops out around the sides of Swaledale and its tributary dales from West Stonesdale (NY 885015) and Stockdale (SD 865980) in the west to near Richmond (NZ 160009) in the east and in a small inlier in Great Sleddale (SD 837993). Outcrop is good in upper Swaledale but it deteriorates farther down the dale. Northeast of Swaledale the Limestone can be traced around both flanks of the Middleton Tyas-Sleightholme anticline from Gilmonby (NY 993130) in the northwest to Middleton Tyas (NZ 228058) in the southeast but exposures are sparse except in the south and east.

In the Middleton Tyas-Sleightholme anticline the Underset Limestone crops out best in the east. It is exposed in several small quarries west of Melsonby. In Low Grange Quarry (NZ 186087), 1.3km west of Melsonby, the Underset Limestone is at least 13.5m thick but its base is not exposed. The lowest 7.5m seen are thick to very thick bedded, light grey crinoidal calcarenites. They coarsen upwards and pass into 6m of light grey crinoid-stem calcirudites with depositional dips of up to 15° and scattered chert nodules. In High Grange Quarry (NZ 168080) 650m farther south, 6.8m of thin to very thick bedded

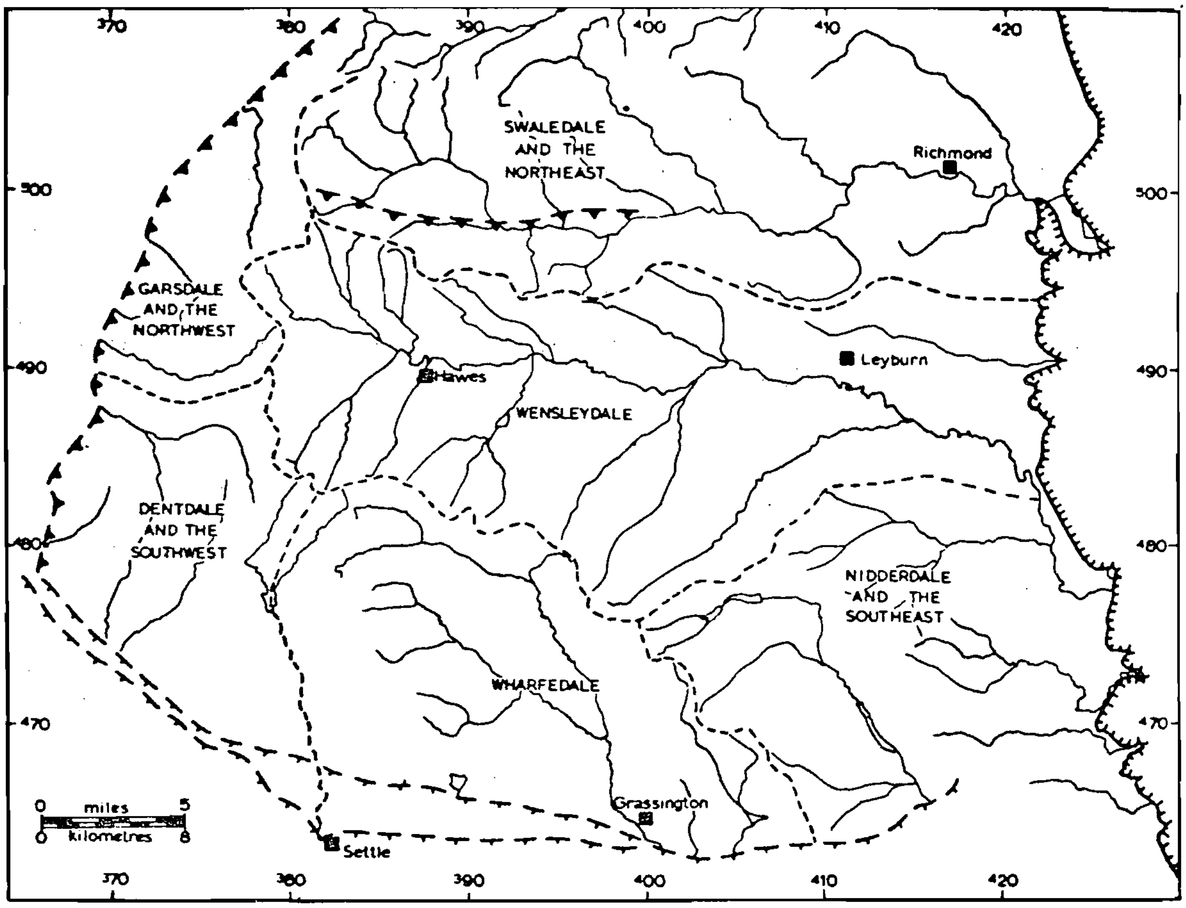


Fig. 37. Areas used for description of Underset Limestone.

crinoid-ossicle calcarenites, dark grey in the lower part but becoming light grey above, rest on gannister. The lowest 1m is intensely dolomitised and weathers orange-brown. A thin tabular chert associated with rare Clisiophyllidae is seen 1.75m above the base.

The roadside quarry (NZ 197082) 200m south of Melsonby exposes 6.7m of medium to thick bedded crinoid-ossicle calcarenites overlain by 2.4m of crinoid-stem calcirudites with depositional dips. Patchily silicified crinoid-stem calcirudites in the upper part of the Limestone also crop out by the roadside and in the beck for 400m east of Melsonby.

The most extensive exposures in this region are in Barton Quarries, 2km east of Melsonby. In Barton Old Quarry (NZ 211081) 4.5m of medium to light grey, medium to very thick bedded crinoidal calcarenites in the lower part of the Underset Limestone are exposed. The upper beds are seen in Barton Quarries (NZ 216083) to the east where 13m of light grey crinoid-stem calcirudites with depositional dips up to 15^{o} are visible. They contain crinoid-stems up to 25cm in length, spirifers and productids, including Gigantoproductus. Chert nodules and irregular silicified patches are common.

In Low Merrybent Farm Quarry (NZ 216083), 1km south of Old Barton Quarry, 12.3m of the Underset Limestone is seen but its base is not exposed. Coarse calcarenites, 2.9m thick and very coarse in the upper part, are overlain by 9.4m of crinoid-stem calcirudites. The upper beds contain scattered chert nodules and a thin nodular chert 9.35m above the base. A similar section in Kneeton Hall Quarry (NZ 214072), 0.75km to the south, shows 10.5m of the Underset Limestone. The lowest 3.75m are thick to very thick bedded crinoid-ossicle calcarenites, overlain by light grey crinoid-stem calcirudites with depositional dips. A localised biostrome 20cm thick with <u>Aulophyllum</u> occurs about 6.5m above the base of the section in the southeastern part of the quarry.

Between Kneeton and Middleton-Tyas there are several small outcrops of crinoid-ossicle calcarenites and crinoid-stem calcirudites but the best exposures are around Middleton Tyas. At Leyberry Plantation (NZ 232059) 15m of coarse crinoidal calcarenites and crinoid-stem calcirudites with depositional dips are overlain by dark grey chert and at Lamberry Bank Plantation (NZ 230057) 10.5m of similar limestones are exposed. An excellent section in Black Scar Quarry (NZ 231052) slightly farther south shows 10.85m of limestone overlain by chert. The lowest 1.85m are coarse crinoidal calcarenites which coarsen upwards and pass into 9m of lenticular bedded, light to medium grey crinoid-stem calcirudites with depositional dips. The calcirudites become cherty in the upper part and contain <u>Hyalostelia</u> spicules and productids. They are overlain by 3.25m of dark grey variably calcareous chert with thin interbedded shales. In the southern part of the quarry a shale 1m thick, which thins out to the north, separates the Underset Limestone from the overlying chert. To the west at "The Rock" (NZ 200047) in Sedbury Park 11.6m of lenticular bedded, light grey crinoidal calcarenites and calcirudites are exposed.

On the southwest limb of the Middleton Tyas-Sleightholme anticline the Underset Limestone is exposed in Skeeby Quarry (NZ 200027) and Oliver Quarry (NZ 183029) where 7m and 4.4m of crinoid-ossicle calcarenites are seen. They contain scattered chert nodules and at Olivers Quarry are patchily dolomitised. Farther northwest in the roadside quarry at (NZ 162035) 5.5m of crinoid-ossicle calcarenites are exposed and in Sturdy House Quarry (NZ 135051) 4.6m of similar beds outcrop. The old quarry (NZ 115055) 1km south of Pace's House shows 3m of crinoid-ossicle calcarenites beneath chert and the small quarry at (NZ 106103) exposes 4.85m of crinoid-ossicle calcarenites.

A good, although incomplete, section is seen in the River Greta at Gilmonby Bridge (NZ 995133). Here the Underset Limestone is a medium to thick bedded, medium grey, sparse crinoid-ossicle calcarenite 3.65m thick, underlain and overlain by shale. Above the Limestone 1.5m of shale outcrops but only the lowest 60cm is well exposed. A 7.6m gap, probably mostly in shale, follows, overlain by at least 3.85m of thin to thick parted, variably calcareous, dark grey, bedded chert.

South of the Middleton Tyas-Sleightholme anticline in Clapgate Beck (NZ 112017), 1.3km northwest of Marske, the Underset Limestone is a medium grey calcarenite at least 3.6m thick. The lowest beds are dolomitised and rest on a thin shale above sandstone. The highest beds are separated by a gap of 1.2m from 3.55m of variably calcareous, thin-parted cherts. The calcareous cherts are shaly at the base and contain nodular diagenetic segregations of silica parallel to the bedding in the upper 1.2m.

To the east at the small quarry (NZ 091025) 0.5km north of Orgate, 6m of crinoid-ossicle calcarenites underlie chert but on the opposite side of Marske Beck at Telfit Bank (NZ 084024) a better section shows the Underset Limestone to be at least 7m thick. It coarsens from a medium grey crinoid-ossicle calcarenite in the lowest 1m into crinoid-stem calcirudites with numerous chert nodules in the upper part and is overlain by 1.65m of chert. The lowest 35cm of chert is dark grey and flinty with large crinoid stems at the base and overlain by 90cm of highly calcareous chert, then 40cm of flinty chert. About 2km farther north at Buzzard Scar (NZ 086042) and at the Scar (NZ 085046) 75m south of Waitgate the Underset Limestone overlies sandstone and is overlain by chert but the sections are slipped. The best outcrop in this area in Rake Beck (NZ 079057), near Rake Gate, shows 7.5m of medium to thick bedded, medium grey crinoid-ossicle calcarenites, dolomitised in the lower part and chertified at the top. A coral biostrome 20cm thick with *Clisiophyllidae*, dominantly *Dibunophyllum*, occurs 2.3m above the base. Dark to light grey, variably calcareous cherts, shaly cherts and cherty shales at least 3.75m thick overlie the Limestone. They contain small brachiopods including spinose productids, brachiopod spines, sponge spicules and *Zoophycos*.

Along Fremington Edge on the east side of Arkengarthdale there are many good sections in the Underset Limestone, a medium grey, medium to very thick bedded, crinoid-ossicle calcarenite. In the southeast (SE 059991) it is at least 9.35m thick and coarse with crinoid stems of rudite size. A coral biostrome 20cm thick with *Dibunophyllum* and *Gigantoproductus* is seen 1.65m above the lowest outcrop but the base of the Limestone is not exposed. The Underset Limestone thins northwestwards to 7.1m at (SE 053996) where the lowest beds, which rest on sandstone, are dolomitised and weather orange-brown. Above these beds *Dibunophyllum* forms a biostrome 30cm thick 1.85m above the base. The Limestone is overlain by at least 2.65m of flinty, calcareous and shaly chert. Several outcrops of limestone and chert occur between this outcrop and the section at (NZ 036011) where the cherts above the Limestone are well exposed (Plate 14). Here an 85cm gap separates non-chertified calcarenites from 75cm of chertified crinoid-stem calcirudites with stems up to 2cm in diameter, overlain by 4.6m of dark grey, very thin to thick parted, variably calcareous cherts. Poor to well defined, extremely siliceous diagenetic segregations form nodules elongated parallel to the bedding in the highly calcareous cherts whilst the less calcareous cherts commonly contain dark grey, slightly bluish, intensely silicified horizons (Plates 14 and 15). Many similar sections are seen along Fremington Edge as at (NZ 035013) where 5m of chert is exposed above the Underset Limestone. The excellent section at (NZ 032016, Plate 16) shows 5.85m of Underset Limestone (resting on sandstone) with the Dibunophyllum biostrome 20cm to 30cm thick 2.05m above its base. The lowest 1.5m is intensely dolomitised and weathers orange-brown. A gap of 35cm separates the Limestone from 7.65m of variably calcareous chert. The Limestone thins to 4.95m at the northwest end of Fremington Edge (NZ 026022) where the lower 1.35m is patchily dolomitised above the sandstone pavement and the coral biostrome, 20cm to 25cm thick with abundant Dibunophyllum, is seen 1.7m above the base. Cherts, 9.25m thick, overlie the Limestone. They are variably calcareous and very thin to very thick parted with very thin to thick interbedded shaly cherts in the middle.

On the west side of Arkengarthdale exposure is poor. In Little Punchard Gill (NY 966044), 3.5m of calcarenite is overlain by at least 3.05m of variably calcareous cherts and farther south, in Reeth Low Moor Quarries (NZ 012008), 3.85m of calcarenite outcrops beneath 3.5m

Plate 14. The Underset Chert, Fremington Edge (NZ 036011), Arkengarthdale. Variably calcareous cherts, the darkest parts being the least calcareous.

Plate 15. The Underset Chert, Fremington Edge (NZ 036011) Arkengarthdale. Highly calcareous chert with chert nodules overlain by darker less calcareous chert.

Plate 16. The Underset Limestone and Chert, Fremington Edge (NZ 032016) Arkengarthdale.

The Underset Limestone, its base brown and dolomitised, overlies sandstone and is overlain by bluish-grey chert.

of calcareous cherts.

On the east side of Gunnerside Gill the Underset Limestone forms Whin Hall Scar (SD 953992) and Low Scar (SD 949987). The coral biostrome 45cm thick, with Dibunophyllum and a thin nodular chert above, is the lowest bed exposed. The Underset Limestone is at least 6.2m thick and has a cherty top. A thin shale separates it from 5.8m of variably calcareous cherts and cherty calcilutites above.

In Gunnerside Gill the outcrop of the Underset Limestone is repeated by faulting and sections are seen at (NY 939010) and (NY 937020). The first locality shows it to be a medium grey, medium to thick bedded calcarenite 8.5m thick with the coral biostrome 2.3m above its base. The biostrome is 40cm thick and contains both Dibunophyllum and Diphyphyllum. Chert overlies the Limestone here but it is seen better farther upstream (NY 937020) where the Limestone is also 8.5m thick and overlies a thin shale resting on a gannister. The coral biostrome is similar in position and thickness but, in addition, a single colony of Diphyphyllum was recorded 50cm beneath. The cherty top of the Underset Limestone is separated by 5cm of shale from 60cm of calcareous chert with Zoophycos, overlain by 1m of shale. A further 80cm of shale and shaly chert succeed the overlying 1.2m of dark grey calcareous chert. Above 3.65m of variably calcareous cherts are exposed, capped by 50cm of very calcareous chert with small highly siliceous nodules.

West of Gunnerside Gill the Limestone is exposed at Low Kisdon (SD 9290983) and around Ivelet Side (SD 913985). At Low Kisdon, the best exposure, it is 9.8m thick, rests on sandstone and is overlain by at least 6.3m of poorly exposed calcareous cherts. The coral biostrome is 2m above the base of the Limestone and 60cm to 70cm thick with abundant Dibunophyllum and sparse Diphyphyllum.

To the west in East Grain (NY 911011) the Underset Limestone thins to 7.65m . The lowest 1.65m is dolomitised and rests on gannister. Dibunophyllum and sparse Diphyphyllum form a biostrome 45cm thick, 2.1m above its base. A thin shale separates the Limestone from 6.25m of dark grey calcareous cherts which are split by 1.75m of shale, 1.95m above their base.

On the south side of Swaledale the most easterly complete section of the Underset Limestone is in Calfhall Wood (NZ 155007), southwest of Richmond. Here it is a medium to very thick bedded, medium grey, sparse crinoid-ossicle calcarenite 4.55m thick. It rests on sandstone and is highly dolomitised at the base but only patchily dolomitised above. A gap of 3m separates the Limestone from at least 2.3m of medium to dark grey calcareous chert with small brachiopods and brachiopod spines.

To the southwest on the north slope of High Harker Hill (SE 020977) it is at least 6.1m thick and of similar lithology but only loose blocks of variably calcareous chert are seen above. The Limestone thickens westwards to 13.3m in Summer Lodge Beck (SD 963954) and Croft Beck (SD 957957) where it also rests on sandstone. The coral biostrome, 25cm to 55cm thick with Dibunophyllum and a few Diphyphyllum, is 2m above the dolomitised base and overlain by 7m of medium to very thick bedded calcarenites. Above the calcarenites another coral biostrome 30cm thick with Diphyphyllum and Heterophyllia and Dibunophyllum in a calcilutite matrix is seen. The following 3.5m of calcarenites which become sparsely crinoidal and cherty in the upper part are overlain by 3.25m of medium to thick bedded cherty calcilutites. Similar sections are exposed along Satron Low Walls (SD 944969) but although sandstone outcrops beneath the Limestone no contact is seen. The lowest 7.75m of the Limestone exposed is a calcarenite with the coral biostrome 75cm thick at the base containing Dibunophyllum and a few Diphyphyllum. Above these beds a 30cm coral biostrome with Diphyphyllum, Dibunophyllum and Heterophyllia in a calcilutite matrix is seen, overlain by 75cm of calcilutite, then 4m of silicified calcilutites. The intensity of silicification varies locally and frequently irregular, highly siliceous patches and nodules are developed in a less siliceous matrix. Crinoid debris in these beds is sparse or absent although bryozoa are seen. The intense silicification of the upper beds disappears to the west and is absent in Stony Gill (SD 924957). Here the coral biostrome, 75cm thick, contains both Dibunophyllum and Diphyphyllum and is 2.2m above the base of the Limestone. It is separated by 6.3m of crinoidal calcarenites from an upper coral biostrome 75cm thick with Diphyphyllum and Dibunophyllum in a calcilutite matrix. Above 1.15m of crinoidal calcilutite is overlain by calcarenites 2.5m thick.

Several of the streams draining Muker Common expose the Underset Limestone. In Duckingtub Gill (SD 906966) it is at least 16m thick but a gap of 85cm separates it from underlying sandstone. Two coral beds 10cm and 15cm thick occur 2.55m and 2.85m above the lowest beds exposed. The lower contains Diphyphyllum, a few Dibunophyllum and Gigantoproductus whereas the upper is packed with Diphyphyllum and contains small brachiopods but only rare Dibunophyllum. Isolated Diphyphyllum colonies occur between the two biostromes. Excepting the calcilutite matrix of the coral biostromes, the lower calcarenites coarsen upwards and pass into 6.35m of crinoid-stem calcirudites. To the east in Greenseat Beck (SD 898966) the Underset Limestone is at least 16.05m thick. The coral biostrome with Diphyphyllum and Dibunophyllum is poorly developed 4.1m above the base and overlain by crinoid-ossicle calcarenites with Gigantoproductus, which coarsen in the upper 2.85m into crinoid-stem calcirudites. The Gill east of Providence Hush (SD 889967) exposes 17.25m of Underset Limestone. The coral biostrome, 15cm thick with Diphyphyllum, a few sparse Dibunophyllum and small brachiopods in a calcilutite matrix, is 4.05m above its base. Gigantoproductus is common just beneath the coral biostrome which is overlain by calcarenites, in places very coarse, containing crinoid stems of rudite size. The outcrop of the Underset Limestone is repeated by faulting in Lover Gill. The most northerly section (SD 880963) shows the coral biostrome 30cm thick with Dibunophyllum resting on 2.3m of calcarenites which are dolomitised in the lower 40cm. Above the coral biostrome 5.3m of crinoid-ossicle calcarenites pass into crinoid-stem calcirudites 1.2m thick, separated from 95cm of similar beds by 2.05m of crinoid-ossicle calcarenites. The uppermost 1.7m are calcarenites which become sparsely crinoidal and cherty in the upper part. The more southerly section (SD 881962), although only 200m away, is different in the upper part. Here the Limestone consists entirely of calcarenites 11.25m thick and is overlain by 3.75m of cherty calcilutites and calcareous cherts.

The outcrops in Cliff Side (SD 878965) and at Cliff Force (SD 875962) are comparable to the northern and southern Lover Gill sections respectively. As in Lover Gill, the Underset Limestone at Cliff

Side, on the left bank of Cliff Beck, overlies sandstone and is dolomitised at the base. Two coral beds are seen 2.45m and 2.95m above the base. The lower is only 10cm thick and consists of scattered Diphyphyllum whereas the upper bed is 30cm thick with both Dibunophyllum and rare Diphyphyllum. Above 5.2m of crinoid-ossicle calcarenites, 90cm of crinoid-stem calcirudites, then 60cm of calcarenite are followed by the uppermost beds, crinoid-stem calcirudites 5.7m thick. Farther upstream at Cliff Force (SD 875962) a similar succession is seen up to the upper coral bed, which reaches 50cm in places, but the overlying calcarenites, 4.7m thick, are succeeded by 2.5m of dark grey calcareous cherts. The crinoid-stem calcirudites seen at Cliff Side (SD 878965), 125m farther downstream, are absent and the Underset Limestone thins from 15.65m at Cliff Side to 11.7m at Cliff Force.

To the northwest in Thwaite Beck (SD 865980) the Underset Limestone is at least 12.1m thick. The coral biostrome with Dibunophyllum is poorly developed about 1.65m above the base and chert nodules are scattered throughout the lowest 8.9m of calcarenites. Coarse calcarenites and crinoid-stem calcirudites 3.2m thick follow separated by a gap of 1.3m from at least 95cm of overlying chert, which becomes shaly towards the top.

Farther northeast at Hooker Mill Scar (SD 894994) the Underset Limestone, a medium grey, medium to very thick bedded calcarenite, thins to 9.9m and overlies sandstone. The coral biostrome, 60cm thick with Dibunophyllum, is seen 1.9m above its base. The top of the Limestone is cherty and overlain by 7m of variably calcareous chert.

In Great Sleddale Beck (SD 837993) the Underset Limestone is also a calcarenite. It varies between 8.5m and 9.25m in thickness because its top is overlain and eroded by a channel sandstone. The lower part of the outcrop is poor but Dibunophyllum is seen near the base of the section. Gigantoproductus is scattered throughout the Limestone which is silicified in the upper part and contains large irregular nodules and stringers of dark grey chert.

Garsdale and the northwest.

In this area the Underset Limestone can be traced around the flanks of Nine Standards Rigg, along the east side of Mallerstang and into Wensleydale. West of Mallerstang it crops out on the flanks of Little Fell, Wild Boar Fell, Swarth Fell and Baugh Fell. Exposure is moderately good except in the vicinity of the Dent Fault where it is poor.

In Faraday Gill (NY 811069), which drains Nine Standards Rigg, a gap of 1.55m separates the Underset Limestone from underlying sandstone. Above the gap 4.3m of calcarenites outcrop with the coral biostrome 80cm thick and containing Dibunophyllum 30cm above the base. About 4.05m of shale separates the Limestone from 4.5m of overlying chert which is thin parted, dark grey and calcareous with small brachiopods including spinose productids.

Farther south in Far Cotes Gill (SD 773969), on the east side of Mallerstang, the Underset Limestone rests on shale. It is a medium to very thick bedded calcarenite 10.2m thick with three coral beds 15cm, 30cm and 7cm thick, 2.7m, 3.25m and 3.7m above the base. The lowest coral bed consists of numerous Dibunophyllum and scattered Diphyphyllum in a calcilutite matrix with shell and crinoid debris whereas the two coral beds above contain abundant Diphyphyllum and a few Dibunophyllum but only sparse bioclastic debris. *Saccaminopsis* is common in the two upper coral beds and rare *Gigantoproductus* is also seen. Chert nodules occur throughout the Limestone but are best developed in and above the coral beds. The top of the Limestone is silicified and overlain by a scree of shaly chert and cherty shale for 1.3m, followed by 80cm of dark grey chert of which the lower 30cm is thin parted.

To the west in Needlehouse Gill (SD 738973) the Underset Limestone rests on sandstone. The lowest calcarenites contain a single coral bed 10cm thick, with *Dibunophyllum*, a few *Diphyphyllum* and chert nodules 2.7m above the base. The coral bed is overlain by 6.6m of crinoid-ossicle calcarenites which coarsen upwards and pass into 3.3m of silicified crinoid-stem calcirudites. A gap of 2.75m separates these beds from 80cm of dark grey chert. The calcirudites are absent in Rawthey Gill (SD 787956) and Slate Gill (SD 733960) 1.5km farther south. Here the Underset Limestone rests on sandstone and is a medium to very thick bedded, medium grey, crinoid-ossicle calcarenite 6.7m and 6.55m thick respectively. In Rawthey Gill (SD 737956) the coral biostrome, with numerous large *Dibunophyllum* and rare *Diphyphyllum*, is 50cm thick and 1.65m above the base but scattered corals are seen both below and above. In Slate Gill the biostrome is 1.4m above the base of the Limestone and 60cm thick with numerous *Dibunophyllum* and *Saccaminopsis*. At both localities chert nodules are common in and near the biostrome. The upper part of the Limestone is cherty and dolomitised and, in Rawthey Gill, separated from 2m of medium to thick bedded, dark grey calcareous chert by 1m of shale. In Slate Gill 2.25m of similar cherts exposed are separated from the Limestone by a gap of 1.25m.

Farther south blocks of Underset Limestone in Nor Gill (SD 708942) and Penny Farm Gill (SD 706932) show it is of similar lithology with the coral biostrome containing Dibunophyllum and Diphyphyllum but the best sections are seen to the southeast along the north side of Garsdale.

In Swarth Gill (SD 731909) the Underset Limestone rests on sandstone and consists of 6.85m of medium to very thick bedded crinoid-ossicle calcarenites. The coral biostrome with Dibunophyllum and Diphyphyllum is 60cm thick and 1.1m above the base. Both nodular and disseminated chert is common throughout, especially in the upper part.

Farther east the Underset Limestone forms two mounds at Greenseat (SD 748905) and Garth Gill Head (SD 763913) but its base is not seen.

At Greenseat the lowest calcarenites contain, in addition to Gigantoproductus and chert nodules, two coral beds 25cm and 30cm thick probably about 1.35m and 2.50m above the base of the Limestone. Although Dibunophyllum and Diphyphyllum occur in both coral beds, Dibunophyllum is more common in the lower whereas the upper is dominated by Diphyphyllum. Above,2m of crinoid-stem calcarenites and calcirudites with chert nodules outcrop. The total thickness of the Underset Limestone is only about 5m. Just west of the mound in Greenside Quarry (SD 746905) at least 1m of dark grey, thin parted,calcareous chert overlies the Limestone with loose blocks of dark grey calcareous cherts above.

At Garth Gill Head (SD 763913) the Underset Limestone is about 9.45m. Here a spring , 1.6m beneath the lowest outcrop, probably marks its base. A lower coral bed 10cm thick with numerous Dibunophyllum and common Diphyphyllum is seen 55cm above the lowest outcrop. This is separated by 25cm of calcarenite from an upper coral bed 25cm thick with

Dibunophyllum and *Diphyphyllum* overlain by 6.7m of thin parted crinoid-stem calcarenites and calcirudites. Scattered chert nodules are seen throughout the succession but are especially common near the coral beds.

Crinoid-stem calcarenites and calcirudites disappear to the east and in Grisedale (SD 760938) the Underset Limestone is a sparse calcarenite at least 7.6m thick. Its base is not exposed but four coral beds 15cm, 25cm, 30cm and 20cm thick are seen, 60cm, 1.05m, 1.55m and 2.35m above the lowest outcrop respectively. The lowest contains *Diphyphyllum* and small brachiopods in a calcilutite matrix whereas those above contain both *Dibunophyllum* and *Diphyphyllum*. Scattered *Dibunophyllum* and *Diphyphyllum* also occur just above the uppermost biostrome and *Gigantoproductus* is seen in the lower beds. The Limestone contains scattered chert nodules and has a cherty top. On the opposite side of Grisedale in Flust Gill (SD 770942) 4.1m of the Underset Limestone is exposed above sandstone. *Dibunophyllum* is scattered throughout the lowest beds but two coral beds, one 20cm thick with *Dibunophyllum* and one 25cm thick with *Dibunophyllum* and *Diphyphyllum*, are seen 2.1m and 2.8m above the base respectively.

Dentdale and the southwest.

In this region the Underset Limestone is confined to the higher ground. It crops out around the flanks of Rise Hill, Widdale Fell, Whernside, Crag Hill, Great Coombe, Green Hill and on the north slope of Park Fell but is absent on Ingleborough farther south. Small outliers are seen at High Pike and Blea Moor. The outcrops at Gayle Wolds, west of Cam End, are also included in this area.

On the north side of Dentdale the Underset Limestone forms mounds at Aye Gill Wold (SD 743878) and Thorn Wold (SD 749880). At Aye Gill Wold it is about 11.5m thick but the lowest beds are not exposed and exposure of the upper beds is poor. A 30cm coral bed with Dibunophyllum and Diphyphyllum, probably about 1.7m to 2.3m above the base of the Limestone, overlies the lowest 10cm of calcarenites seen. It is overlain by a thin nodular chert and crinoid-ossicle and crinoid-stem calcarenites and calcirudites of which only the lowest 3.3m are well exposed. The feature formed by the Limestone shows it to thin to the west and east but to thicken again 0.75km to the northwest into a small mound on Thorn Wold (SD 749880). Here a 1.5m gap separates the lowest beds exposed from the underlying sandstone. The coral biostrome, 25cm thick, is 60cm above the lowest calcarenites exposed and contains Dibunophyllum, Diphyphyllum in places and small brachiopods. It is overlain by 2.65m of crinoidal calcarenites and crinoid-stem calcirudites. Thin nodular cherts rest on top of, and occur 20cm beneath, the coral biostrome. East of Thorn Wold, around the east end of Rise Hill, the feature formed by the Underset Limestone disappears.

On the southwest end of Widdale Fell, the Underset Limestone is exposed in Kel Beck (SD 775870). It is a medium to thick bedded, medium grey crinoid-ossicle calcarenite 9.95m thick and rests on sandstone. Its cherty top is overlain by at least 2.6m of thin-parted calcareous cherts and cherty calcilutites with small brachiopods and fenestellid bryozoa.

To the southeast, west of Cam End, the Underset Limestone is exposed at Gayle Wolds. The coral biostrome is about 80cm above the base of the Limestone and 40cm thick with Dibunophyllum, and a thin nodular chert above. The Limestone rests on shaly chert and is a calcarenite at least 9.7m thick with scattered chert nodules.

In the southwest, on the west side of Barbon Fell (SD 686833) the Underset Limestone swells locally in thickness to over 15m and forms a mound. The base of the Limestone is not exposed but the coral biostrome appears absent. The Limestone coarsens upwards from crinoid-ossicle calcarenites in the lower part into crinoid-stem calcarenites and calcirudites.

The Underset Limestone is also locally thick at Binks (SD 709836) about 2km farther east but its base is not exposed. Gigantoproductus is common about 2m to 3m above its base but the coral biostrome appears absent. The lower beds, crinoid-ossicle calcarenites, coarsen upwards and pass into calcirudites with large crinoid-stems which occasionally show a sub-parallel orientation. The calcirudites are chertified in the upper part with thin, highly chertified bands every 20cm in the upper 1.8m. Above, 40cm of chert with abundant crinoid-stems is overlain by 1.2m of dark grey flinty chert with occasional small lenses of crinoid debris, followed by 55cm of dark grey calcareous chert with spirifers, productids and bryozoa. The uppermost bed, a highly calcareous chert 35cm thick, is overlain by shale. From here the Underset Limestone thins to about 8.5m at Little Binks (SD 706832) only 0.5km to the southwest where lower calcarenites coarsen upwards into crinoid-stem calcirudites overlain by chert.

Although absent at Binks, the coral biostrome is up to 40cm thick at High Pike (SD 717826), 1.3km to the southeast. It is about 80cm above the base of crinoidal calcarenites with bryozoa and contains Dibunophyllum, Diphyphyllum and rare Syringopora.

The Underset Limestone thickens northeastwards to over 16m on the north slopes of Whernside. The lowest beds are exposed above some of the small springs which issue from the base of the Limestone. They are crinoid-ossicle calcarenites with bryozoa and the coral biostrome 1m to 1.35m above their base. The biostrome is 25cm thick and contains both *Dibunophyllum* and *Diphyphyllum*. The upper beds are thin parted crinoid-stem calcarenites and calcirudites. They are especially coarse and thickest at each end of Great Wold where the top of the Limestone is mounded and depositional dips of up to 15° are seen. The mounds are up to 250m in diameter, although usually less than 200m, and close together. They swell the thickness of the Limestone from a minimum of about 6.6m in the centre of Great Wold to at least 15.2m in the west and 16.1m in the east. Unfortunately the middle of the section is not well exposed but the walls nearby contain many blocks of calcilutite with trepostone and some fenestellid bryozoa, identical in lithology to mound cores elsewhere (p.352). As the walling stones certainly come from the Underset Limestone it seems likely that the crinoid-stem calcarenites and calcirudites are cored by bryozoan calcilutite mounds.

South of Great Wold the Underset Limestone thins rapidly to only 3m in Force Gill (SD 751824) where it is a medium grey, thick bedded crinoid-ossicle calcarenite. It rests on sandstone and has two tabular cherts 21cm and 12cm thick with very irregular lower margins, 45cm and 65cm above its base. The coral biostrome, 45cm thick with *Dibunophyllum*, occurs 85cm above the base. The top of the Underset Limestone is burrowed.

Further thinning occurs to the south and at Coombe Scar (SD 781796) and Two Gills Foot (SD 729793) it is 2.35m thick. At both localities it is a very thick bedded, medium grey, crinoid-ossicle calcarenite but at Coombe Scar it rests on sandstone whereas in Two Gills Foot it overlies shale. At Two Gills Foot two thin cherty horizons are seen, 50cm and 70cm above the base and a coral bed 15cm thick with Dibunophyllum occurs 1m above the base.

South of Whernside the Underset Limestone crops out only on Park Fell where it is poorly exposed but seen best on Fell Close (SD 765773). The badly weathered outcrop shows an orange-brown decalcified limestone, less than 1m thick and with spirifers, overlying shale. It thins out completely to the south and on Ingleborough is absent.

Wensleydale.

In this region the Underset Limestone crops out on both sides of Wensleydale from the head of the dale to just east of Middleham where it disappears beneath the valley floor. Its northern outcrop is generally parallel to the River Ure except near the head of Wensleydale where it passes around the sides of Cotterdale and Fossdale. Its southern outcrop follows the sides of the tributary dales which deeply dissect the south side of Wensleydale.

On the north side of Wensleydale at the head of the dale the Underset Limestone is well exposed in Shaws Gill (SD 796948), Johnson Gill (SD 808939) and Tarn Gill (SD 810934). It is a medium grey, medium to very thick bedded crinoid-ossicle calcarenite, 5.7m, 8.35m and 4.9m thick respectively. The coral biostrome with Dibunophyllum is 35 cm to 45 cm thick and 1.1m to 1.35m above the base of the Limestone. At all three localities the top of the Limestone is cherty and overlain by chert. In Shaws Gill the chert is 6.2m thick with a crinoidal calcilutite 50cm thick above. The lower 4m are thin bedded and calcareous whereas the upper part is flinty. In Johnson Gill 1.65m of highly siliceous chert, then a similar thickness of calcareous chert with scattered crinoid-ossicles are seen and in Tarn Gill 5.8m of thin parted, variably calcareous cherts overlie the Limestone.

In Cotterdale the Underset Limestone is of similar lithology and also overlies sandstone. It is 6.05m thick in Benton Gill (SD 822952) and 7.6m thick in West Gill (SD 822956) with Dibunophyllum scattered 1.5m to 2.4m above the base. A nodular chert up to 10cm thick is associated with the corals and the upper part of the Limestone is cherty. The overlying cherts are calcareous and fissile in the lower part but flinty and blocky above. They are seen best in West Gill where they are 3.8m thick and overlain by 1m of calcilutite with Zoophycos. East of Cotterdale the poor exposures in Fossdale (SD 865936, SD 864937) show the Underset Limestone thickens to about 9m. The coral biostrome with Dibunophyllum is seen above the base but there is no sign of chert above the Limestone.

On the south side of Stags Fell the Underset Limestone is a crinoid-ossicle calcarenite which coarsens upwards. At Low Clint (SD 872925) it is 12.8m thick with a single bed of Dibunophyllum and/or Diphyphyllum just above the base in the west but with several coral beds elsewhere. In most places Dibunophyllum is scattered throughout the lowest part of the Limestone but also forms two coral beds each 20cm thick, 1.35m and 1.8m above the lowest outcrops. A thin nodular chert often marks the top of the uppermost bed which is overlain by 60cm of calcarenite with occasional Gigantoproductus, then two more coral beds 40cm apart, the lower

15cm thick, the upper 10cm thick. Both contain Diphyphyllum as the dominant coral and sparse Dibunophyllum.

Between Low Clint (SD 872925) and Little Fell Clint (SD 891920) Dibunophyllum and Diphyphyllum are common from 90cm to 2.2m above the dolomitised base of the Limestone. Diphyphyllum is dominant in the lowest 40cm whereas Dibunophyllum is most common above. A thin nodular chert overlain by 70cm of calcarenite separates these beds from another coral bed, 10cm thick, with numerous Diphyphyllum and a few Dibunophyllum. Gigantoproductus and small chert nodules are scattered throughout the lowest part of the Limestone.

The Limestone thickens from at least 13.5m at Little Fell Clint to 16.95m at Whitfield Scar (SD 928928) where the lowest 60cm is dolomitised and overlain by 2m of calcarenites with Dibunophyllum and occasional Diphyphyllum. Above 4.55m of calcarenites with chert nodules in the upper part are overlain by 1.5m of crinoid calcirudites, then 5.8m of crinoid-ossicle calcarenites. A 15cm thick coral biostrome with Diphyphyllum in a calcilutite matrix overlies these beds followed by a further 75cm of calcarenite then crinoid-stem calcarenites 1.5m thick.

At Ellerkin Scar (SD 962922) the Underset Limestone is even thicker; at least 20m in the east and 22m in the west.
In the west Diphyphyllum forms the lowest coral bed which is 10cm thick and 1.6m above the base. The overlying 1.7m of calcarenites contain scattered Dibunophyllum in all but the lowest 45cm and are overlain by a 25cm thick coral bed with both Diphyphyllum and Dibunophyllum. At the east end of the Scar Dibunophyllum is scattered for 1.8m, 4.25m above the base of the Limestone, beneath a 15cm thick coral

bed with *Diphyphyllum*. Above, the beds coarsen rapidly and pass into a lenticular development of coarse crinoid-stem calcarenites and calcirudites 7m thick. These beds are overlain by 2.45m of calcilutites with scattered crinoid debris and nodules and stringers of chert, then 70cm of calcarenite with *Dibunophyllum* in all but the uppermost 15cm and a well developed coral biostrome 15cm to 40cm thick with *Diphyphyllum* and *Dibunophyllum* in a calcilutite matrix. The overlying 5.7m of calcarenites become very cherty and at the top of the Scar are overlain by at least 1m of dark grey bedded chert.

The Underset Limestone is similar in lithology at Ivy Scar (SD 987904) and about 17.65m thick. In the east two coral beds are seen 2.5m and 3.1m above the base of the Limestone. The lower is 20cm thick with scattered small *Dibunophyllum* whilst the upper is 25cm thick and contains numerous *Dibunophyllum* and *Diphyphyllum*. Above, 7.4m of calcarenites pass into 1.65m of crinoid-stem calcirudites, overlain by 3.45m of sparse calcarenites packed with *Dibunophyllum* and *Diphyphyllum*. Chert nodules and stringers become common, although scattered nodules are seen throughout the succession. The corals die out in the lowest part of the 2.6m of overlying calcarenites. The beds, more than 11m above the base of the Limestone, coarsen towards the west and pass laterally into crinoid-stem calcirudites.

From Ivy Scar (SD 987904) the Underset Limestone thins eastwards to about 5.35m at Low Scar (SE 051923), Redmire. Its base is not exposed but a coral bed 75cm thick with *Dibunophyllum* and very poor *Diphyphyllum* is seen 1.85m above the lowest exposure. The Limestone is a calcarenite throughout except in a bed 35cm thick, 3.25m above the base, where the lower 25cm is a crinoid-stem calcarenite which grades into a crinoid-stem calcirudite. Cherts 3.85m thick overlie the Limestone, the lower 1.15m being calcareous, the upper 2.7m flinty.

On the opposite side of the dale the Limestone is exposed in the bank of the River Cover east of Hullo Bridge (SE 122865). Here it is a very thick bedded, medium grey calcarenite only 3.1m thick resting on sandstone. The coral biostrome is absent but cherts are developed above the Limestone. The lowest 40cm of chert, thin parted and somewhat shaly, is overlain by 15cm of dark grey calcareous chert, then 1.9m of calcareous chert with highly siliceous nodules and stringers. The uppermost cherts are about 1m thick and dark grey and flinty with traces of lamination. To the southeast at Elm Gill (SE 094853) 1.1m of very thin parted calcareous chert separates the Underset Limestone from the sandstone beneath. It is dark grey with a fauna of fenestellid bryozoa and small brachiopods and pelecypods. The lowest 8m of the overlying Limestone are thick to very thick crinoid calcarenites which coarsen upwards and pass into 45cm of crinoid-stem calcirudite with a cherty top, followed by 1.5m of thin parted calcareous chert, then 1.8m of chertified crinoid-ossicle and -stem calcarenites and calcirudites. A cherty shale 15cm thick separates these beds from 60cm of blocky laminated chert.

In Fleemis Gill (SE 029821) only the lowest 1.2m of the Underset Limestone, a patchily dolomitised calcarenite, is exposed above shale but farther southeast cherts are seen again beneath the Limestone. The sections in West Gill (SE 011791) and Downs Gill (SE 006786) expose 60cm and 55cm of very thin parted calcareous chert with fenestellid bryozoa and small brachiopods beneath the Underset Limestone, a calcarenite

3.35m and 2.75m thick respectively, with scattered chert nodules and a cherty base and top. Farther southeast the cherts thicken to 1.6m in East Stone Gill (SD 990772) where they underlie 5.5m of calcarenite. In Hazel Bank Gill (SD 991773) 75cm of similar chert is exposed beneath 3.7m of calcarenite.

On the north flank of Penhill the Underset Limestone crops out near New Plantation (SE 046876) and at Low Dove Scar (SE 034876). At New Plantation it is about 4m thick. No cherts are seen beneath but loose blocks occur above the section. At Low Dove Scar 1.2m of very thin parted, dark grey calcareous chert with a fauna of small productids and fenestellid bryozoa underlie the Limestone, a calcarenite 8m thick with scattered chert nodules. It contains two coral beds, the lower 20cm thick with a few Dibunophyllum and Gigantoproductus 90cm above the base and a better developed bed 30cm thick with Dibunophyllum and Diphyphyllum 2.35m above the base. Above the Limestone 1.2m of chert is poorly exposed, the lowest 60cm being thin parted and calcareous with Zoophycos, the upper 60cm flinty and dolomitised.

A good section is seen at the Waldendale Head where 1.4m of very thin parted, dark grey calcareous cherts are seen beneath the Underset Limestone. Above,8.4m of medium grey, medium to very thick bedded, crinoid-ossicle calcarenites, quite coarse in places and with spirifers and trepostome bryozoa locally common, are overlain by 3.6m of calcareous chert.

At the head of Bishopdale the Underset Limestone thickens to 31.35m at Dale Head Scar (SD 955805). It is a calcarenite in the lower part with chert nodules and Gigantoproductus but coarsens upwards into coarse crinoid-stem calcarenites and calcirudites with spirifers.

Beneath the Limestone 1.25m of chert is exposed above shale.

An even better section is seen on the opposite side of the Dale at Kidstones Scar (SD 946813) where the Limestone is at least 20m thick. The underlying beds, seen best in Cray Gill (SD 940808) by the side of Stake Road (Plate 17), are fissile calcareous cherts 1.9m thick with a fauna of small brachiopods and fenestellid bryozoa. The lowest 3m of the Underset Limestone are crinoidal calcarenites with a thin nodular chert 50cm to 1m above the base. They coarsen above into lenses of unbedded crinoid-stem calcirudites, commonly 25m but up to 100m in length and 4m to 10m thick, capped and flanked by thin parted crinoid-stem calcirudites and calcarenites with depositional dips of up to 20° (Plates 18 and 19). Abundant spirifers and occasional Gigantoproductus are seen in these beds.

In Back Gill (SD 944822) 2.95m of calcareous chert, fissile in the lowest 2.25m, underlies the Underset Limestone, here 26.4m thick and coarsening rapidly from calcarenites at the base into crinoid-stem calcarenites and calcirudites above. At High Scar (SD 956843) neither the top nor base of the Limestone is exposed but it is at least 19.1m thick and similar in lithology to Back Gill. The lower 4.3m, medium to very thick bedded and dolomitised at the base, is overlain by lenticular bedded calcirudites.

To the north the Underset Limestone forms the summit of Addleborough (SD 945882). It is at least 14m thick but the base of the Limestone is not seen. Two to three coral beds each 10cm to 20cm thick with Diphyphyllum and Dibunophyllum are seen with chert nodules in the lowest 4.2m of calcarenites exposed, the lowest coral bed about 2m above

Plate 17. The Underset Limestone, Cray Gill (SD 940808), Wharfedale. Thin parted, medium to dark grey, calcareous cherts underlying lighter weathering, medium to thick bedded calcarenites at the base of the Underset Limestone. The upper beds of the Limestone are exposed in the left background.

Plate 18. The Underset Limestone, Kidstones Scar (SD 946813), Bishopdale. The best exposure showing lenticular bedding in the middle and upper parts of the Underset Limestone.

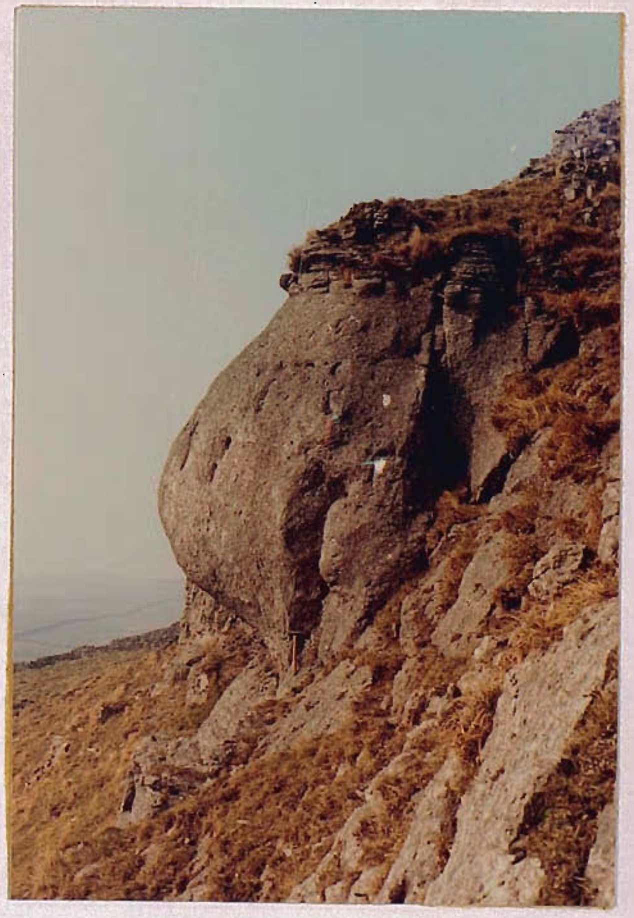


Plate 19. The Underset Limestone, Kidstones Scar (SD 946813), Bishopdale. A lens of unbedded crinoid-stem calcirudite capped and flanked by thin parted crinoid-stem calcarenites and calcirudites in the upper part of the Limestone.

the base. The overlying beds become coarser and are crinoid-ossicle and -stem calcarenites and calcirudites with spirifers and bryozoa. Near the top of the section small isolated outcrops of calcilutites with both fenestellid and trepostome bryozoa and variable contents of crinoid debris are seen which, by comparison with other sections (see below), are undoubtedly mound cores.

Mounds are also seen in the Underset Limestone on the Haws (SD 926853) about 3km southwest of Addleborough where they form small hillocks. Although not mapped during this study at least 20 mounds can be recognised by their topographic expression but all are poorly exposed. The most complete section shows 2.2m of medium to thick bedded, medium grey, crinoid-ossicle calcarenites overlain by 12.4m of medium to light grey crinoid-stem calcarenites and calcirudites, medium to thick bedded in the lower 3.7m but thin parted above. Spirifers are common in the upper beds.

At Greenscar (SD 923830), farther south, 9.9m of calcarenites which coarsen upwards and contain trepostome bryozoa overlie sandstone. The lower part of the Limestone is dolomitised and has a 20cm thick coral bed with Dibunophyllum and small brachiopods 50cm above its base. The coral bed has a similar position and fauna in Thornrake Gill (SD 913820) and thickens to 50cm. Here the Underset Limestone is at least 16.15m thick with numerous small brachiopods in the cherty lowest 1m. The calcarenites coarsen above the coral bed and pass into crinoid-stem calcarenites and calcirudites with trepostome bryozoa and spirifers.

At the head of Raydale on Wold Side (SD 883829) the Underset Limestone is at least 16.25m thick but its base is not exposed. The lower beds, exposed in Outershaw Gill (SD 883827). are calcarenites dolomitised at the base and cherty above. They are overlain by 1.5m of thin bedded crinoid-stem calcirudites then 1.1m of calcarenites. A lens of bryozoan calcilutite 1m thick capped by 3.5m of crinoid-stem calcirudite is seen above. The upper beds, exposed elsewhere along Wold Side, consist of crinoid-stem calcarenites and calcirudites with trepostome bryozoa and spirifers.

West of Raydale, at Scout Crag (SD 878865), the lowest beds seen are calcarenites with chert nodules and a 20cm thick coral biostrome with both Dibunophyllum and a few Diphyphyllum 85cm above their base. The Underset Limestone is at least 14.85m thick and coarsens from bedded crinoid-ossicle calcarenites to crinoid-stem calcirudites in the upper 3m.

A similar upward coarsening succession is seen in Yorburgh (SD 887882) farther south where the Underset Limestone is about 18.15m thick. Its base is not exposed but Diphyphyllum is seen about 2m above the lowest outcrop. The upper beds are coarse crinoid-stem calcarenites and calcirudites with trepostome and fenestellid bryozoa and spirifers.

On the opposite side of Sleddale 13.45m of the Underset Limestone crops out at Great Scar (SD 851877) on Ten End. A coral biostrome 20cm thick with Dibunophyllum, small brachiopods and chert nodules is seen 1.2m above the lowest exposure. The lowest beds, calcarenites with a nodular chert 1.75m above the coral bed, coarsen upwards into crinoid-stem calcarenites.

At the head of Sleddale in Bank Gill (SD 847845) the Underset

Limestone is only 4.85m thick. It is a thick to very thick bedded crinoid-ossicle calcarenite and overlies a thin shale. A coral bed 50cm thick with both Dibunophyllum and Diphyphyllum is seen 1m above the base. Whereas Diphyphyllum is most abundant in the lower part Dibunophyllum is dominant above. The top of the Limestone is cherty and overlain by 3.8m of thin-parted, dark grey calcareous cherts. They are shaly in places and overlain by 65cm of cherty burrowed calcarenite, then 50cm of shaly calcilutite with crinoid debris.

On the west side of Dodd Fell 12m of the Underset Limestone outcrops at Bousty Nest Scar (SD 831842). Its base is not exposed but the coral bed, with Dibunophyllum and numerous small brachiopods, is 20cm thick and 65cm above the lowest outcrop. The lower calcarenites contain a thin nodular chert 30cm above the coral bed and coarsen upwards into crinoid-stem calcarenites and -calcirudites.

To the west the Underset Limestone is at least 13.2m thick and forms the summit of Snaizeholme Fell. Its base is dolomitised and rests on 1m of thin-parted, shaly, dark grey, calcareous chert which, in turn, overlies sandstone and is best exposed in the southeast (SD 816847). The lowest calcarenites contain a 20cm coral bed with Dibunophyllum, Diphyphyllum and small brachiopods 1.5m above their base. Small brachiopods, dominantly productids, are common in the calcilutite matrix of the coral bed and in the overlying 80cm of calcilutite which contains scattered corals. The calcarenites above coarsen into crinoid-stem calcarenites and -calcirudites but these pass into calcarenites in the upper part of the Limestone.

The Limestone thins to the northwest and in Widdale Foot Gill

(SD 816887) on the northwest side of Widdale it is a medium grey, medium to thick bedded calcarenite only 4.2m thick. The coral biostrome with Dibunophyllum is 50cm thick and 1.05m above the lowest outcrop which is separated from underlying sandstone by a gap of 80cm. Although there is no evidence of chert above the Limestone on Snaizeholme Fell, here 5.25m of medium to thick bedded, dark grey, calcareous chert with flinty patches is developed. The lower part which contains crinoid debris, like the upper part with Zoophycos, is highly calcareous.

Wharfedale.

In this region the Underset Limestone crops out around the sides of Langstrothdale and around upper Wharfedale as far south as Park Gill Beck (SD 990752). It is also seen in upper Littondale but it thins southwards and is absent on Penyghent and Fountains Fell. Although the most southerly outcrop of the Underset Limestone is in Park Gill Beck, Wharfedale, it is recorded farther south in Providence Mine (Phillips, 1836).

The Underset Limestone forms a line of scars along the side of Langstrothdale but the best section is in Deepdale Gill (SD 899815) where it is at least 17.5m thick and separated from 60cm of underlying fissile, dark grey, calcareous chert with fenestellids and small brachiopods by a gap of 30cm. The chert rests on sandstone. The lowest part of the Limestone consists of medium to very thick bedded, medium grey, crinoid-ossicle calcarenites with a thin nodular chert 1.4m above their base. Diphyphyllum forms a biostrome 20cm thick 1.75m above the lowest outcrop and Dibunophyllum is scattered for 50cm beneath. The calcarenites above the biostrome contain sparse scattered Gigantoproductus and coarsen upwards into crinoid-stem calcirudites which constitute most of the Limestone.

In Littondale, south of Deepdale, the Underset Limestone is exposed in Halton Gill (SD 883775). It overlies 65cm of shaly calcareous chert with irregular lenses of cherty calcilutite underlain by cherty sandstone and shales. A gap of 1.65m separates the lowest bed of the Limestone, 35cm of calcilutite with scattered crinoid debris, from 9.9m of crinoidal calcarenites which coarsen into crinoid-stem calcirudites in the upper part. South of Littondale the sections on Penyghent and Fountains Fell show the Underset Limestone has thinned out completely and is absent.

The Underset Limestone also thins southwards along the east side of Wharfedale from over 30m on the north slope of Buckden Pike at Dale Head Scar (SD 955805; p.231) to only 1.8m in Providence Mine (Phillips, 1836; Ingleborough Memoir, 1890; Dakyns 1892; Chubb 1926). This southward thinning is accompanied by a decrease in size of the constituent crinoid debris and an increase in calcilutite matrix. Wilson (1960) recorded 5 feet (1.5m) of limestone in Lime Kiln Pasture (SD 983754) and noted that farther west at Diamond Hill (SD 980753) chert occurs above, and possible beneath, the Limestone which is not exposed. The best section in this area, and the most southerly outcrop of the Underset Limestone, is in Park Gill Beck (SD 990752) where at least 80cm of medium to dark grey, sparse crinoid-ossicle calcarenite overlies 1.5m of dark grey calcareous chert with spirifers. A gap of 1.8m separates the cherts from a further 60cm of underlying calcareous chert beneath which is a 3m gap then the Three Yard Limestone. Although the Underset Limestone is not exposed farther south it was recorded in Providence Mine (Phillips, 1836 ; Ingleborough Memoir, 1890; Dakyns,1892 ; Chubb, 1926) where it overlies shale from which Chubb recorded fenestellid bryozoa. As fenestellids are a characteristic faunal element of the fissile calcareous cherts underlying the Underset Limestone, their presence in Providence Mine at this level suggests that the shales are probably cherty.

Nidderdale and the southeast.

In this area the Underset Limestone crops out only around Angram Scar House Reservoirs.

Several of the small streams flowing into Angram Reservoir expose the Underset Limestone. The section in Crook Dyke (SE 026761) shows 4.25m of medium grey, crinoid-ossicle calcarenite overlying medium to dark grey, shaly calcareous chert. Another good section is exposed near the head of Scar House Reservoir (SE 046766) where 2.6m of cherty crinoid-ossicle calcarenite is underlain and overlain by 2.6m and 1.2m of dark grey shaly chert respectively. Farther east in the River Nidd (SE 071769) the Underset Limestone is a crinoid-ossicle calcarenite 4m thick underlain by 1.7m of shaly chert.

FIGURED SECTIONS OF THE UNDERSET LIMESTONE.

1.	Low Grange Quarry	NZ 186087	27.	Lover Gill	SD 880963
2.	High Grange Quarry.	NZ 186080	28.	Cliff Side	SD 878965
3.	Barton Quarry.	NZ 216083	29.	Cliff Beck	SD 875962
4.	Low Merrybent Farm Quarry	NZ 211077	30.	Thwaite Beck	SD 865980
5.	Kneeton Hall Quarry	NZ 214072	31.	Hooker Mill Scar	SD 894994
6.	Black Scar Quarry	NZ 231052	32.	Great Sleddale Beck	SD 837993
7.	Clapgate Bridge	NZ 112017	33.	Faraday Gill	NY 811069
8.	Rake Gate	NZ 079057	34.	Far Cotes Gill	SD 773969
9.	Gilmonby Bridge	NY 995133	35.	Needlehouse Gill	SD 738973
10.	Telfit Bank	NZ 084024	36.	Rawthey Gill	SD 737956
11.	Fremington Edge	NZ 032016	37.	Slate Gill	SD 733960
12.	Fremington Edge	NZ 026022	38.	Swarth Gill	SD 731909
13.	Little Punchard Gill	NY 965044	39.	Green Seat	SD 748905
14.	Reeth Low Moor Quarries	NZ 012008	40.	Garth Gill Head	SD 763913
15.	Low Scar	SD 949997	41.	Grisedale	SD 760938
16.	Gunnerside Gill	NY 937020	42.	Flust Gill	SD 770942
17.	Low Kisdon	SD 920983	43.	Aye Gill Wold	SD 743878
18.	East Grain	NY 911011	44.	Thorn Wold	SD 749880
19.	Calfhall Wood	NZ 155007	45.	Kel Beck	SD 775870
20.	High Harker Hill	SE 020977	46.	Great Wold End	SD 742847
21.	Summer Lodge Beck	SD 963954	47.	Binks	SD 709836
22.	Satron Low Walls	SD 944969	48.	Barbon High Fell	SD 686833
23.	Stony Gill	SD 924957	49.	Force Gill	SD 751824
24.	Duckingtub Gill	SD 906966	50.	Coombe Scar	SD 731796
25.	Greenseat Beck	SD 898966	51.	Two Gills Foot	SD 729793
26.	Gill east of Providence Hush.	SD 889967	52.	Fell Close	SD 765773

53.	Little Wold	SD 811832
54.	Shaws Gill	SD 796948
55.	Johnston Gill	SD 803939
56.	Tarn Gill	SD 810934
57.	Benton Gill	SD 822952
58.	West Gill	SD 822956
59.	Low Clint	SD 872925
60.	Little Fell Clint	SD 891920
61.	Whitfield Scar	SD 928928
62.	Ellerkin Scar	SD 962922
63.	Ivy Scar	SD 987904
64.	Low Scar	SE 051923
65.	River Cover	SE 122865
66.	Elm Gill	SE 094853
67.	East Stone Gill	SD 990772
68.	Hazel Bank Gill	SD 991773
69.	Downs Gill	SE 006786
70.	West Gill	SE 011791
71.	New Plantation	SE 046876
72.	Low Dove Scar	SE 034876
73.	Walden Head	SD 974790
74.	Dale Head Scar	SD 955805
75.	Kidstones Scar	SD 946813
76.	Back Gill	SD 944822
77.	High Scar	SD 956843
78.	Addleborough	SD 945882
79.	Green Scar	SD 923830
80.	Thornrake Gill	SD 913820
81.	Wold Side	SD 883829
82.	Scout Crag	SD 878865
83.	Yorburgh	SD 887882
84.	Bank Gill	SD 847845
85.	Great Scar	SD 851877
86.	Bousty Nest Scar	SD 831842
87.	Snaizeholme Fell	SD 812843
88.	Widdale Side	SD 816887
89.	Deepdale Gill	SD 899815
90.	Halton Gill	SD 883775
91.	Park Gill Beck	SD 990752
92.	Crook Dike	SE 026761
93.	Scar House Reservoir	SE 046766
94.	River Nidd	SE 071769

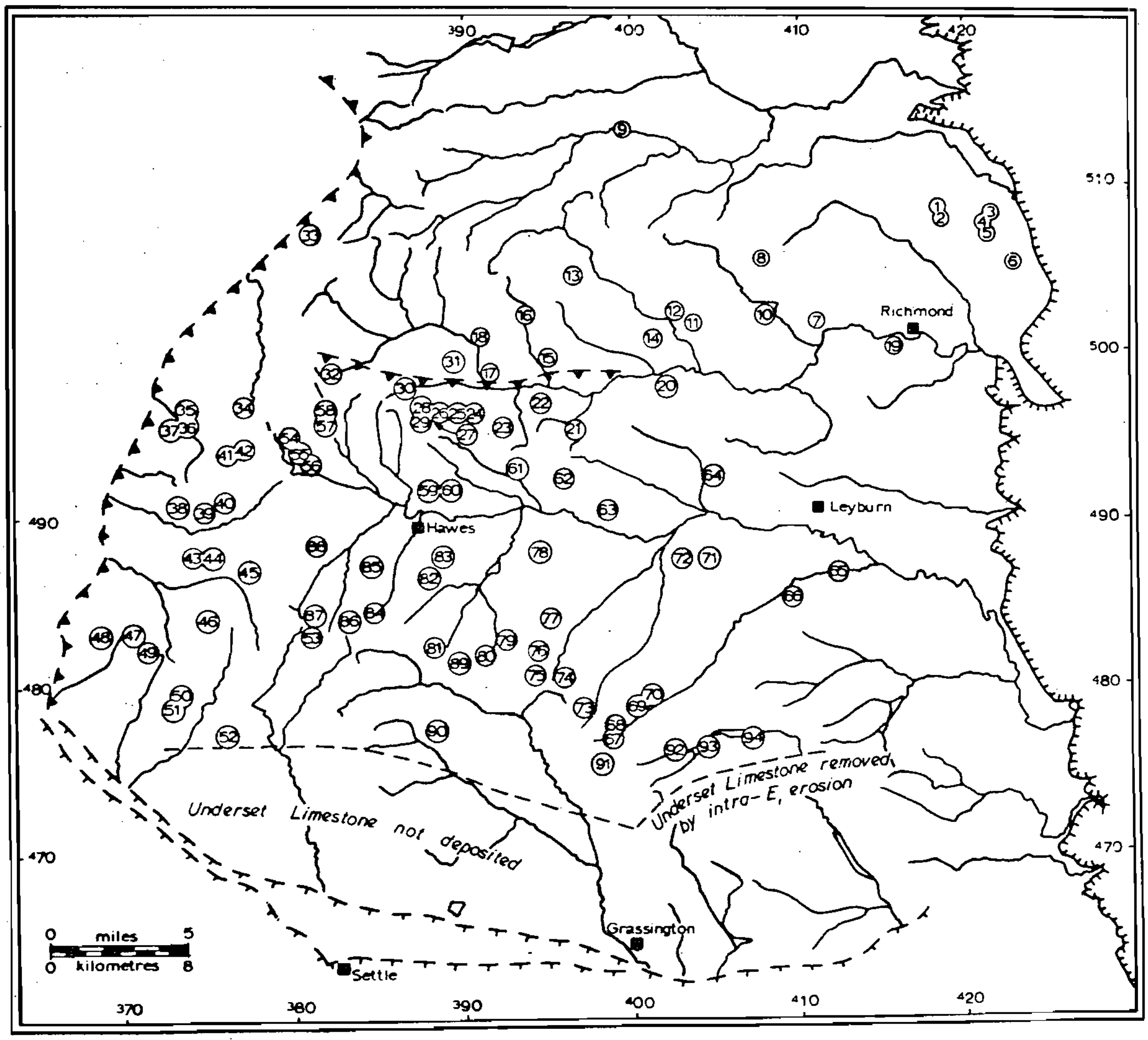


Fig. 38. Map showing location of figured sections of Underset Limestone.

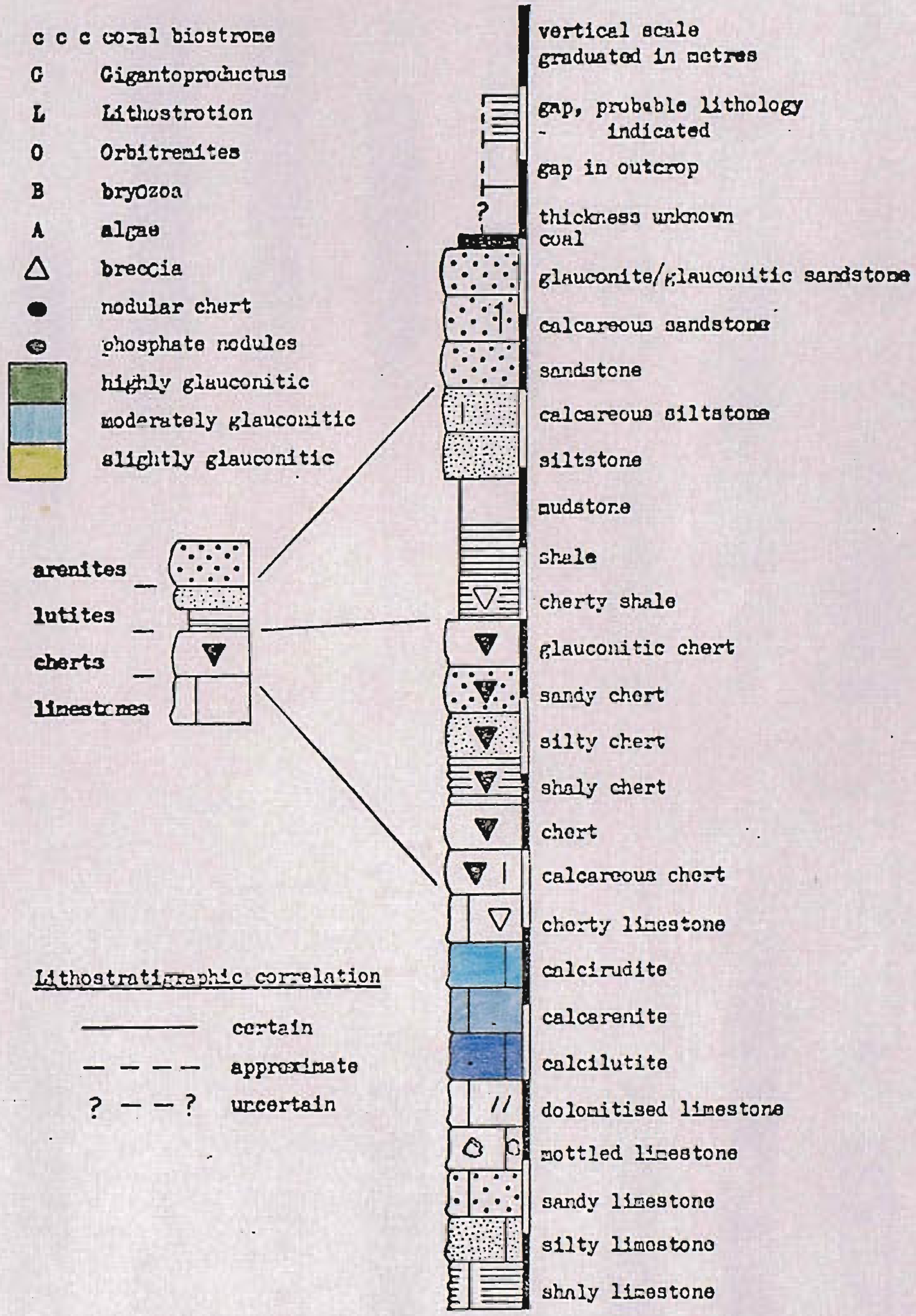


Fig. 39. Key to symbols used in the figured sections.

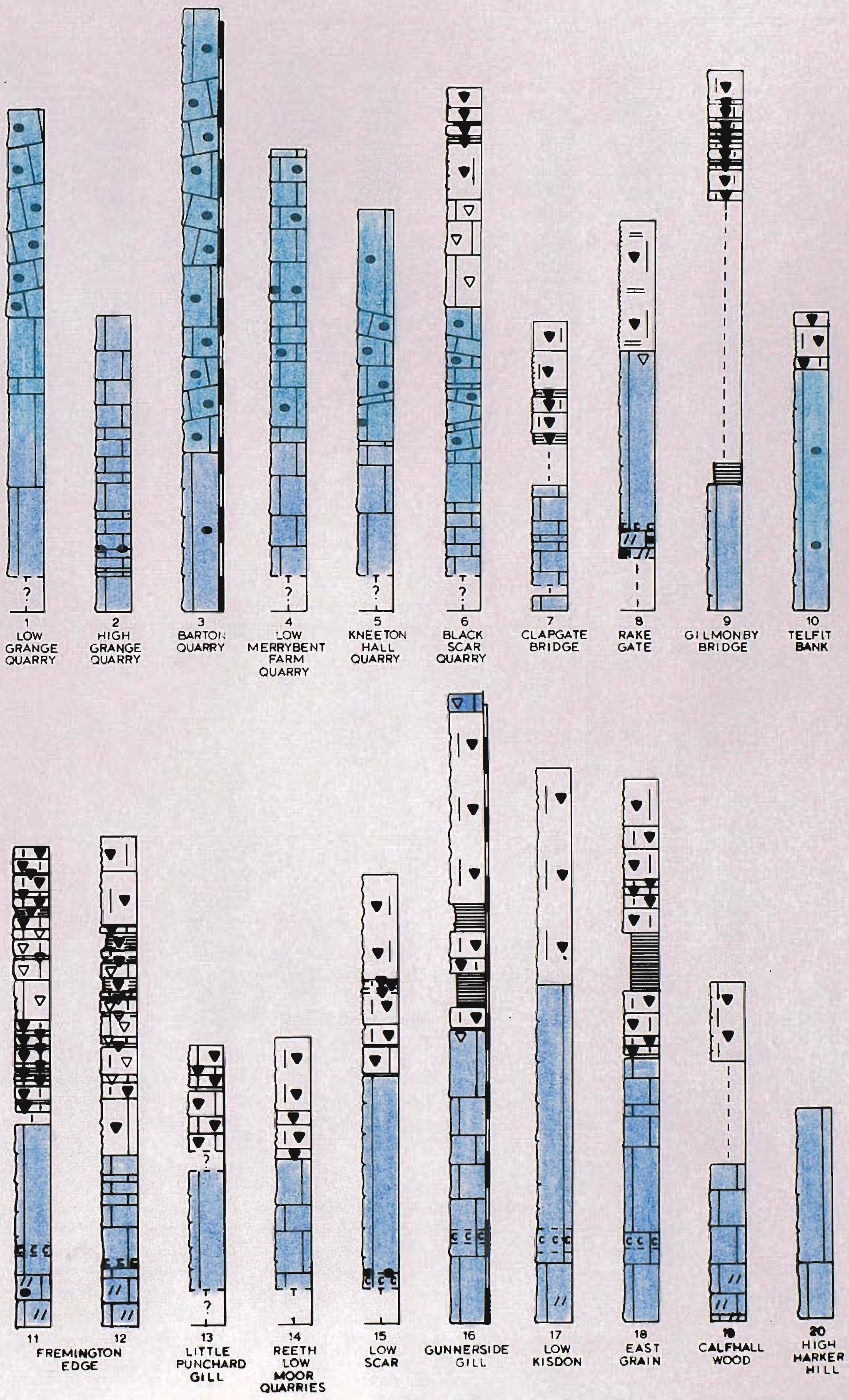

1
LOW
GRANGE
QUARRY
2
HIGH
GRANGE
QUARRY
3
BARTON
QUARRY
4
LOW
MERRYBENT
FARM
QUARRY
5
KNEETON
HALL
QUARRY
6
BLACK
SCAR
QUARRY
7
CLAPGATE
BRIDGE
8
RAKE
GATE
9
GILMONBY
BRIDGE
10
TELFIT
BANK
11
12
FREMINGTON
EDGE
13
LITTLE
PUNCHARD
GILL
14
REETH
LOW
MOOR
QUARRIES
15
LOW
SCAR
16
GUNNERSIDE
GILL
17
LOW
KISDON
18
EAST
GRAIN
19
CALFHALL
WOOD
20
HIGH
HARKER
HILL

Fig. 40.

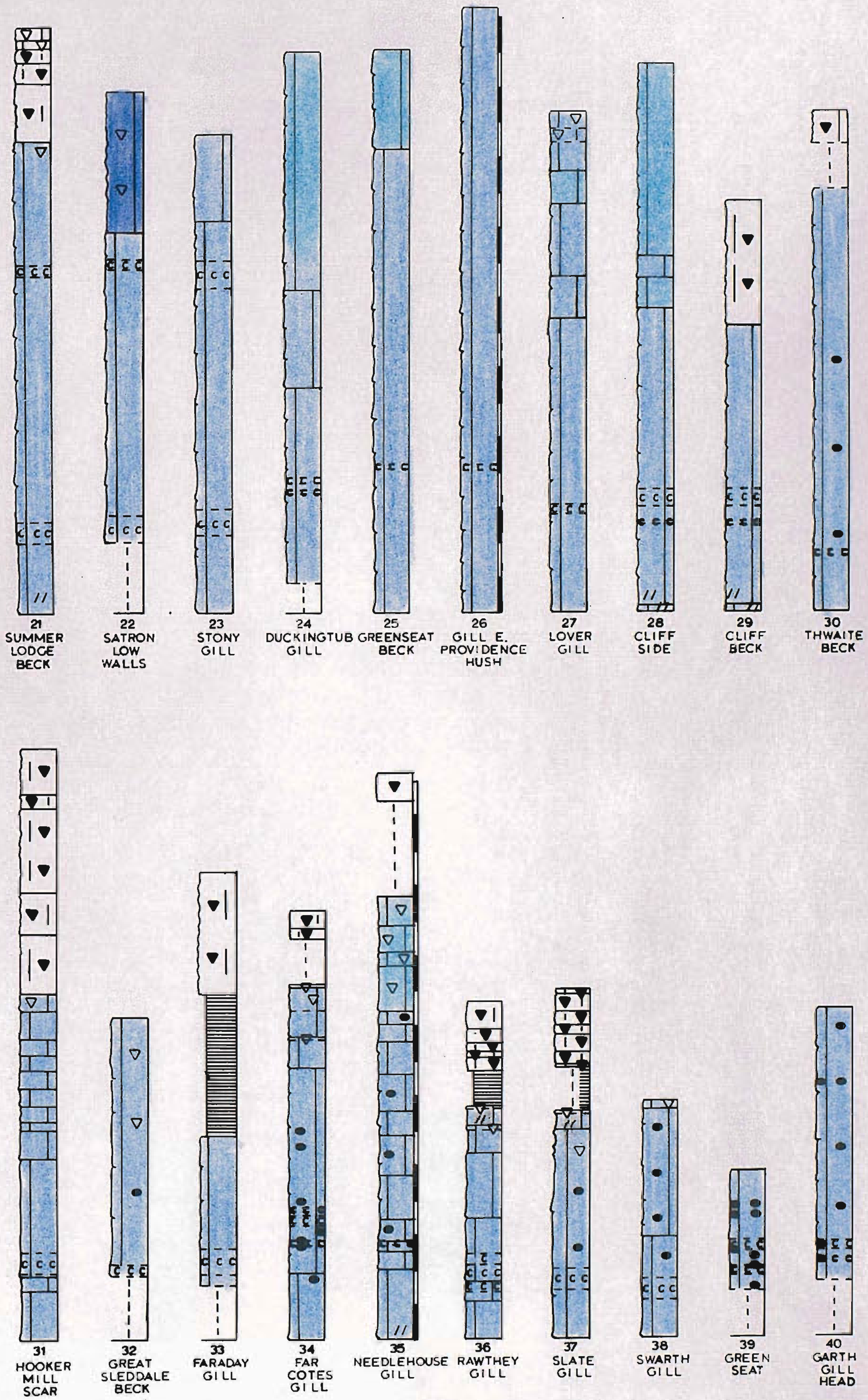

21
SUMMER
LODGE
BECK
22
SATRON
LOW
WALLS
23
STONY
GILL
24
DUCKINGTUB
GILL
25
GREENSEAT
BECK
26
GILL E.
PROVIDENCE
HUSH
27
LOVER
GILL
28
CLIFF
SIDE
29
CLIFF
BECK
30
THWAITE
BECK
31
HOOKER
MILL
SCAR
32
GREAT
SLEDDALE
BECK
33
FARADAY
GILL
34
FAR
COTES
GILL
35
NEEDLEHOUSE
GILL
36
RAWTHEY
GILL
37
SLATE
GILL
38
SWARTH
GILL
39
GREEN
SEAT
40
GARTH
GILL
HEAD

Fig. 41.

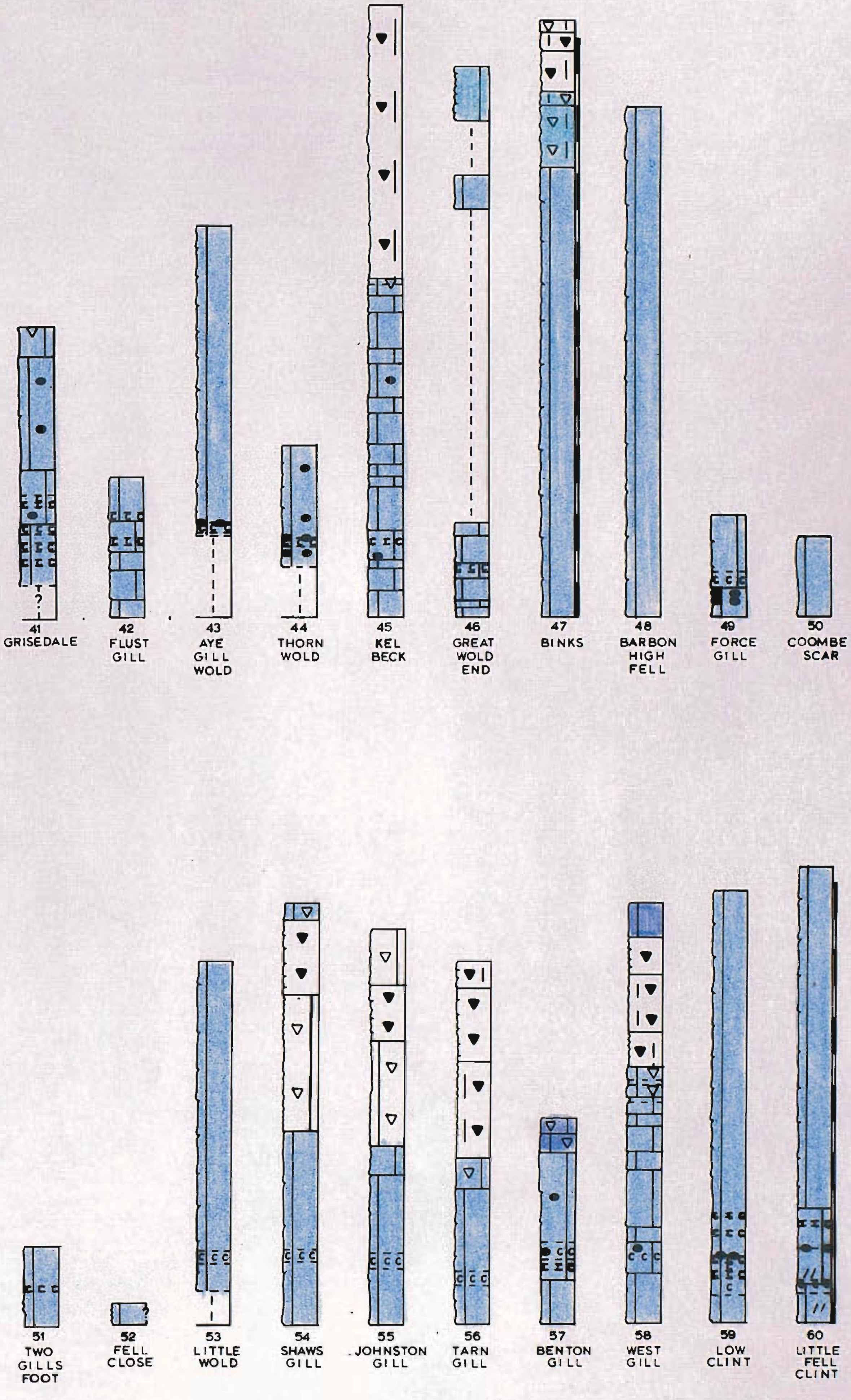

41 GRISEDALE
42 FLUST GILL
43 AYE GILL WOLD
44 THORN WOLD
45 KEL BECK
46 GREAT WOLD END
47 BINKS
48 BARBON HIGH FELL
49 FORCE GILL
50 COOMBE SCAR
51 TWO GILLS FOOT
52 FELL CLOSE
53 LITTLE WOLD
54 SHAWS GILL
55 JOHNSTON GILL
56 TARN GILL
57 BENTON GILL
58 WEST GILL
59 LOW CLINT
60 LITTLE FELL CLINT

Fig. 42.

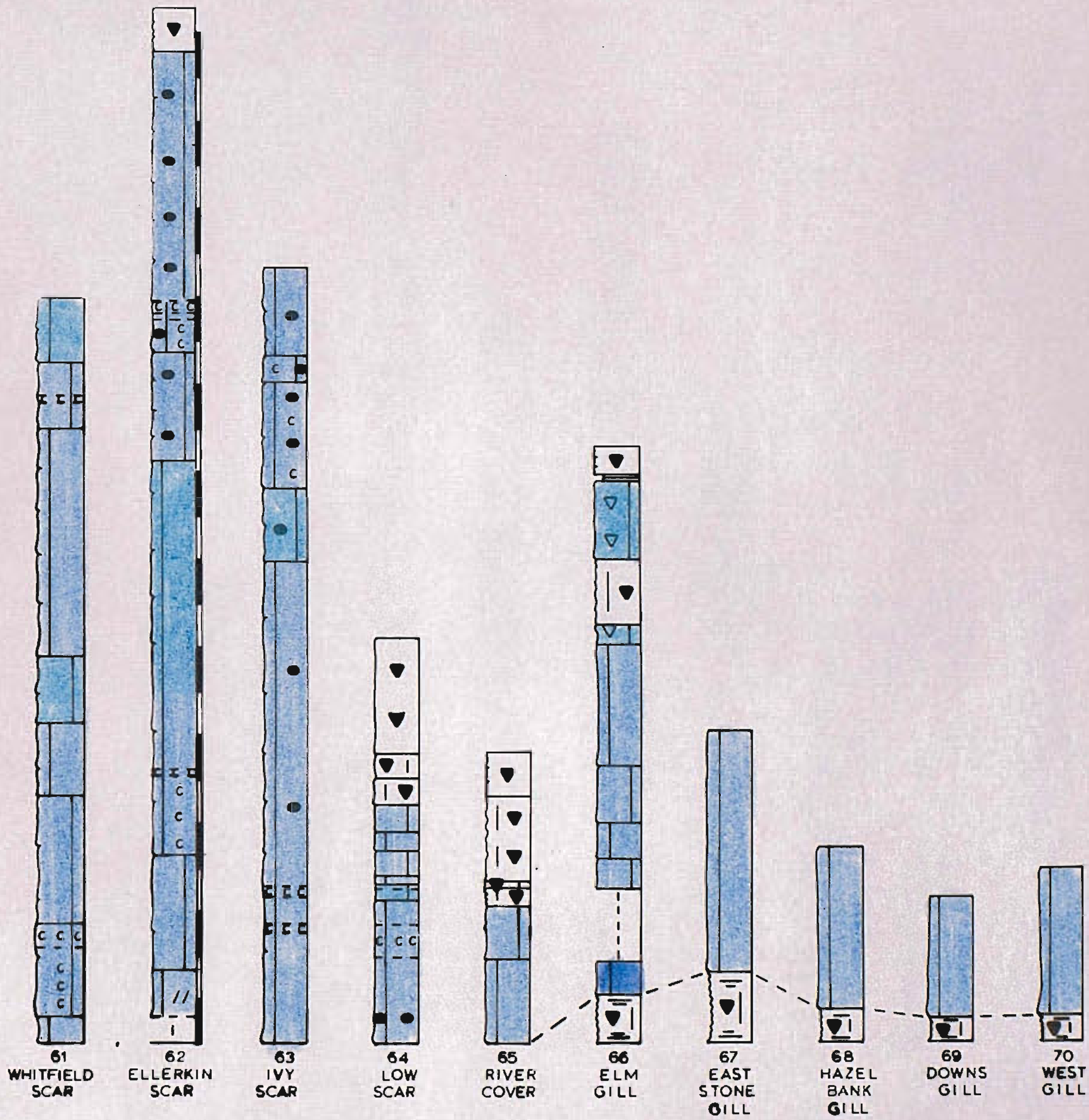

61
WHITFIELD
SCAR
62
ELLERKIN
SCAR
63
IVY
SCAR
64
LOW
SCAR
65
RIVER
COVER
66
ELM
GILL
67
EAST
STONE
GILL
68
HAZEL
BANK
GILL
69
DOWNS
GILL
70
WEST
GILL

Fig. 43.

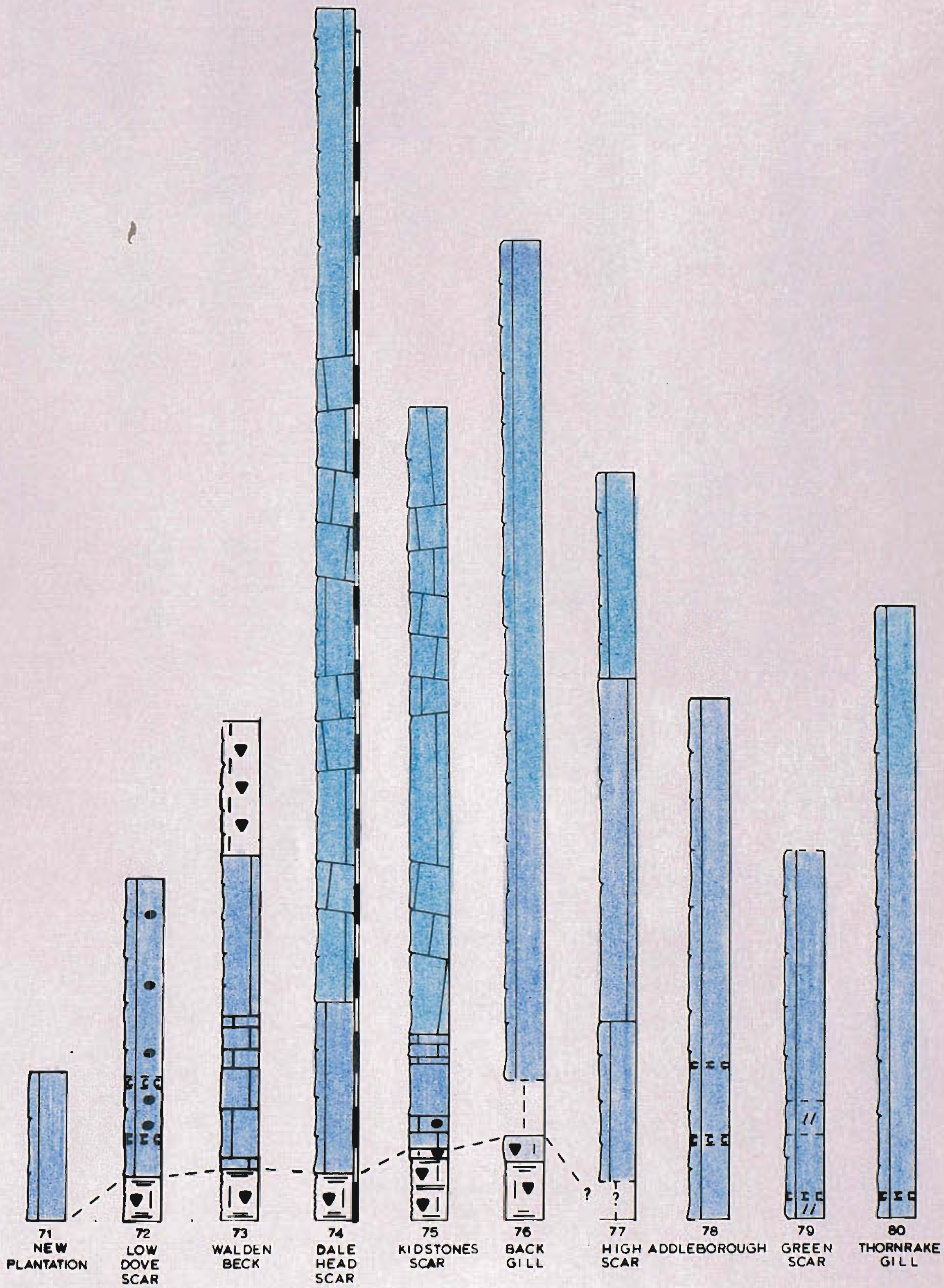

71
NEW
PLANTATION
72
LOW
DOVE
SCAR
73
WALDEN
BECK
74
DALE
HEAD
SCAR
75
KIDSTONES
SCAR
76
BACK
GILL
77
HIGH
SCAR
78
ADDLEBOROUGH
79
GREEN
SCAR
80
THORNRAKE
GILL

Fig. 44.

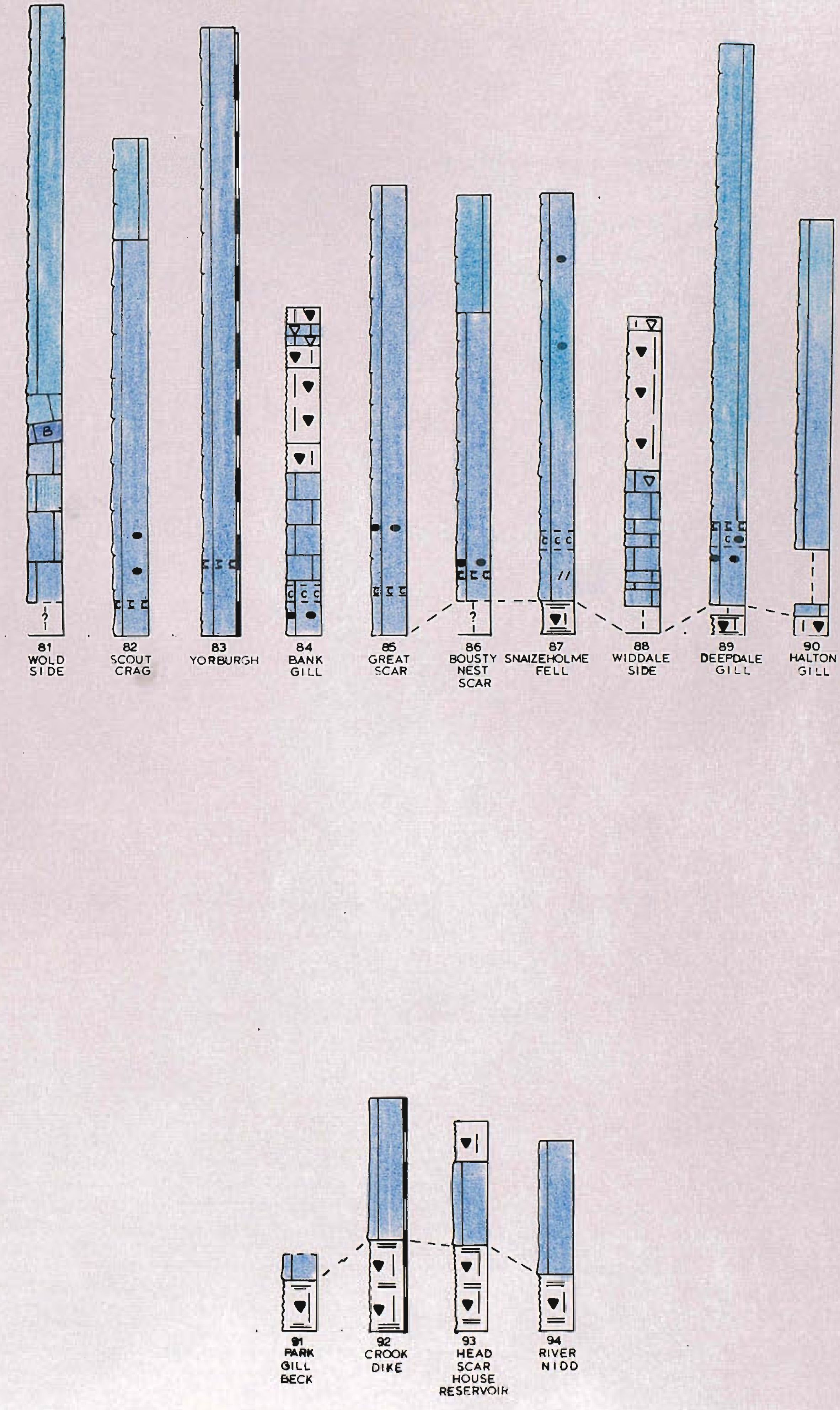

81 WOLD SIDE
82 SCOUT CRAG
83 YORBURGH
84 BANK GILL
85 GREAT SCAR
86 BOUSTY NEST SCAR
87 SNAIZEHOLME FELL
88 WIDDALE SIDE
89 DEEPDALE GILL
90 HALTON GILL
91 PARK GILL BECK
92 CROOK DIKE
93 HEAD SCAR HOUSE RESERVOIR
94 RIVER NIDD

Fig. 45.

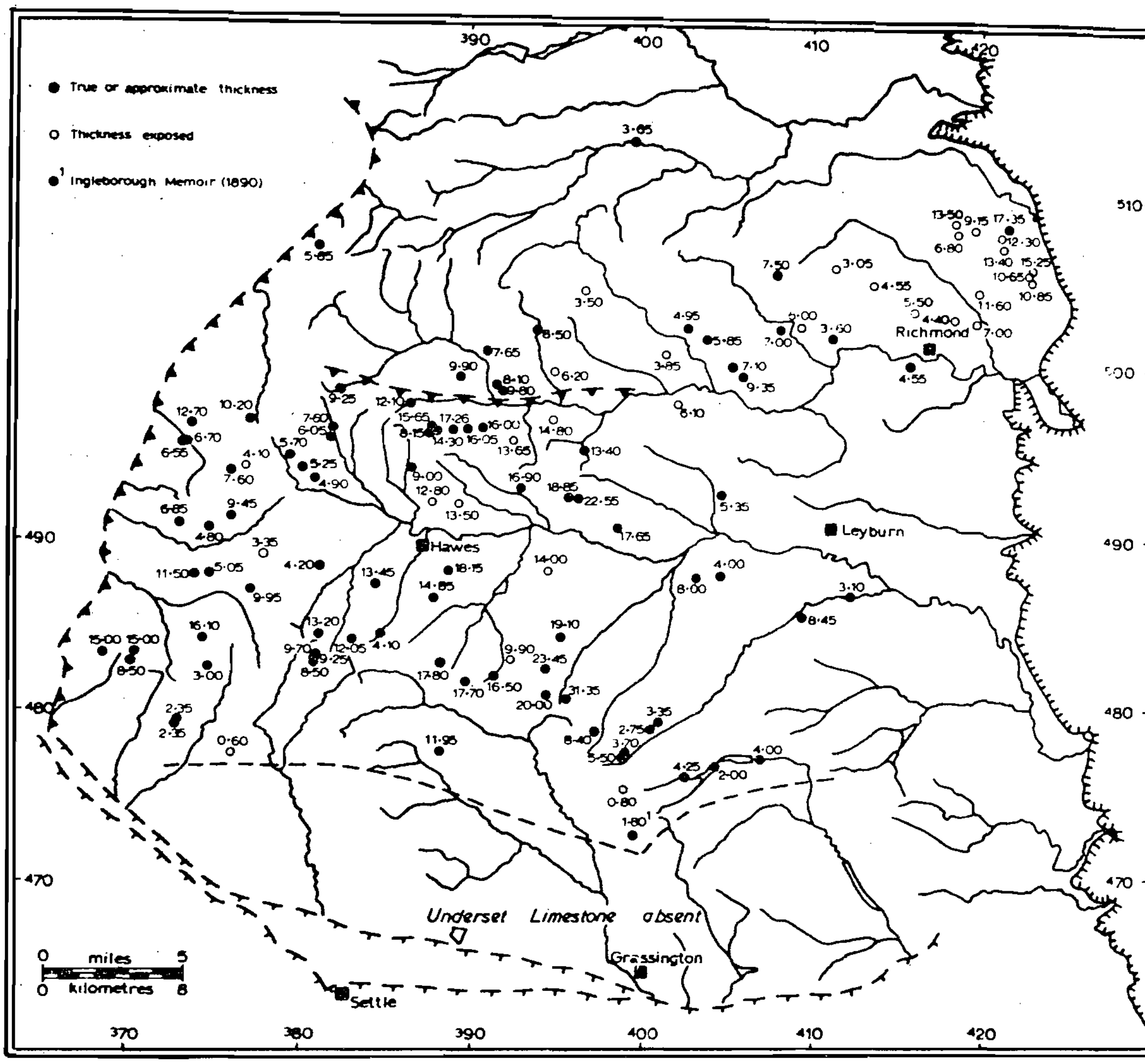


Fig. 46. Map showing thickness of Underset Limestone.

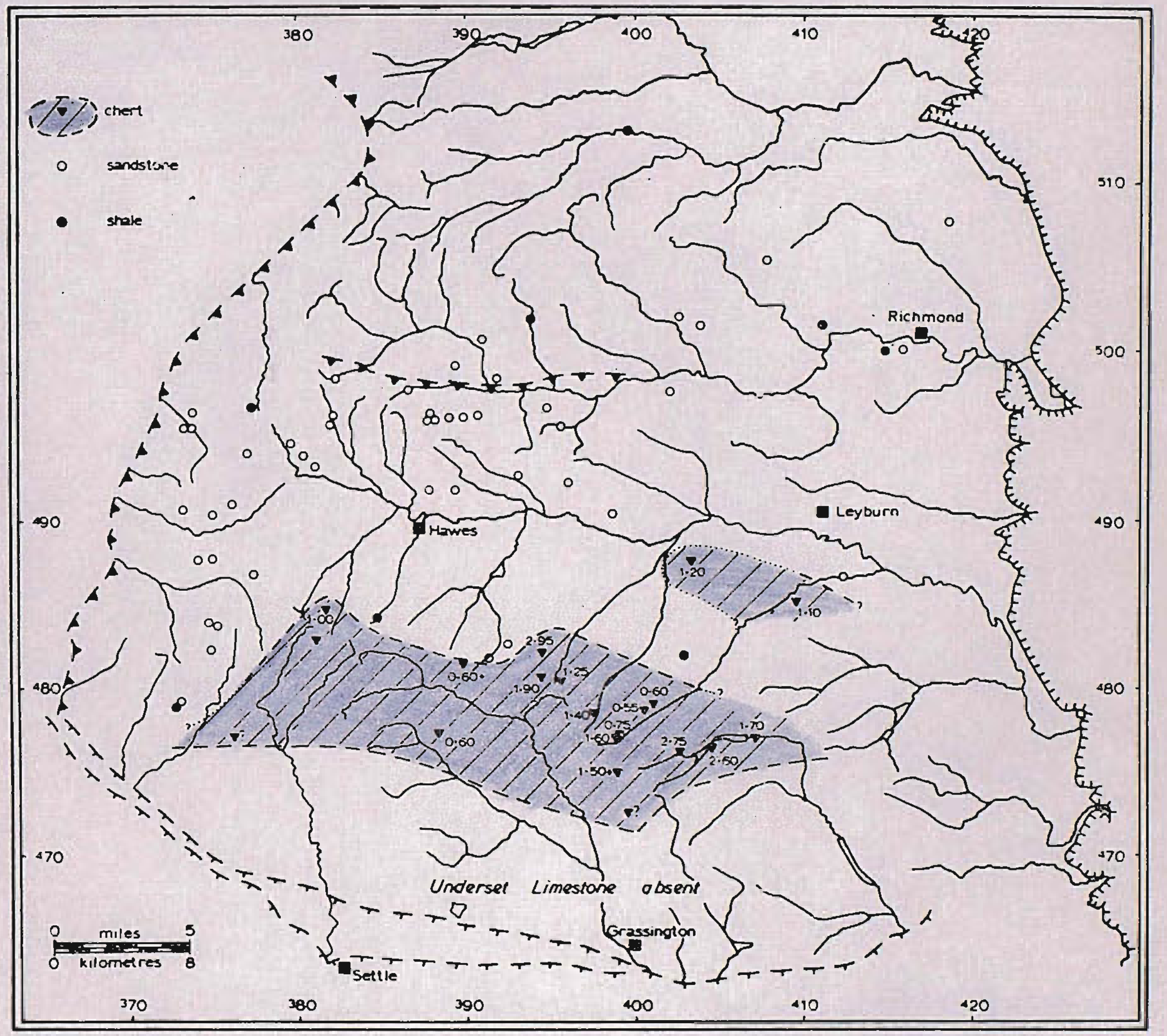


Fig. 47. Map showing pavement beneath Underset Limestone.

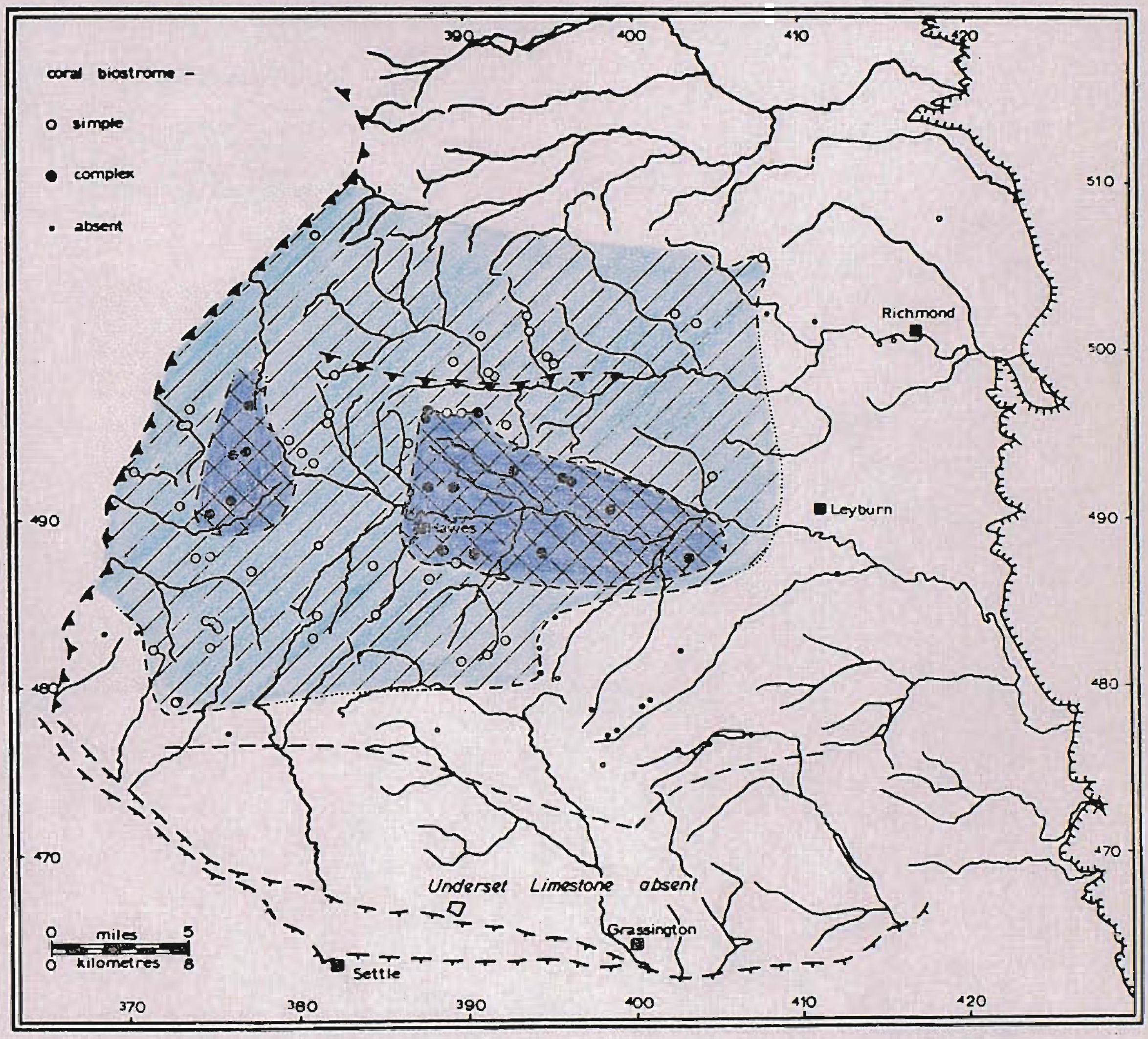


Fig. 48. Map showing distribution of coral biostrome at base of Underset Limestone.

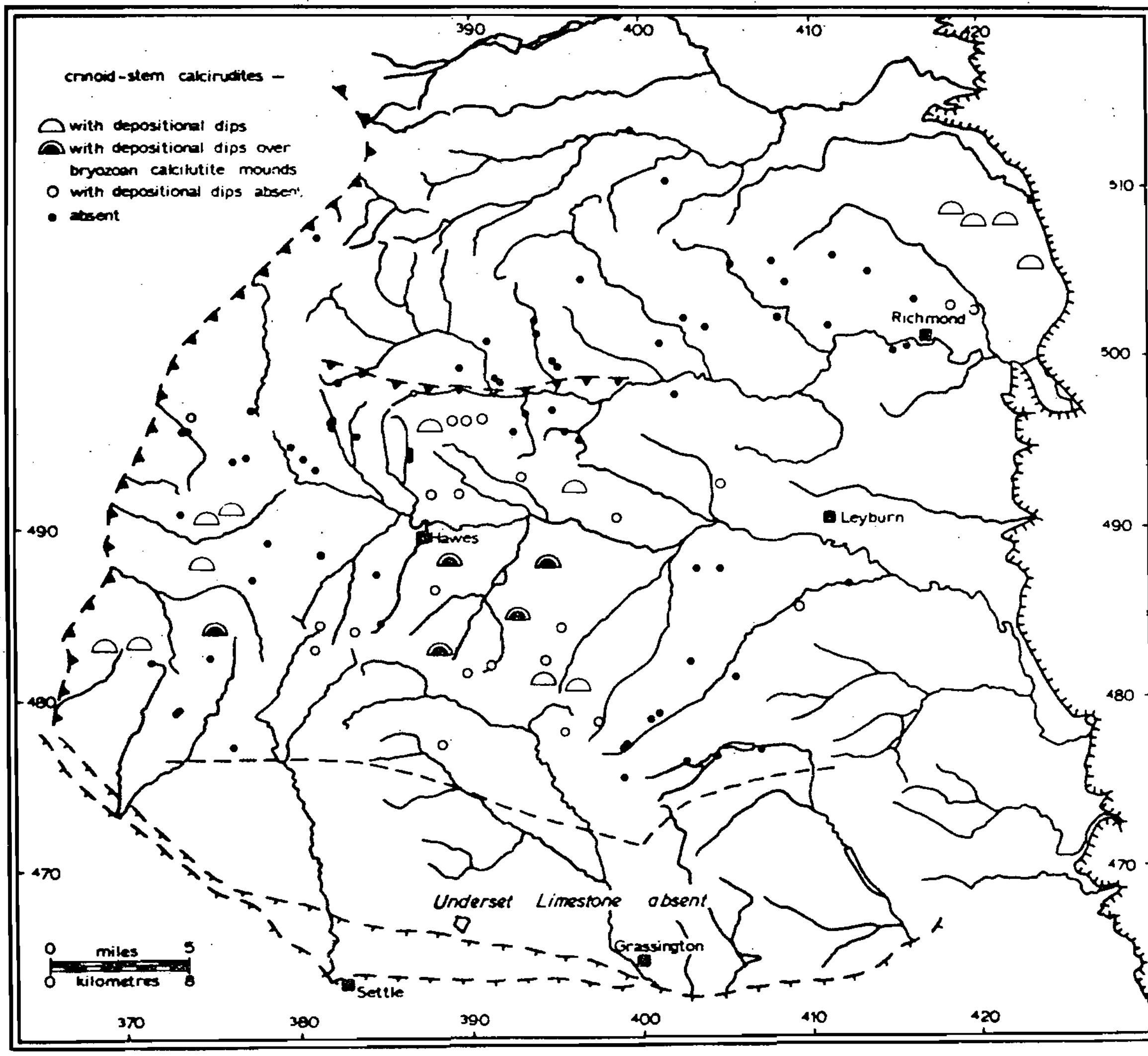


Fig. 49. Map showing distribution of bryozoan calcilutite mounds and crinoid-stem calcirudites in Underset Limestone.

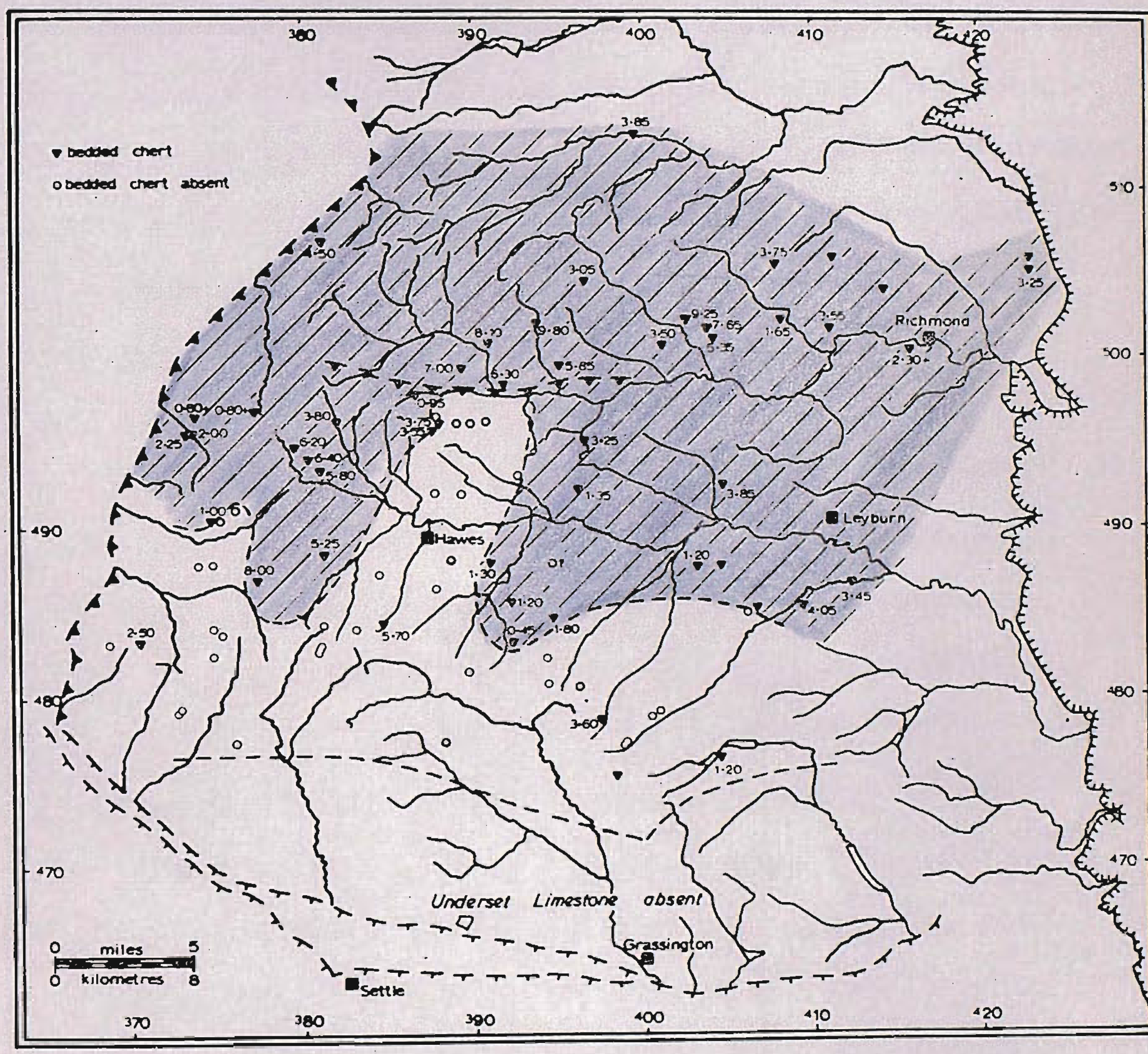


Fig. 50. Map showing distribution of bedded chert above Underset Limestone.

THE UNDERSET LIMESTONE.

DISCUSSION.

The Underset Limestone accumulated over all the area except the southern part of the Askrigg Block. In the southern Barnard Castle trough it is only 3.65m thick at Gilmonby Bridge (NY 995133) but it thickens southwards to 10m in the vicinity of the Stockdale Fault and eastwards to nearly 20m in the area northeast of Richmond (Fig.46) On the Askrigg Block a maximum thickness of over 30m is seen at Bishopdale Head and it is more than 15m thick on Abbotside, Askrigg and Muker Commons, Wether Fell, in the region around and between Bishopdale and Cragdale and on the north slope of Whernside. The thicker developments occur where biogenic mounds locally swell the Limestone (Fig.49) The Limestone thins away from these areas but is rarely less than 5m thick except in the south towards which it thins before failing completely. This southerly thinning is seen best along the east side of Whernside from over 16m at Wold End (SD 742847) to only 2.35m at Coombe Scar (SD731796) and Two Gills Foot (SD 729793). The Limestone can be located on the northern slope of Park Fell (SD 765773) to the southeast but is absent farther south. Similar thinning is seen on the east side of Wharfedale where it is only 1.8m thick where last recorded in Providence Mine (SD 993728) (Phillips, 1836; Ingleborough Memoir, 1890; Dakyns, 1892 Chubb, 1926).

Various interpretations have been proposed to account for the absence of the Underset Limestone over the southern part of the Askrigg Block. Sedgwick (1835) considered the Underset and Main Limestones are fused in this region but Phillips (1836) recorded the Underset Limestone absent and thought it did not accumulate here. More recently O'Connor (1954), the Institute of Geological Sciences (1" to 1 mile Geological Sheet 50, Hawes, 1970), and Ramsbottom (1974) have shown the Underset Limestone present on Fountains Fell even though it is now generally considered absent on Penyghent to the northwest, Ingleborough to the west and southeast of Kettlewell to the east.

In the Ingleborough Memoir (1890) the Geological Survey recorded two thick limestones in the upper part of the Yoredale Group on Fountains Fell which, from initial mapping, they considered to be the Underset and Main Limestones. However, they noted that the strata between the two Limestones are fissile calcareous cherts similar to the beds which overlie the Main Limestone in places. They eventually concluded that the lower Limestone is the Main Limestone and that the upper Limestone corresponds to the 'Red Beds Limestone' of Swaledale, where a similar cherty series overlies the Main Limestone. They also thought it possible that the Main Limestone seen on Penyghent splits southwards forming two Limestones on Fountains Fell with thin intermediate cherts.

Although difficult to prove because nearby outcrops are poor or absent it seems likely that the Underset Limestone is absent on Fountains Fell and that the Main Limestone splits. Evidence for this is indirect. Fountains Fell lies well south of any positively identified outcrop of Underset Limestone and southwest of Penyghent where the Limestone is absent. The southward regional thinning out, well shown between the north slope of Whernside and Park Fell, along the east side of Wharfedale north of Kettlewell to the westnorthwest and eastnortheast of Fountains Fell respectively, suggests the Limestone is absent. The splitting of the Main

Limestone in the south is not unique for shaly intercalations also appear in the Hardraw Scar, Five Yard and Three Yard Limestones.

Absence of the Underset Limestone over the southern part of the Askrigg Block results from non-accumulation, not post-depositional removal. Its gradual thinning and eventual disappearance is not accompanied by any evidence of erosion except in the southeast, south of Angram and Scar House Reservoirs, where its feather edge has been removed by intra-E_1 erosion preceding deposition of the Grassington Grit.

The Underset Limestone rests on a pavement of sandstone in the central-southern and eastern parts of the southern Barnard Castle Trough and shale in the north and west. On the Askrigg Block it overlies sandstone over most of the northern, central and western areas except in the northwest where it rests on shale. To the south it sometimes rests on shale but over most of this region and in an area encompassing Penhill and part of lower Coverdale, chert overlies the shale and forms the pavement. The lithology of the pavement in shown in Fig. 47.

The cherts underlying the Underset Limestone are thickest at the heads of Nidderdale, Coverdale, Waldendale and Bishopdale reaching a maximum of nearly 3m. They are medium to dark grey, laminated, fissile, variably calcareous and shaly. Their contact with the underlying shale is gradational rather than abrupt and in some places they become so calcareous that they pass into cherty calcilutites. One of the most distinctive features of these beds is their characteristic fauna of abundant fenestellid bryozoa and small brachiopods, dominantly productids, including spinose types. The fenestellid colonies are up to 10cm in length and, although crushed, are exquisitely displayed on bedding and laminae planes along which the chert splits easily. The presence of this specific and characteristic faunal assemblage suggests, although does not prove, that high silica concentrations in the sea may have favoured growth of these organisms and possibly inhibited growth of others.

The lowest beds of the Underset Limestone are crinoid-ossicle calcarenites. They contain a fauna of small brachiopods, dominantly Eomarginifera, and are commonly dolomitised. Except where associated with vein mineralisation, intense dolomitisation is usually restricted to the lowest beds where they overlie sandstone. The general relationship between dolomitisation and substrate suggests that dolomitisation is not related directly to differences in original composition of the carbonate sediment. Neither is it related to the trapping of downward percolating solutions at the base of the Limestone because dolomitisation occurs mainly over sandstone cemented relatively late (p.401), not where the limestone overlies relatively impervious shale. It seems probable that dolomitisation was effected by Mg-rich connate pore-fluids which moved upwards through the sandstone before its complete cementation and reacted with the overlying carbonate. Although some of the magnesium may have come from the change high Mg calcite to low Mg calcite, it is thought that most of the Mg was released during diagenesis of clay minerals in the shales underlying the sandstone.

After a period of carbonate accumulation corals colonised all except the eastern part of the Barnard Castle Trough and the southern and eastern parts of the Askrigg Block. Over most of the area they form a single biostrome 20cm to 75cm thick, 50cm to 4.1m above the base of the Limestone but in upper Garsdale and part of Mallerstang and over the northern central part of the Askrigg Block corals are developed at several horizons separated by crinoid-ossicle calcarenites (Fig.48).

In the Barnard Castle Trough the single biostrome consists almost entirely of Clisiophyllidae, dominantly Dibunophyllum bipartitum bipartitum (McCoy), although Diphyphyllum fasciculatum (Fleming) becomes important in the vicinity of the Stockdale Fault. On the Block Diphyphyllum is common. It sometimes replaces Dibunophyllum as the dominant coral where only a single coral bed occurs but where there are several coral beds Diphyphyllum is commonly the dominant coral. The corals disappear gradually at the extremities of the biostrome (Fig.48) becoming scattered, then sparse before they finally disappear.

Where the coral biostrome has a fauna of Clisiophyllidae, especially where only a single biostrome occurs, it has a crinoid-ossicle calcarenite matrix. The clisiophyllids lie on their sides and frequently have imperfect outer dissepimental zones. They appear to have been rolled about on the sea-floor and, because of their abundance, may have been concentrated by sedimentary processes, probably winnowing of the finer matrix by currents.

In contrast to the Clisiophyllidae, the colonies of Diphyphyllum are in their growth position. When Diphyphyllum is abundant the biostrome has a calcilutite matrix with little crinoid-debris and a fauna of small telotrematous brachiopods which occur between both colonies and individual corallites. Even when Diphyphyllum occurs scattered in a clisiophyllid dominated part of the biostrome the crinoidal matrix of the biostrome often passes into calcilutite in the vicinity of the Diphyphyllum colony and small brachiopods appear. The Diphyphyllum colonies, especially where numerous, seem to have been current baffles restricting water movement in their vicinity and trapping carbonate mud. The protected environment must have been an ideal habitat for small brachiopods.

There is little difficulty in correlating the coral biostrome where it is simple and well developed but where several coral beds are developed then correlation is difficult. Although the fauna of the coral biostrome varies where it is simple, even greater variability occurs where it is complex. Here, within the confines of a small outcrop, a single coral bed can be dominated by Clisiophyllidae in one part yet Diphyphyllum in another. Besides differences in fauna, the coral beds often vary in number and thickness from outcrop to outcrop. Nevertheless, whilst there is great variability, the lowest coral bed, usually the thickest, is commonly dominated by Clisiophyllidae with subsidiary Diphyphyllum. The upper coral beds are thinner, generally 10cm to 30cm, and usually contain Diphyphyllum as the dominant coral with subordinate Dibunophyllum. They are separated from one another by crinoid-ossicle calcarenites usually 20cm to 50cm thick but sometimes more.

The development of several coral beds over part of the Askrigg Block suggests either the single coral biostrome splits or that new biostromes became established after a period of sediment accumulation post-dating death of the previous biostrome. Lack of extensive exposures in the critical areas prevents continuous tracing of the coral beds but the evidence collected suggests that a single complex biostrome exists rather than several separate ones. Where several coral beds are developed they are separated by crinoid-ossicle calcarenites with no corals at most localities but sometimes, as at Ellerkin Scar (SD 962922), corals are seen in the intervening calcarenites proving continuity of coral growth in places. It seems that after initial colonisation the corals were killed except at certain places within the areas where the coral biostrome is complex. As many of the clisiophyllids appear to have been rolled on the sea floor, death of the biostrome over most of the area may have resulted from increased current activity. Corals survived the following accumulation of carbonate sediment only locally within the areas where more than one coral bed is present but afterwards, probably during a period of reduced sediment accumulation, managed to recolonise only a relatively small area. This happened up to four times in the lower part of the Underset Limestone.

Dibunophyllum bipartitum bipartitum (McCoy) and Diphyphyllum fasciculatum (Fleming) are the commonest corals by far in the biostrome but Aulophyllum fungites (Fleming), Koninckophyllum magnificum (Thompson and Nicholson) and rarely Caninia sp. are also present.

The Diphyphyllum colonies are broadly conical with their coralites widespread. This contrasts with the compact bun-shaped form of the colonial corals in the biostrome at the base of the Single Post Limestone and may indicate that conditions during growth were less turbulent. Small brachiopods, abundant in the calcilutite associated with Diphyphyllum, include Eomarginifera, Dielasma, Dictyoclostus, Chonetes, Phricidothyris, Echinoconchus and spirifers. Occasionally sparse Gigantoproductus is also associated with the corals though, more usually, it occurs just beneath or just above the uppermost coral bed.

Chert nodules are common in or near the coral biostrome and many of the corals are completely or partly silicified, frequently standing proud on weathered surfaces.

Abundant decaying organic material in the biostrome is thought to have provided a locally favourable environment for silicification (p. 376).

Above the coral biostrome the Underset Limestone consists dominantly of medium to very thick bedded, medium grey, crinoid-ossicle calcarenites with abundant bryozoan debris, occasional Gigantoproductus and scattered chert nodules. Locally, the calcarenites coarsen and pass laterally into biogenic mounds which swell the thickness of the Limestone considerably.

Biogenic mounds occur in all except the southern and eastern areas on the Askrigg Block and are developed best over the central area. They are seen around the west end of Muker Common, northeast of Askrigg at Ellerkin Scar, on the south side of Baugh Fell and Rise Hill, on the west side of Barbondale, at Binks on the east side of Great Coum, on the north end of Whernside, on Yorburgh and Addleborough, between the Haws and Bishopdale Head and on Wold Side. They are also present in the south-eastern part of the Barnard Castle Trough in the area north and northeast of Richmond.

At most localities they appear as unbedded lenses of coarse crinoid-stem calcirudites capped and flanked by laminated coarse crinoid-stem calcirudites with depositional dips of up to 15°. The lenses are exposed best at Kidstones Scar (SD 946813), Bishopdale Head, where they are commonly 25m, but up to 100m, in length and 4m to 10m thick. They consist almost entirely of coarse crinoid debris with a few brachiopods, dominantly spirifers, and bryozoa.

On Yorburgh, Addlebborough, the Haws and Wold Side laminated, coarse crinoid-stem calcirudites cap and flank poorly exposed bryozoan calcilutite mounds. Similar mounds, although not exposed, must be present beneath the exposed crinoid-stem calcirudites on the north end of Whernside because blocks of calcilutite with abundant bryozoa are common in the walls nearby. The apparent absence of calcilutite cores at the other localities may result simply from non-exposure but it seems likely that in many cases crinoid-banks now represented by lenses of coarse crinoid debris also developed in places where bryozoan calcilutite mounds were absent. Both the calcarenite lenses and the calcilutite mounds are considered to be bioherms (p.352).

On Crackpot Moor, Summer Lodge Moor, Carperby Moor and Askrigg Common, corals reappear in a biostrome in the upper part of the Underset Limestone. It has a fauna of Diphyphyllum fasciculatum (Fleming), Diphyphyllum ingens (Hill), Dibunophyllum bipartitum (McCoy) and Heterophyllia but is much less extensive than the biostrome near the base of the Limestone. Moore (1958) noted that the two species of Diphyphyllum do not exist together; Diphyphyllum fasciculatum occurring only on the fringes of the biostrome. The biostrome is 15cm to 30cm thick except at Ivy Scar (SD 787904) where in places Diphyphyllum and Dibunophyllum occur throughout 3m of limestone. Like the Diphyphyllum dominated part of the lower biostrome, the corals occur in a calcilutite matrix, are usually silicified and have an associated fauna of small telotrematous brachiopods. Near the fringe of the biostrome, the calcilutite matrix contains scattered crinoid debris but there is always marked contrast with the underlying crinoid-ossicle calcarenites.

The upper part of the Underset Limestone is often cherty, especially where bioherms are absent, but on Crackpot and Carperby Moor above the upper coral biostrome and in Great Sleddale most of the upper part of the Limestone is silicified. The silicified beds are dark grey calcilutites with bryozoa but only very sparse crinoid debris of small size and contrast with the calcarenites and calcirudites at the top of the Underset Limestone elsewhere which contain abundant crinoid debris. Whereas the beds beneath contain only scattered chert nodules both nodular and disseminated chert is abundant in these upper beds. The nodules are so profuse that they coalesce forming irregular patches, layers and stringers of chert. Frequently all that is left of the calcilutite are tiny patches surrounded by chert. The appearance of chert and disappearance of abundant crinoid debris seems related. Either this lithology has been silicified preferentially or the silica is a primary, though locally redistributed, constituent of the sediment. The disappearance of most of the fauna except bryozoa suggests that the silica was a primary component of the sediment which became mobilised during diagenesis but was later precipitated locally.

Over much of the area the Underset Limestone is overlain by bedded chert. In the north the chert is separated from the Limestone by 4m of shale but the shale thins to the south and southeast. It reaches the northwest part of the Askrigg Block where it is about 1m thick but fails to the southeast and is absent over the rest of the area. In the region around Bowes the shale is exposed poorly but in the Mount Pleasant Borehole (NZ 032151) Johnson obtained a rich fauna including Girtyoceras costatum (Ruprecht) and other specimens referable to Girtyoceras indicating a high P_2 age (Rayner, 1953).

The bedded cherts above are rarely fully exposed and this, with their variability in thickness, makes construction of accurate isopachs impossible (Fig.50). They reach a maximum thickness of about 10m in the central parts of the southern Barnard Castle Trough but thin out towards, are are absent in, the area northeast of the Gilling Valley and north of Middleton Tyas. Although the cherts are thick in the area around Bowes they are absent over most of the Cotherstone Syncline to the north (Reading, 1957) and on the Alston Block. Chert is widely distributed over the northern part of the Askrigg Block, except on Muker Common, but from Garsdale and Wensleydale southwards it is developed only locally. It overlies the Underset Limestone at Binks on the east side of Great Coum, just south of the north end of Whernside, on Widdale Fell, at the heads of Sleddale and Waldendale, on Penhill and in Lower Coverdale and Nidderdale. On the Askrigg Block the chert is thickest at the head of Wensleydale where it exceeds 6m but, over the rest of the Block, the local developments are thinner and exceed 4m only at the head of Sleddale and Waldendale.

The bedded cherts are very thin to very thick bedded, sometimes laminated and medium to dark grey. Although some are flinty most are at least slightly calcareous, many are highly calcareous and some are argillaceous and shaly. Within the cherts variably silicified calcilutites and shales are common. The cherty calcilutites and calcareous cherts frequently contain areas of intense diagenetic silicification which form highly siliceous, sometimes flinty, irregular patches, nodules or bands, usually parallel or subparallel to the bedding. The fauna of the bedded cherts is variable and includes, besides crinoid debris, small brachiopods including spinose productids, bryozoa, sponge spicules and Zoophycos. The calcareous fauna and Zoophycos are commonest in the calcareous cherts whereas the siliceous sponge spicules are usually most abundant in the high siliceous cherts. The cherts are more fully discussed later (p.387).

The relationship between the bedded cherts and biogenic mounds at the top of the Underset Limestone was first recorded by Moore (1958). Using the sections on the west end of Muker Common at Cliff Side (SD 878965) and Cliff Beck (SD 875962) (p.217) he showed the bedded chert above the Underset Limestone occupies an intermound position and is absent over the bioherms. This is substantiated here and shown by comparison of the distribution of the bedded chert (Fig.50) and biogenic mounds (Fig.49) although occasionally, as at Binks (SD 709836), bedded chert does extend over the mounds. The restriction of bedded chert in many places to an intermound position is further proof the bioherms stood as elevations on the sea floor (p.356).

Lithostratigraphic evidence suggests the bedded cherts pass southwards, at least in part, into the upper part of the Underset Limestone. Lack of extensive exposures in critical areas makes this difficult to prove but the increasing carbonate content of the bedded cherts southwards and the cherty nature of the top of the Underset Limestone where the bedded cherts first disappear, support this interpretation. Comparison of the sections around Gunnerside (SD 951982) on the north side of Swaledale where bedded cherts are well developed above the Underset Limestone with those on the south side of Swaledale on Satron Low Walls (SD 944969) where bedded cherts are absent but the upper 4m of the Underset Limestone is highly siliceous best illustrates the relationship. The bedded cherts also pass northwards into carbonate around Bowes where the Iron Post Limestone is developed (Reading, 1957).

THE CROW LIMESTONE.

THE CROW LIMESTONE.

SUMMARY.

The Crow Limestone rests on or occurs just above sandstones of the Uldale Sill. It reaches a maximum thickness of over 20m in the northeast and thins southwestwards but did not accumulate over the southern part of the Askrigg Block or along the south side of the Stockdale Fault in the region of Great Shunner Fell.

Over most of the northern Askrigg Block, except in the region of Great Shunner Fell and between Baugh Fell and Wild Boar Fell and over the eastern and central part of the southern Barnard Castle Trough, the Crow Limestone consists of light to dark grey crinoid-ossicle calcarenites, crinoid-stem calcirudites, bedded, usually calcareous cherts and interbedded shales.

The calcarenites are medium to very thick bedded, frequently have a cherty matrix and are often dolomitised. They coarsen locally into crinoid-stem calcirudites. Although no bioherms are exposed the calcirudites are thought to be related to bioherm development.

Bedded cherts are common in the upper part of the Crow Limestone in the northeast. They are medium to dark grey, variably calcareous and pass transitionally into cherty calcarenites and cherty shales. Both limestones and cherts contain a macrofauna including brachiopods, bryozoa and sponge spicules including *Hyalostelia* . Crinoid debris is usually the most abundant skeletal component although sponge spicules dominate in some of the flinty cherts.

Thin impersistent shales are common, especially in the upper part of the Limestone but a thick shale, reaching a maximum thickness of 5.75m in West Stonesdale, can be traced over most of the southern Barnard Castle Trough. It is also seen on the Askrigg Block in Fossdale and between Baugh Fell and Wild Boar Fell.

The Crow Limestone is absent in a belt at least 2½km long and ¾km wide along the south side of the Stockdale Fault in the region of Great Shunner Fell. Here, local uplift of the north edge of the Askrigg Block elevated the Uldale Sill above surge base to form a sandbank on which the Crow Limestone did not accumulate. Crinoid growth was prolific round the southern edge of the sandbank and resulted in accumulation of coarse crinoid-stem calcirudites.

To the north of the sandbank, in the western part of the southern Barnard Castle Trough, a small basin developed. Here thin lower and upper cherty glauconite sandstones and glauconitic cherts accumulated separated by a thick shale. Both quartz sand and silt decrease in quantity and grain size away from the sand bank which was clearly their source. The glauconite shows a similar distribution and appears to have formed on the sandbank and later been swept northwards into the basin by currents. The basin had semi-stagnant bottom conditions as the Crow Limestone here contains phosphate nodules and has a poor calcareous fauna.

Another small basin developed on the Askrigg Block between Swarth Fell and Wild Boar Fell. Here the surrounding crinoidal limestones pass laterally into a thin lower crinoidal calcilutite and thin, upper, bedded chert, separated by thick shale. The lower crinoidal calcilutite contains scattered quartz sand and silt, glauconite and phosphate nodules. Comparison with the area to the northeast suggests that this basin may have formed behind a sandbank developed by local uplift along the Dent Fault.

THE CROW LIMESTONE.

Although the Crow Limestone and overlying cherts were well known by the early miners, Phillips (1836) was first to record them in the literature. Later, after mapping in the 1870's and 1880's, the Geological Survey described their outcrops and lithology (Ingleborough Memoir, 1890: Mallerstang Memoir, 1891). In 1924 Hudson briefly mentioned the Crow Limestone. He recognised its entire thickness is sometimes represented by chert but usually it consists of a lower limestone overlain by cherts with impersistent limestones. Sargent (1929) described the Crow Cherts in Arkengarthdale and mid-Swaledale which were later visited by a field meeting led by Hudson (1933). The stratigraphy of the beds including the Crow Limestone in the area between Tan Hill and Alston Moor were briefly mentioned by Carruthers (1938) and in 1944 Hudson correlated the Crow Limestone with the Crag Limestone on the Alston Block.

More recently the Crow Limestone and the Crow Chert in the area south and southeast of Richmond were described by Hey (1955). Mapping and description of the Namurian of the northwest corner of the Askrigg Block by Rowell & Scanlon (1957) and of the Carboniferous rocks of the area around Coverdale by Wilson (1960) led to documentation of the Crow Limestone in these areas.

Frequently in the literature these beds are referred to lithostratigraphically as Crow Limestone and Crow Chert, the Crow Chert overlying the Crow Limestone. Whilst it is true that the upper beds are usually more siliceous than the lower beds, chert is encountered at varying positions in the sections and at some localities occurs at the base. To avoid ambiguity, the lithostratigraphic term "Crow Chert" is dropped and the formation of carbonates, cherts and intervening clastics is referred to as the Crow Limestone.

THE CROW LIMESTONE.

DETAILS.

To facilitate description of the Crow Limestone the region studied has been divided into six areas, Lower Swaledale, Upper Swaledale and the northwest, Mallerstang, Garsdale, Baugh Fell and the southwest, Upper Wensleydale and Lower Wensleydale (Fig. 51).

Lower Swaledale.

In the area north of the River Swale, the Crow Limestone is confined to the higher ground. It occurs as outliers, often faulted, and is poorly exposed. To the south its outcrop is high up on the southern bank of the River Swale, approximately parallel to the River, but is complicated by faulting especially in the area south of Richmond.

North of the River Swale the outcrop is usually marked by loose fragments of cherty calcarenites and cherts rather than in situ exposures. The lower part of the succession consists mainly of variably chertified, patchily dolomitised, crinoid-ossicle calcarenites whilst the upper part is dominantly flinty and calcareous chert.

On Moresdale Ridge (NZ 025043) fragments of flinty and decalcified calcareous chert abound. Many fragments of the decalcified calcareous chert are extremely conspicuous as they weather very light grey. They have a variable content of crinoid debris and a fauna of small brachiopods, mainly productids and spirifers. Small outcrops do occur in this region and in the dry beck (NZ 025041) where 1.2m of shaly weathering, medium grey, calcareous chert with crinoid debris and small brachiopods is exposed. Nearby at NZ 025040 2m of weathered

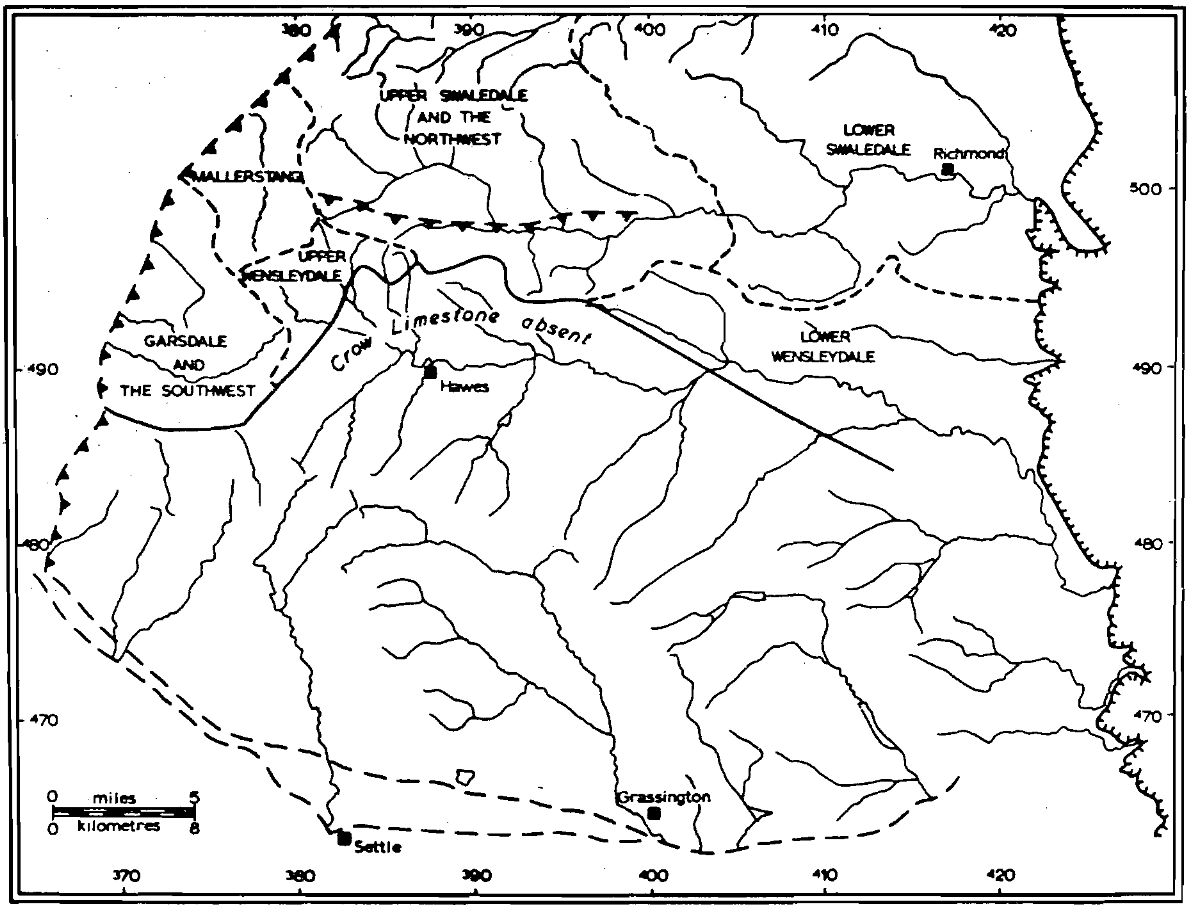


Fig. 51. Areas used for description of Crow Limestone.

highly siliceous crinoid-ossicle calcarenites and calcareous cherts are seen and to the southwest in a small tributary of Slei Gill (NZ 023031), poor exposures of cherty crinoid-ossicle calcarenites and cherts are visible above sandstones of the Uldale Sill.

On the south side of the River Swale the most easterly exposure of the Crow Limestone is in Hagg Gill (SE 184994). Hey (1956) recorded 30 feet (9.15m) of Crow Limestone here but now only 3.1m of medium grey, medium to thick bedded, cherty crinoid-ossicle calcarenites with very thin interbedded shales are visible in situ although loose fragments of siliceous crinoid-ossicle calcarenites and cherts are seen above.

East of Hagg Gill (SE 184994) there are good exposures in the disused quarries on the south side of Sand Beck. The lower part of the Crow Limestone is exposed in the quarry (SE 171998) 200m southwest of Sandbeck East Bridge. Hey (1956) recorded the top of the Ten Fathom Grit and the base of the Crow Limestone here but now the quarry has become partly infilled with debris and the Ten Fathom Grit is no longer visible. However, loose blocks of sandstone still litter the quarry floor. The quarry exposes 9.2m of medium to light grey, medium to very thick bedded, patchily dolomitised, variably chertified crinoid-ossicle calcarenites with shaly partings and thick to very thick interbedded shales. Where dolomitised the calcarenites are light brown. The lowest 4.4m are thick to very thick bedded, patchily dolomitised, cherty crinoid-ossicle calcarenites with a 40cm shale and traces of cross lamination 1m and 2.1m above their base respectively. Locally intense silicification has led to incipient development of chert nodules with poorly defined margins. These beds are overlain by two cherty shales 1.1m and 35cm thick separated by 80cm of highly dolomitised calcarenite which, where weathered, is porous, earthy and stained light brown by iron-oxide. The overlying medium to thick bedded crinoid-ossicle calcarenites, besides being more intensely dolomitised than the lower beds, are also more siliceous and contain a thin shaly chert 40cm thick 1m from the top of the section. Loose blocks of siliceous calcarenite and chert are seen above.

A greater thickness of the Crow Limestone is exposed in Spring Wood Quarry (SE 168997) 200m to the southeast. The section starts above the base of the Limestone and exposes 20m of patchily dolomitised, variably siliceous, medium to very thick bedded crinoid-ossicle calcarenites with shaly partings, medium to very thick, usually siliceous, interbedded shales and medium to thick bedded cherts. The lowest 8.15m are medium to very thick bedded siliceous crinoid-ossicle calcarenites with a 30cm shale 3.85m above the base. Koninckophyllum interruptum (Thompson & Nicholson), identified by Hey (1956), occurs 60cm beneath the shale. Above 1.95m of siliceous shale, chertified in its upper part, is overlain by 3.75m of medium to very thick bedded crinoid-ossicle calcarenites with 40cm of siliceous shale, also chertified in its upper part, 1.1m above its base. Shale 3.3m thick separates these beds from the uppermost beds exposed, 1.8m of medium and thick bedded cherts with interbedded shaly cherts and cherty shales, overlain by a very cherty crinoid-ossicle calcarenite . The thick shale appears to thin eastwards across the outcrop

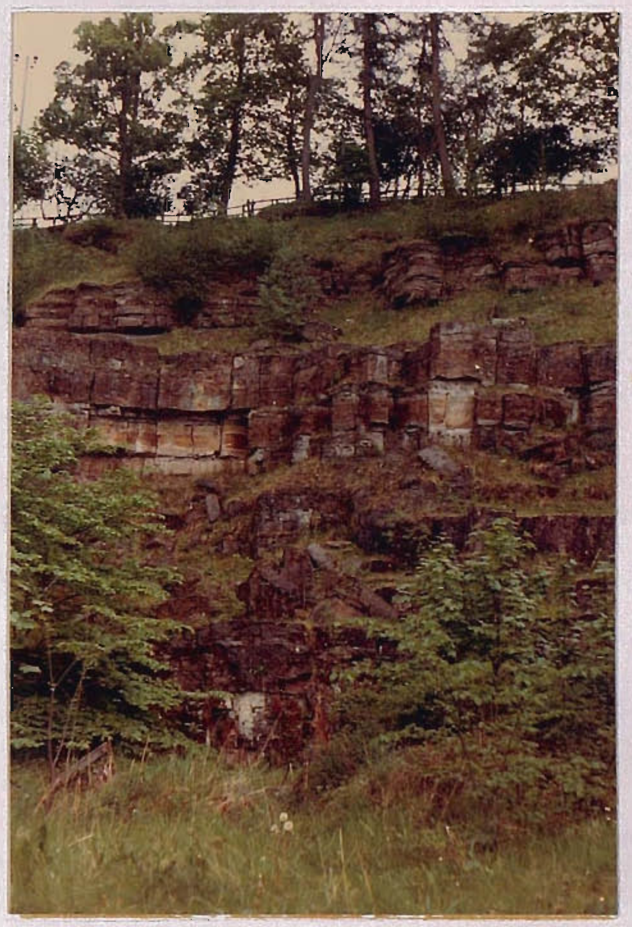


Plate 20. The Crow Limestone, Spring Wood Quarry (SE 168997), 1 km south of Richmond.

Medium to very thick bedded, patchily dolomitised and variably siliceous, crinoid-ossicle calcarenites with interbedded shales form most of the section. The grassed slope marks the position of a thick shale beneath the uppermost outcrops which are medium to thick bedded cherts with interbedded shaly cherts and cherty shales.

but this apparent thinning seems due to slippage of the overlying beds.

East of Spring Wood Quarry along the southside of Sandbeck small disused quarries expose medium to medium light grey crinoid-ossicle calcarenites. The best sections are in the small roadside quarries (SE 162998) where 6m of medium to very thick bedded, patchily dolomitised, variably siliceous crinoid-ossicle calcarenites are seen with chert nodules and very thin to thin cherty shale partings in the upper 1.75m. At SE 152995 3.5m of similar calcarenites are exposed.

In the area around Hudswell (NZ 146002), 1km to the north-west, several of the small streams flowing north into the River Swale expose the Crow Limestone. In Church Gill (NZ 141004) poor outcrops of patchily dolomitised, siliceous crinoid-ossicle calcarenites and cherts are seen but in Scarcote Gill (NZ 141004) to the east 20.8m of the Crow Limestone is patchily exposed. Here the lowest 4.35m of the Limestone rests on sandstone and consists of thick bedded, light grey to yellowish-brown, dark-streaked, dolomitised, calcareous cherts with Zoophycos. A gap of 1.7m separates these beds from shale at least 90cm thick which crops out on the north side of a fault. This fault downthrows south, dropping the upper part of the section, but gaps above may conceal other faults. On the south side of the fault 50cm of cherty shale is overlain, after a gap of 1.8m, by 1.65m of cherty shale and shaly chert followed by another gap of 5.35m. Thick bedded, dolomitised, siliceous calcarenites 1.85m thick are seen above overlain by 45cm of yellowish-brown, dark streaked, calcareous cherts with Zoophycos separated by a gap of 1.65m from similar beds 40cm thick. Blocks of Crow Limestone are well displayed in the nearby walls which, in addition to the lithologies seen in Scarcote Gill, contain shaly and calcareous cherts and crinoid-stem calcirudites with chert nodules. Small brachiopods, dominantly productids and spirifers, and spicules of Hyalostelia are common.

In High Spring Beck (SE 117996), 4½km southwest of Scarcote Gill, 16.16m of Crow Limestone is partly exposed. The lowest beds, medium to thick bedded, very siliceous, crinoid-ossicle calcarenites 4.75m thick, rest on sandstone and are overlain after a gap of 40cm by 70cm of siliceous shale. The outcrops above consist of light grey to yellowish-brown, dark-streaked cherts with a variable content of crinoid debris, small brachiopods and Zoophycos, but gaps of 2.4m, 70cm and 1m are seen 9.2m, 12m and 14.85m above their base respectively.

Farther south 5.65m of the Crow Limestone is seen in White Earth Quarry (SE 115984), 1/2km north of Downholme, but neither its base nor top is exposed (Plate 21). The lowest 3.85m are bluish-grey to light brownish-grey, thick to very thick bedded, patchily dolimitised, siliceous crinoid-ossicle calcarenites which become increasingly siliceous in the upper part. In addition to scattered chert nodules a thin nodular chert occurs 1.1m above the base. They are separated by 35cm of medium grey shaly chert from bluish-grey to greyish-orange, medium to thick bedded cherts and intensely but variably silicified crinoid-ossicle calcarenites 1.9m thick with fenestillid bryozoa and small brachiopods. Local variation in intensity of silicification is shown in Plate 22. For about 1m

Plate 21. The Crow Limestone, White Earth Quarry (SE 115984), Downholme. Very thick bedded siliceous crinoid-ossicle calcarenites separated from overlying variably calcareous cherts and very cherty crinoid-ossicle calcarenites by a poorly exposed shale.

Plate 22. The Crow Limestone, White Earth Quarry (SE 115984), Downholme. Close-up of the calcareous chert seen 1m above the scale in Plate 21. The dark bluish-grey patch is more highly silicified than the lighter surrounding area and shows diagenetic redistribution of silica was irregular.

above the outcrop loose blocks of chert are numerous.

Several small disused quarries expose the Crow Limestone near Coldstorms (SE 119967), 1.25km south of Downholme. The best section is in Coldstorms Quarry (SE 118996) where 4.3m of thick to very thick bedded, patchily dolomitised, siliceous calcarenites with scattered chert nodules and occasional clisiophyllid corals are exposed.

Upper Swaledale and the Northwest.

In the north of this area the outcrop of Crow Limestone passes eastward from Frumming Beck (NY 923083) to Dry Gill (NY 903084) on Sleightholme Moor but is then faulted out as far as Brownber. It reappears under Brownber Edge (NY 871086) and can be traced westwards around Nine Standards Rigg into Mallerstang. The outcrop can also be followed along the north side of Swaledale around the side of its northern tributary valleys from the head of Arkengarthdale westwards to Birkdale. It crosses Birkdale and passes eastwards along the southside of Swaledale to Downholme.

In the west of this region the best section of Crow Limestone is in Great Punchard Gill (NY 949042) where it is at least 18.9m thick and overlies sandstone. The lowest 6m are light grey, medium to very thick bedded, patchily dolomitised and silicified crinoid-ossicle calcarenites with 40cm of cherty shale 4.5m above their base. They are overlain by 8.35m of medium to light grey crinoid-ossicle calcarenites which are medium bedded with thin to medium interbedded cherty shales in the lower part but thick to very thick bedded in the upper part where interbedded shales are absent. Scattered grains of glauconite occur in the lower part and the upper calcarenites are dolomitised. About 3m of shale separates these beds from 1.35m of chert, the uppermost beds exposed. The chert is medium grey with darker grey streaks and blocky except at the top which is shaly. Small brachiopods, dominantly productids, and *Zoophycos* are common.

North of Punchard Gill the outcrops are poor. In Roe Beck (NY 949052) 40cm of cherty shale with scattered crinoid debris is overlain by 1m of yellowish-brown to greyish-orange, decalcified siliceous crinoid-ossicle calcarenite. The calcarenite contains small brachiopods, fenestellid bryozoa, *Hyalostelia* spicules and *Zoophycos*. Farther northwest in Lad Gill (NY 944057) at least 6.5m of similar beds are seen and at Annaside Head (NY 935060) several outcrops show at least 8m of the Crow Limestone but do not provide a continuous section. The beds exposed are light and medium grey to dark yellowish-orange, siliceous, usually decalcified, crinoid-ossicle calcarenites and cherts with a fauna of small brachiopods and *Zoophycos*. A complete section at Annaside Head was recorded by the Geological Survey (Mallerstang Memoir, 1891) : -

Chert	15'	(4.57m)
Shale	2'	(0.60m)
Limestone and chert	15'	(4.57m)

South of Great Punchard Gill the Crow Limestone is exposed again in Little Punchard Gill (NY 951031) but the section is faulted. It consists of medium and light grey to yellowish-brown, siliceous, crinoid-ossicle calcarenites and cherts with small brachiopods and *Zoophycos*.

Farther south several sections are recorded in the literature from mines:-

Arkendale.

(from Winch; Phillips, 1836)

Flinty Chert	16'	(4.88m)
Shale	1'	(0.30m)
Chert	6'	(1.83m)
Shale	9'	(2.74m)
Chert	12'	(3.66m)
Limestone	12'	(3.66m)

Old Moulds Arkengarthdale.

(Phillips, 1836)

Flinty Chert	36'	(10.97m)
Plate	15'	(4.57m)
Limestone	18'	(5.49m)

Old Gang, Swaledale.

recorded by Forster (Phillips, 1836)

Flinty Chert	12'	(3.66m)
Shale & Limestone	15'	(4.57m)
Chert	9'	(2.74m)
Limestone & coal	12'	(3.66m)

Shaft at Fourth Whim, Wet Shaw, Arkendale.

(Mallerstang Memoir, 1891)

Flinty Chert	15'	(4.57m)
Shale	3'	(0.91m)
Chert	8'	(2.44m)
Shale	9'6"	(2.90m)
Chert	13'	(3.96m)
Limestone	12'	(3.66m)

To the west the Crow Limestone forms scars on both sides of Blakethwaite Gill, near Blakethwaite Dam, and is well exposed.

The best section is in Benty Gutter (NY 936030), a small tributary of Blakethwaite Gill, where it overlies shale and is at least 20.75m thick. The lowest 30cm is a medium grey chert separated by a thin shale parting from 65cm of siliceous crinoid-ossicle calcarenite with a very cherty top. Above, shale 1.75m thick with brachiopods and scattered crinoid debris is overlain by 2.35m of shaly calcareous chert with scattered, crushed crinoid debris and small brachiopods. Light grey to greyish-orange, chertified crinoid-stem calcirudites

6.25m thick follow with numerous large Hyalostelia spicules in bundles on bedding surfaces and brachiopods including productids and spirifers. These beds are overlain by 35cm of calcareous shale then two thin limestones, a lower slightly cherty crinoid-stem calcirudite 25cm thick separated from an overlying slightly cherty crinoid-ossicle calcarenite with argillaceous streaks by a thin shale parting. Above 3.05m of shale, cherty in the upper 60cm, is overlain by 5.05m of medium to light grey chert with dark grey streaks. The chert has a thin shale parting 60cm above its base, contains sponge spicules and molds of small brachiopods and is overlain by shale.

The Crow Limestone thins eastwards to 14m in East Grain where it is separated from sandstones of the Uldale Sill by a thin shale. The lowest 1.75m is thick bedded and passes rapidly from calcilutite with scattered crinoid ossicles at the base into cherty crinoid-ossicle calcarenites. A gap of 1.1m separates these beds from 2.5m of thick to very thick bedded calcareous cherts which are shaly in the lowest part and contain Zoophycos. Above 3.3m of light grey siliceous crinoid-stem calcarenites and calcirudites are followed by 60cm of laminated chert with Zoophycos. The succeeding beds are now poorly exposed but Scanlon (1955) recorded 7' (2.13m) of shale, then a cherty glauconitic limestone 3'6" (1.07m) thick, separated by a gap of 3' (91cm) from the uppermost bed, 1' (30cm) of cherty limestone. A thick shale overlies the Limestone.

Siliceous calcarenites and calcirudites are also exposed in a scar on the east side of Swinner Gill (NY 911013) but a complete section crops out in Hind Hole Beck (NY 913017). Here the Crow Limestone is 8.35m thick and separated from the Uldale Sill by 50cm of shale with a thin calcilutite. Dark grey calcilutite with scattered shell debris forms the lowest 85cm of the Limestone. It is overlain by 45cm of siliceous calcilutite which has a highly siliceous upper part and passes up into light grey, siliceous, crinoid-ossicle calcarenites with dark grey Zoophycos and a very cherty, highly burrowed top. Above, 1.05m of light grey calcareous chert with a shaly lower part and Zoophycos passes into 1.6m of light grey, very cherty crinoid-ossicle calcarenite which become less crinoidal and shaly at the top. These beds are overlain by 90cm of shale with scattered small phosphate nodules, then 2.4m of blocky calcareous cherts with two thin shale partings 7cm and 15cm thick, 1.45m and 2.05m above their base. The chert above the shale partings contains small scattered phosphate nodules and is overlain by shale.

In East Gill (NY 904032) the Crow Limestone is also separated from the Uldale Sill by a thin shale but thins to 7.85m. Dark grey, thin parted calcareous cherts 90cm thick with productids and Hyalostelia spicules are overlain by light grey, thick to very thick bedded, siliceous crinoid-ossicle calcarenites. A gap of 1.2m separates these beds from 60cm of dark grey calcilutite with scattered crinoid ossicles and small brachiopods. Above 60cm of calcareous shale with productids, productid spines and scattered crinoid debris is succeeded by 2.65m of medium grey, siliceous crinoidal calcilutites and calcarenites with a 35cm calcareous shale

75cm above their base. The calcarenites contain a fauna of productids and Hyalostelia spicules.

Several outcrops of Crow Limestone are seen in West Stonesdale. In Haw Gill (NY 891031) about 3.25m of medium grey, cherty limestone with thin shaly partings, scattered crinoid debris, brachiopods, fenestellid bryozoa and Hyalostelia spicules are exposed. The slipped section is very weathered and much of the limestone decalcified and stained yellowish-orange. Farther north in Mould Gill (NY 889037), only 1.25m of medium grey, cherty calcilutite with scattered crinoid debris and Hyalostelia spicules is seen, overlain by poor outcrops of cherty bioclastic calcilutites. Scanlon (1955) however, recorded the following succession:- cherty limestone 6" (15cm), shale 1'6" (45cm), cherty limestone 2'0" (60cm), gap 3'0" (91cm), grey limestone 5' (1.52m) of which 1.25m is now exposed, cherty limestone with sponge spicules, organic debris and rare glauconite near the top 4' (1.22m), sandy limestone 6" (15cm), shale 1'0" (30cm) and finally 8" (20cm) of silty crinoidal limestone.

In the disused quarry (NY 885042) 100m east of Stonesdale Bridge the Crow Limestone crops out again. Here 1.2m of cherty shale is overlain by 40cm of dark grey, cherty calcilutite with scattered bioclasts. Scanlon (1957) recorded a gap of 5'0" (1.52m) beneath the shale, then 6" (15cm) of grey fossiliferous limestone separated by a 1'6" (45cm) gap from 1' (30cm) of grey sandy fossiliferous limestone giving the Crow Limestone a thickness of at least 4m. In Stonesdale Beck (NY 886042) at least 50cm of dark grey calcilutite with disseminated pyrite and rare glauconite is separated by a gap of 45cm, probably in shale, from 35cm of cherty shale, overlain by 30cm of cherty, slightly pyritic, calcilutite with rare glauconite. To the north on High Brown Hill (NY 887054), just east of West Stonesdale to Tan Hill Road, 1.8m of cherty crinoid-ossicle calcarenites and calcilutites with scattered crinoid debris, a few glauconite grains and Zoophycos are seen whilst at the confluence of Tan Gill and Stonesdale Beck (NY 886054) 1.85m of cherty calcilutite with sparse bioclastic debris and Zoophycos is overlain by 1.15m of cherty crinoidal calcarenite with small brachiopods and spicules of Hyalostelia .

On the west side of West Stonesdale 1.65m of dark grey calcareous chert overlying 50cm of cherty shale is exposed in Thomas Gill (NY 883056). Farther south in Wetshaw Gill (NY 881041) 30cm of calcareous, silty, glauconite sandstone with numerous rounded phosphate nodules up to 5cm in diameter, especially abundant in the upper part, overlies shale. A lower bed of similar thickness was recorded by Scanlon (1955) beneath 2.15m of shale underlying the upper leaf.

In Birkdale the Crow Limestone consists of a thin lower and upper leaf separated by a thick shale. In Birkdale Beck (NY 853011), 0.5km downstream from Ellers Bridge , the lower leaf is a dark grey, quartz sandstone 30cm thick with Zoophycos. It overlies sandstone of the Uldale Sill and is separated from the upper leaf by about 1.6m of shale of which only the upper 30cm, containing phosphate nodules, is exposed. The upper leaf forms a highly jointed pavement below Ellers Bridge (NY 849012). It is a siliceous, phosphatic, glauconite sandstone with thin shale partings at the top, numerous dark grey phosphate nodules and Zoophycos. The phosphate nodules are exceptionally numerous on certain bedding planes and seen best on blocks detached from the outcrop (Plate 24). They are round to subround, up to 10cm in diameter although commonly 1cm to 5cm, weather pale grey and distort laminae in the surrounding rock. Farther upstream (NY 837018), near the confluence with Brigstone Gill, the Crow Limestone is exposed again. Here the lowest leaf is 1.35m thick and divided by 30cm of siliceous shale with phosphate nodules into a lower and upper dark grey, phosphatic chert 35cm and 70cm thick respectively, with disseminated pyrite, scattered glauconite and phosphate nodules in the upper part. It is separated from the upper leaf, a dark grey, phosphatic, sandy chert with phosphate nodules and scattered grains of glauconite by 3m of shale of which only the upper 25cm is exposed.

At the head of Birkdale the lower leaf is exposed in Uldale Beck (NY 813033) where 1.9m of fissile, dark grey, phosphatic, silty chert with Zoophycos overlies a gap of 15cm above the Uldale Sill.

North of Birkdale in Whitsundale, the shale separating the lower and upper parts of the Crow Limestone thickens. In Hoods Bottom Beck (NY 863038) the lower leaf is a calcareous, sandy, cherty, glauconite sandstone only 15cm thick with phosphate nodules, separated from the Uldale Sill by 80cm of shale. It is overlain by 5.75m of shale with siderite nodules scattered throughout the lower 3.1m and a 10cm bed of siderite 1.1m above its base. The

Plate 23. The Crow Limestone, Hoods Bottom Beck (NY 863038), Whitsundale. The lowest bed forms the prominent ledge above the stream. The uppermost bed is seen just beneath the top of the bank above the bend in the stream. Both are thin glauconite sandstones and are separated by shales with sideritic concretions.

Plate 24. The Crow Limestone, Birkdale Beck (NY 852012), Birkdale.

The underside of a loose block of cherty glauconite sandstone from the upper part of the Crow Limestone showing abundant well developed phosphate nodules.

upper leaf is a cherty, calcareous, sandy, glauconite sandstone varying in thickness from 25cm to 35cm. The upper leaf is of similar lithology in Long Gill (NY 865033) and Caveside Gill (NY869026), where it is 1m and 25cm thick respectively. It is underlain by shale at least 3.5m thick in Caveside Gill and 1.5m in Long Gill but the lower leaf is not exposed at either locality. In Whitsundale Beck (NY 850037) farther west the Crow Limestone also overlies shale which is cherty in the upper part and overlain by 45cm of dark grey, fissile, silty chert with Zoophycos. This is separated from 23cm of cherty, calcareous, sandy, glauconite sandstone with numerous phosphate nodules by a shale parting 8cm thick. The lower leaf is overlain by a thick shale but only the lower 50cm with phosphate nodules is exposed. The upper leaf is not seen in situ but loose blocks show it to be a silty glauconite chert 60cm thick with a thin shale parting in the centre.

Farther north several of the small streams draining Brownber Edge expose the Crow Limestone. In Roantree Gill (NY 871086) the lowest bed, a silty, calcareous, glauconite chert with small lenses of glauconite at the base and small scattered phosphate nodules, overlies at least 1.3m of shale. A gap of 2.3m separates it from 1m of shale, followed by 1.15m of dark grey, silty chert. Similar sections are seen in Deepgill Sike and Bleaberry Beck farther east. In Deepgill Sike (NY 864081) the lowest bed also overlies shale and is a silty, glauconitic, calcareous chert 45cm thick with abundant glauconite at the base and phosphate nodules up to 1cm in diameter. A gap of 50cm separates this bed from 90cm of siliceous calcilutites overlain by 40cm of dark grey, laminated, siliceous calcilutite. Another gap of 90cm follows, then 10cm of dark grey, calcareous chert with Zoophycos, overlain by loose blocks of calcilutite. In Bleaberry Beck (NY 843071) the lowest 60cm of Crow Limestone exposed is a dark grey, pyritic and glauconitic, siliceous calcilutite. It is overlain by 20cm of shale followed by a 2.25m gap then 40cm of shale. Above the shale 1.5m of light grey to greyish-orange chert is seen with pale grey-weathering, dark grey phosphate nodules. The chert, especially the upper 60cm, weathers very light grey.

On the north flank of Nine Standards Rigg in Williamson Gill (NY 832076) 1.2m of medium grey, calcareous chert with small lenses of glauconite are overlain by 60cm of shale. A scree with small, loose fragments of very light grey chert with phosphate nodules is seen above.

To the west in Bields Gill (NY 820076), on the northwest slopes of Bastifell, 40cm of dark grey calcareous chert with small dark grey phosphate nodules, disseminated pyrite and Zoophycos, overlies shale but better sections are seen in the streams draining the west side of Nine Standards Rigg.

In Rollinson Gill (NY 818057) 2.7m of light grey to greyish-orange calcareous cherts overlie shale. The lowest 1.9m contains dark grey phosphate nodules and glauconite and weathers yellowish-orange whereas the upper 80cm weathers very light grey. Similar beds are seen in the unnamed gill (NY 816061) north of Rollinson Gill where 60cm of medium grey, yellowish-orange-weathering chert with dark grey phosphate nodules and scattered grains of glauconite are overlain by 50cm of very light grey weathering, medium grey, calcareous chert with brachiopods. A more complete section is visible in Jack Standards Gill (NY 818054) farther south although the upper part is disturbed by faulting. The lowest beds overlie shale and are dark grey cherts, 1.7m thick with Zoophycos. A 15cm shale separates them from 8.8m of highly weathered, yellowish-orange, calcareous cherts and cherty calcarenites with a 70cm shale 3.2m above the base. They contain crinoid debris, brachiopods (dominantly small productids including spinose types) and Hyalostelia spicules. The uppermost beds are greyish-orange, very light grey-weathering cherts 70cm thick with dark grey phosphate nodules and small brachiopods.

On the south side of Swaledale in Great Sleddale the Crow Limestone is seen north of the Stockdale Fault (NY 851004) as 60cm of well jointed, sandy, glauconitic chert but to the south of the Fault in Stackers Gill (SD 838984) and Brian Grain (SD 841983) it is absent. In Stackers Gill 2.4m of shale separates the Uldale Sill from the Lower Stonesdale Limestone and in Brian Grain the Lower Stonesdale Limestone is only 60cm above the Uldale Sill. There is no trace of the Crow Limestone at either locality. The Crow Limestone is also absent in Thwaite Beck (SD 860977), 2km to the southeast. Here 2.4m of shale separates the top of the Uldale Sill, which is calcareous and glauconitic, from the Lower Stonesdale Limestone. The Crow Limestone reappears in Grainy Gill (SD 869970) 1km to the southeast, as a sandy crinoid-ossicle calcarenite 60cm thick, especially sandy at the base and top.

Small blocks of coarsely crinoidal Crow Limestone are seen beneath the Lower Howgate Edge Grit on Long Scar (SD 875959) but from Long Scar eastwards as far as Stony Gill (SD 919953) it has been removed by intra-E_1 erosion preceding deposition of the Lower Howgate Edge. It reappears at Stony Gill Head (SD 919953) where 3.7m of very light grey to greyish-orange, siliceous crinoid-ossicle calcarenites and crinoid-stem calcirudites outcrop beneath the Lower Howgate Edge Grit. Crinoid stems, up to 20cm long and 2cm in diameter, and thin cherty streaks occur throughout. Between Stony Gill and Summer Lodge Beck the Crow Limestone is not exposed but at the latter locality small loose blocks of crinoidal calcarenites are seen beneath the Lower Howgate Edge Grit.

To the east the Crow Limestone thickens and becomes increasingly siliceous. In Sod Dyke Nick (SD 973954) it is about 8.7m thick but apart from 35cm of chert seen 3m above the top of the Uldale Sill the lower 3.95m is not exposed although loose cherty fragments are common. Above, 2.95m of highly weathered, calcareous cherts and siliceous calcarenites outcrop with a 20cm gap 70cm above their base. The lowest 40cm is a siliceous, decalcified, yellowish-orange-weathering calcarenite, overlain by calcareous cherts with much organic debris including brachiopods and crinoid and echinoid debris. These beds are overlain by 2.3m of laminated chert, capped by a distinctive, pale-grey-weathering, partly decalcified, calcareous chert 50cm thick.

On Grinton Moor small outcrops of flinty chert belonging to the Crow Limestone are seen at SE 037955, SE 039975 and SE 031957 but each shows less than 2m, Farther east, near Haggs Gill Bridge SE 063955), loose fragments of cherty crinoid-ossicle calcarenites, calcirudites and flinty and shaly cherts with Hyalostelia spicules are seen but the next good sections are those around Downholme (p.281).

Mallerstang.

On the east side of Mallerstang the outcrop of the Crow Limestone is parallel to the River Eden and occurs high up on the side of the valley. On the west side of the dale it passes around the flanks of Swarth Fell, Wild Boar Fell and Little Fell. Splinter faults trending southeast-northwest from the east end of the Stockdale monocline displace the outcrop.

On the east side of Mallerstang the Crow Limestone is exposed in Red Scar Gill (NY 791027), Sloe Brae Gill (NY 792013) and Hell Gill Beck (SD 794981). In Red Scar Gill (NY 791027), the most northerly outcrop, 1.5m of chert and cherty calcilutite overlie shale. The lower 90cm is shaly-weathering, slightly calcareous, silty chert with small brachiopods whereas the upper part consists of siliceous, silty calcilutite with shell debris. Zoophycos occurs in both lower and upper parts. In Sloe Brae Gill (NY 792013) at least 45cm of calcareous, silty, glauconitic chert with phosphate nodules overlies shale but farther south the Crow Limestone becomes crinoidal. In Hell Gill Beck (SD 794981) the lowest bed is a cherty, crinoid-ossicle calcarenite 1.2m thick but crinoid debris is sparse at the base and top which are very cherty. It is overlain by 1m of calcareous chert. Hyalostelia spicules are common throughout but especially abundant near the base and top of the calcarenite.

On the west side of Mallerstang 45cm of slightly silty chert with rare glauconite grains is seen in Fall Gill Sike (NY 775013) and to the south, in Deep Gill (NY 774003), 2m of silty, calcareous, glauconitic chert with Hyalostelia spicules, occasional brachiopods and scattered small crinoid ossicles, commonest in the upper part, overlies shale. Farther west the Crow Limestone crops out in the south bank of Long Gill (NY 760006) where at least 90cm of dark grey, calcareous chert with phosphate nodules up to 1cm in diameter is seen disturbed by faulting. On the north flank of Wild Boar Fell the Crow Limestone becomes crinoidal. In Scandal Beck (SD 758995) 2.7m of cherty crinoid-ossicle and -stem calcarenite is seen in situ but loose blocks indicate the Limestone to be at least 4m thick. A similar section on the northeast end of Wild Boar Fell (SD 765996) shows 2.9m of the Limestone. The lower 1.6m, a slightly silty chert with numerous Hyalostelia spicules, becomes calcareous upwards and passes up into 1.3m of cherty crinoid-ossicle calcarenites also with Hyalostelia. In Far Cote Gill (SD 766969), 3km farther south, the Crow Limestone is a dark grey, silty, calcareous chert at least 60cm thick.

Garsdale, Baugh Fell and the Northwest.

In this area the outcrop of the Crow Limestone passes around the flanks of Baugh Fell and the summit of Aye Gill Pike to the south but exposures are confined to the streams draining the north and east flanks of Baugh Fell.

In Swere Gill (SD 744935) a gap of 80cm separates the Crow Limestone from underlying sandstone. The lowest bed is a medium to dark grey, slightly silty calcilutite 65cm thick. It is shaly with numerous small crinoid-ossicles at the base and slightly glauconitic with small phosphate nodules and scattered crinoid and shell debris above. A gap of about 3m separates this bed from 1.9m of shale overlain by at least 60cm of dark grey, laminated chert with sponge spicules. The chert also crops out in Rawthey Gill to the west where it is at least 90cm thick and overlies 1.57m of shale.

East of Swere Gill the Crow Limestone becomes coarsely crinoidal. In Cartmire Gill (SD 753935) and Shorter Gill (SD 761932) thick to very thick bedded, patchily dolomitised, crinoid-ossicle and -stem calcarenites at least 2.05m and 2.45m thick respectively are exposed. They are very cherty in the upper part and at both outcrops the uppermost 15cm is a dolomitic crinoidal chert. In Ceaseat Beck (SD 762918) only 40cm of crinoid-ossicle calcarenite is exposed.

On Aye Gill Pike, south of Baugh Fell, the Crow Limestone is of similar lithology for Strahan (1891) recorded "a thin encrinital limestone about three feet (90cm) thick" on the south and east sides of Rise Hill.

South of Dentdale the Crow Limestone is absent but it has not been removed by intra-E_1 erosion since the base of the Grassington Grit rests on a stratigraphically higher horizon. The conformable nature of the succession at the level of the Crow Limestone and the absence of evidence of erosion shows that the limestone did not accumulate in this area.

Upper Wensleydale.

The outcrop of the Crow Limestone passes along the north side of Wensleydale from the head of the dale around Lunds Fell eastwards into Cotterdale. Between Cotterdale and Fossdale, because of poor exposure, it is not known if the Crow Limestone is present or whether it has been removed by intra-E_1 erosion preceding deposition of the Grassington Grit. In Fossdale Beck (SD 863958) it is exposed beneath the Grit but farther east it has been removed. On the south side of Wensleydale it is seen only at the head of the dale on the southwest slopes of Swarth Fell. Elsewhere it has been removed by intra-E_1 erosion.

The most westerly section in this region is in Goodham Gill (SD 772950), on the southwest slope of Swarth Fell, where 60cm of dark grey, silty, calcareous chert with productids and orthotetids is seen. Rowell & Scanlon (1957) recorded part of a *Megalichthys* from this bed and a siliceous plant bed beneath the Limestone.

On the opposite side of the dale exposures in the streams draining Lunds Fell are poor. In Washer Gill (SD 797958) 60cm of calcareous chert is all that is seen but in Dove Gill (SD 807946) to the south 3m of calcareous chert with sparse crinoid debris crops out. Crinoid debris becomes more abundant to the south and east and in Johnston Gill (SD 811942), although only 15cm of crinoid-ossicle calcarenite is seen in situ, a loose block of cherty, coarse crinoid-ossicle and -stem calcarenite above indicates a thicker sequence.

The Crow Limestone is also coarsely crinoidal in Cotterdale. In Howmea Gill (SD 819965) 1.6m of cherty, coarsely crinoidal calcarenite is exposed but a more complete section exposing 7m of the Crow Limestone is seen in Far Howmea Gill (SD 819968). The lowest 3.2m are medium grey, thin parted cherts which pass locally into cherty, crinoid-ossicle calcarenites where their variable content of crinoid debris increases. They are separated by a gap of 45cm from underlying sandstone and overlain by 70cm of dark grey chert with scattered crinoid debris and abundant Hyalostelia spicules in the upper part. The uppermost 2.65m are very thick bedded, patchily dolomitised, cherty crinoid-ossicle calcarenites. A similar succession is exposed in East Gill (SD 837967) where 4.13m of the Crow Limestone is exposed above sandstone. The lowest 2.65m, medium to very thick bedded, cherty crinoid-ossicle calcarenites are overlain by 1.48m of chert with scattered crinoid debris. Hyalostelia spicules are common throughout.

East of Cotterdale the Crow Limestone is next exposed in Fossdale Beck 1.8m beneath the Lower Howgate Edge Grit. The lowest bed, a dark grey, calcareous sandstone, 36cm thick, with scattered grains of glauconite, phosphate nodules and Zoophycos is overlain by 50cm of medium grey, laminated, micaceous siltstone, also with scattered grains of glauconite. The uppermost bed is a medium grey, pyritic, calcareous, glauconitic sandstone, 30cm thick with small phosphate nodules and Zoophycos. In Upper Wensleydale, east of Fossdale Beck, the Crow Limestone has been removed by intra-E_1 erosion.

Lower Wensleydale.

Over most of this area the Crow Limestone has been removed by intra-E_1 erosion preceeding deposition of the Grassington Grit. On the north side of Wensleydale it is absent west of Beldon Beck (SD 974939) except in the vicinity of Whitby Gill Head (SD 918952). East of Beldon its outcrop passes along the northside of the dale as far as Jervaulx Abbey (SE 164862) where it crosses the River Ure. It then trends westwards along the south side of Wensleydale under East Witton as far as the north slope of Crundel Hill (SE 111856) but farther west and to the south it is absent.

The most westerly exposure of the Crow Limestone in this area is at Whitby Gill Head (SD 918952) where, at least 2.75m of very light grey to greyish-orange, cherty crinoid-stem calcarenites and calcirudites outcrop beneath the Lower Howgate Edge Grit. To the east several sections are seen in the upper tributaries of Apedale Beck, the best at SE 007954. A gap of 2.1m separates the lowest bed exposed, a crinoid-ossicle calcarenite 50cm thick, from 1.7m of medium to thick bedded, dark grey chert with Zoophycos. A further gap of 1.5m separates these beds from 3.5m of light grey-weathering, laminated cherts.

Only small exposures are seen in the disused quarries around Yarker Bank Farm (SE 105915), northwest of Leyburn. The base of the Limestone is poorly seen in Yarker Bank Quarry (SE 108912) where cherty crinoid-ossicle calcarenites overlie sandstone but thicker sections are seen in the old quarries at SE 104913 and SE 104917 where 4.15m and 3.1m of light grey, siliceous crinoid - ossicle calcarenites outcrop respectively. They contain scattered chert nodules and a highly chertified horizon about 20cm thick.

Between Yarker Bank Farm (SE 105915) and Stoop House Quarry (SE 147902) several disused quarries expose small thicknesses of light grey, chertified crinoid-ossicle calcarenites with scattered chert nodules but the best section, in Stoop House Quarry (SE 147902), shows 4.5m of thin to very thick bedded, siliceous crinoid-ossicle calcarenites with very thin cherty shale partings. Intense silicification of the calcarenites, usually in thin bands or irregular areas, gives them a flinty appearance locally.

Siliceous calcarenites are visible in several small quarries to the east of Spennithorne (SE 145891) but none exposes more than 1.25m. In the old quarry (SE 152876), southwest of Hollins House, 2.2m of less crinoidal calcarenites are seen with a glassy chert in the upper part and two shales, 20cm and 10cm thick, 55cm and 1.15m above the base of the section respectively.

The Crow Limestone was recorded from a borehole near Croft House (SE 198888) by the Institute of Geological Sciences (pers. comm.). The borehole penetrated 18.2m of limestone beneath the Grassington Grit but failed to reach its base. The lowest 6.88m and uppermost 7.45m encountered were variably cherty crinoid-ossicle calcarenites separated by calcilutites with Zoophycos.

South of the River Ure the Crow Limestone outcrops in Red Beck Gill (SE 121857), west of East Witton, where it rests on sandstone. Here it is 6m thick and consists of medium grey crinoid-ossicle calcarenites with two thin nodular cherts 1.15m and 1.50m above its base. Phillips (1836) recorded that 7 yards (6.4m) of limestone were sunk through in East Witton. As the village is situated below the top of the Crow Limestone the thickness of limestone must be greater than 6.4m, probably 9m or 10m. To the south the Crow Limestone has been removed by intra-E_1 erosion.

FIGURED SECTIONS OF THE CROW LIMESTONE.

1.	Quarry 200m southwest Sandbeck East Bridge	SE 171998	27.	Red Scar Gill	NY 791027
2.	Spring Wood Quarry.	SE 168997	28.	Sloe Brae Gill	NY 792013
3.	Quarry 500m west Sandbeck West Bridge.	SE 162997	29.	Fallgill Sike	NY 775013
4.	Scarcote Gill	NZ 129007	30.	Long Gill	NY 760006
5.	Great Punchard Gill.	NY 149042	31.	Long Gill	NY 774006
6.	Benty Gutter	NY 936030	32.	Deep Gill	NY 774003
7.	East Grain	NY 914013	33.	High Dolphinsty	SD 765996
8.	Hind Hole Beck	NY 913017	34.	Scandal Beck	SD 758995
9.	East Gill	NY 904032	35.	Hell Gill Beck	SD 794981
10.	Mould Gill	NY 889037	36.	Far Cote Gill	SD 766964
11.	Stonesdale Bridge Quarry	NY 885042	37.	Goodham Gill	SD 772950
12.	Tan Gill.	NY 886059	38.	Rawthey Gill	SD 737934
13.	Wetshaw Gill	NY 881041	39.	Swere Gill	SD 744935
14.	Caveside Gill	NY 869026	40.	Cartmire Gill	SD 753935
15.	Long Gill	NY 865033	41.	Shorter Gill	SD 761932
16.	Hoods Bottom Beck	NY 863038	42.	Ceaseat Beck	SD 762918
17.	Whitsundale Beck	NY 850037	43.	Rise Hill	SD 725885
18.	Birkdale Beck	NY 852012	44.	Washer Gill	SD 797958
19.	Birkdale Beck	NY 837018	45.	Dove Gill	SD 807946
20.	Widdale Beck	NY 813033	46.	Howmea Gill	SD 819965
21.	Jack Standards Gill	NY 818054	47.	Far Howmea Gill	SD 819968
22.	Rollinson Gill	NY 818057	48.	East Gill	SD 837967
23.	Williamson Gill	NY 832076	49.	Stackers Gill	SD 838984
24.	Bleaberry Beck	NY 843071	50.	Thwaite Beck	SD 860977
25.	Deepgill Sike	NY 864081	51.	Grainy Gill	SD 869970
26.	Roantree Gill	NY 871086	52.	Fossdale Gill	SD 863958

53.	Stony Gill Head	SD 919953
54.	Whitby Gill Head	SD 918952
55.	Sod Dyke Nick	SD 973954
56.	Apedale Beck	SE 007954
57.	High Spring Beck	SE 117996
58.	White Earth Quarry	SE 115984
59.	Coldstorms Quarry	SE 118966
60.	Yarker Bank Farm Quarry	SE 108912
61.	Stoop House Quarry	SE 146902
62.	Croft House Borehole	SE 198888
63.	Red Beck Gill	SE 121857

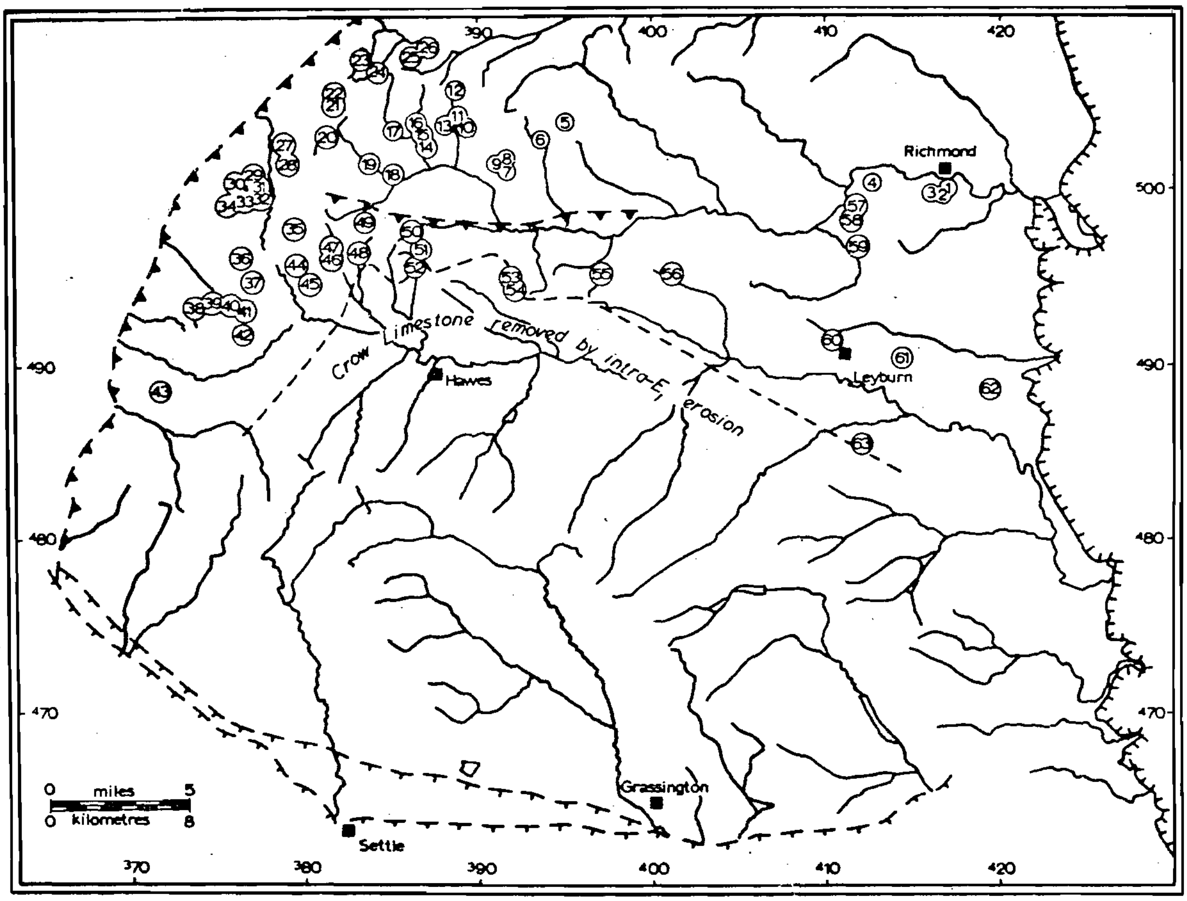


Fig. 52. Map showing location of figured sections of Crow Limestone.

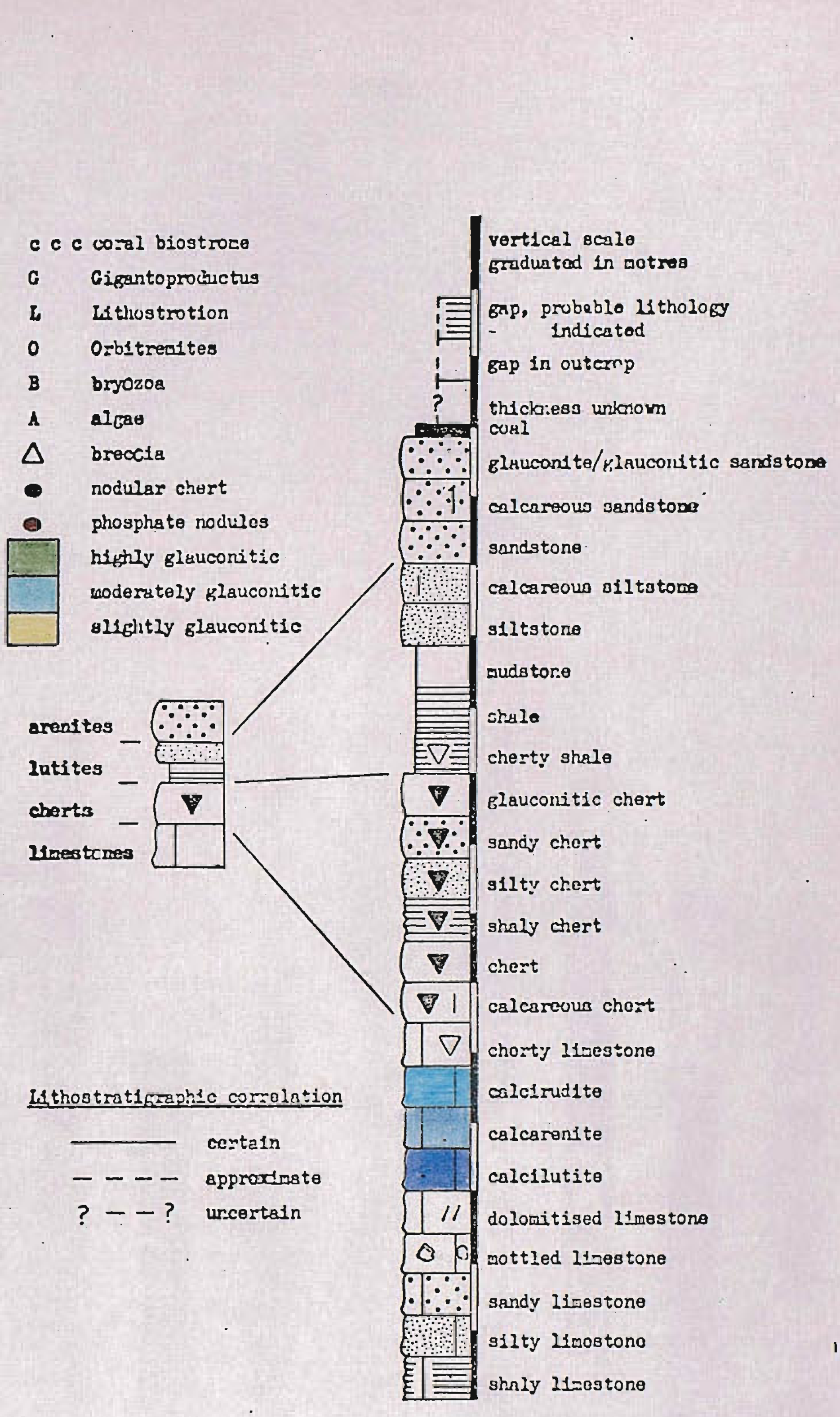


Fig. 53. Key to symbols used in the figured sections.

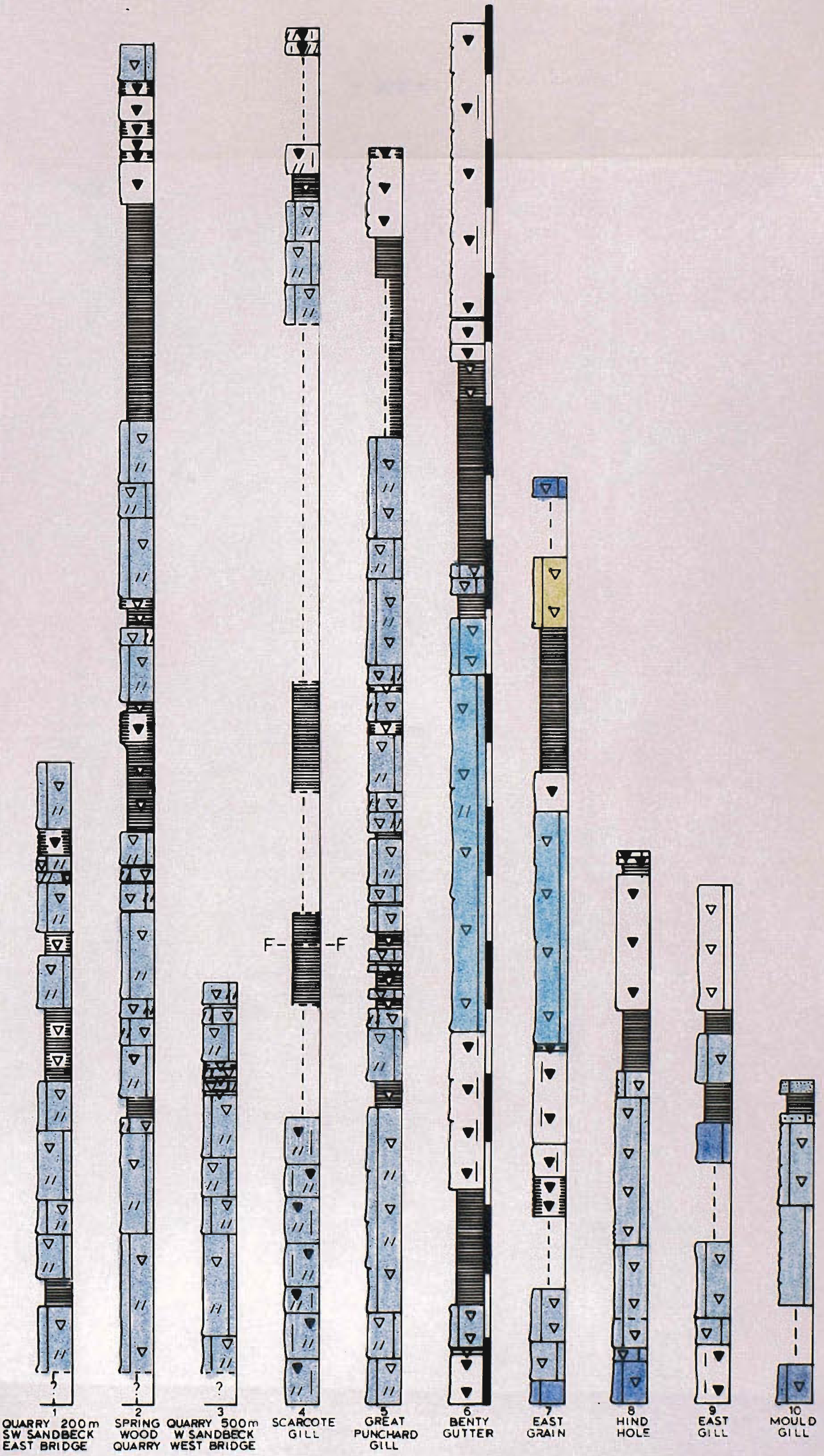

F- -F
?
?
?
1
QUARRY 200m
SW SANDBECK
EAST BRIDGE
2
SPRING
WOOD
QUARRY
3
QUARRY 500m
W SANDBECK
WEST BRIDGE
4
SCARCOTE
GILL
5
GREAT
PUNCHARD
GILL
6
BENTY
GUTTER
7
EAST
GRAIN
8
HIND
HOLE
9
EAST
GILL
10
MOULD
GILL

Fig. 54.

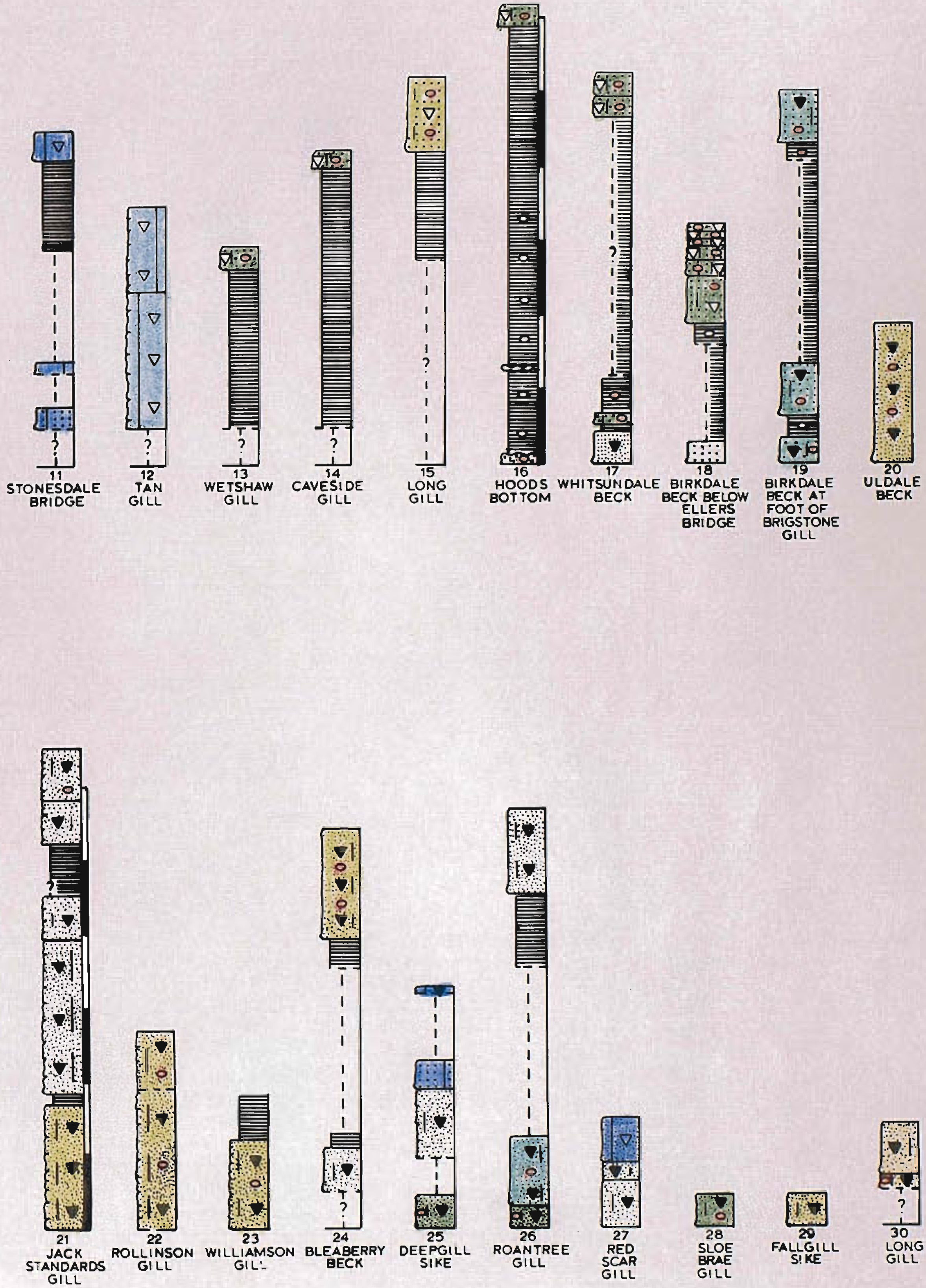

11 STONESDALE BRIDGE
12 TAN GILL
13 WETSHAW GILL
14 CAVESIDE GILL
15 LONG GILL
16 HOODS BOTTOM
17 WHITSUNDALE BECK
18 BIRKDALE BECK BELOW ELLERS BRIDGE
19 BIRKDALE BECK AT FOOT OF BRIGSTONE GILL
20 ULDALE BECK
21 JACK STANDARDS GILL
22 ROLLINSON GILL
23 WILLIAMSON GILL
24 BLEABERRY BECK
25 DEEPGILL SIKE
26 ROANTREE GILL
27 RED SCAR GILL
28 SLOE BRAE GILL
29 FALLGILL SIKE
30 LONG GILL

Fig. 55.

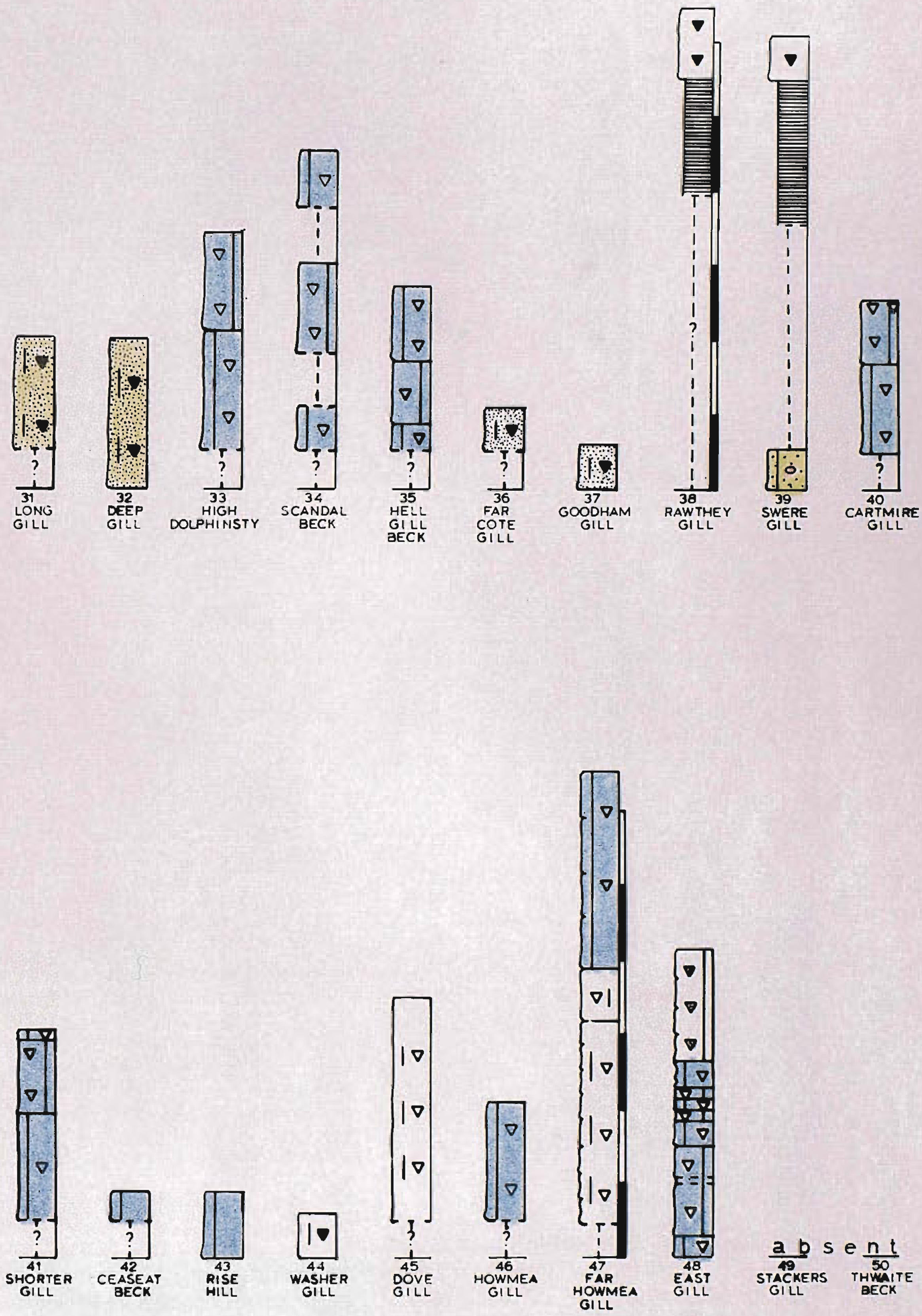

31
LONG
GILL
32
DEEP
GILL
33
HIGH
DOLPHINSTY
34
SCANDAL
BECK
35
HELL
GILL
BECK
36
FAR
COTE
GILL
37
GOODHAM
GILL
38
RAWTHEY
GILL
39
SWERE
GILL
40
CARTMIRE
GILL
41
SHORTER
GILL
42
CEASEAT
BECK
43
RISE
HILL
44
WASHER
GILL
45
DOVE
GILL
46
HOWMEA
GILL
47
FAR
HOWMEA
GILL
48
EAST
GILL
absent
49
STACKERS
GILL
50
THWAITE
BECK

Fig. 56.

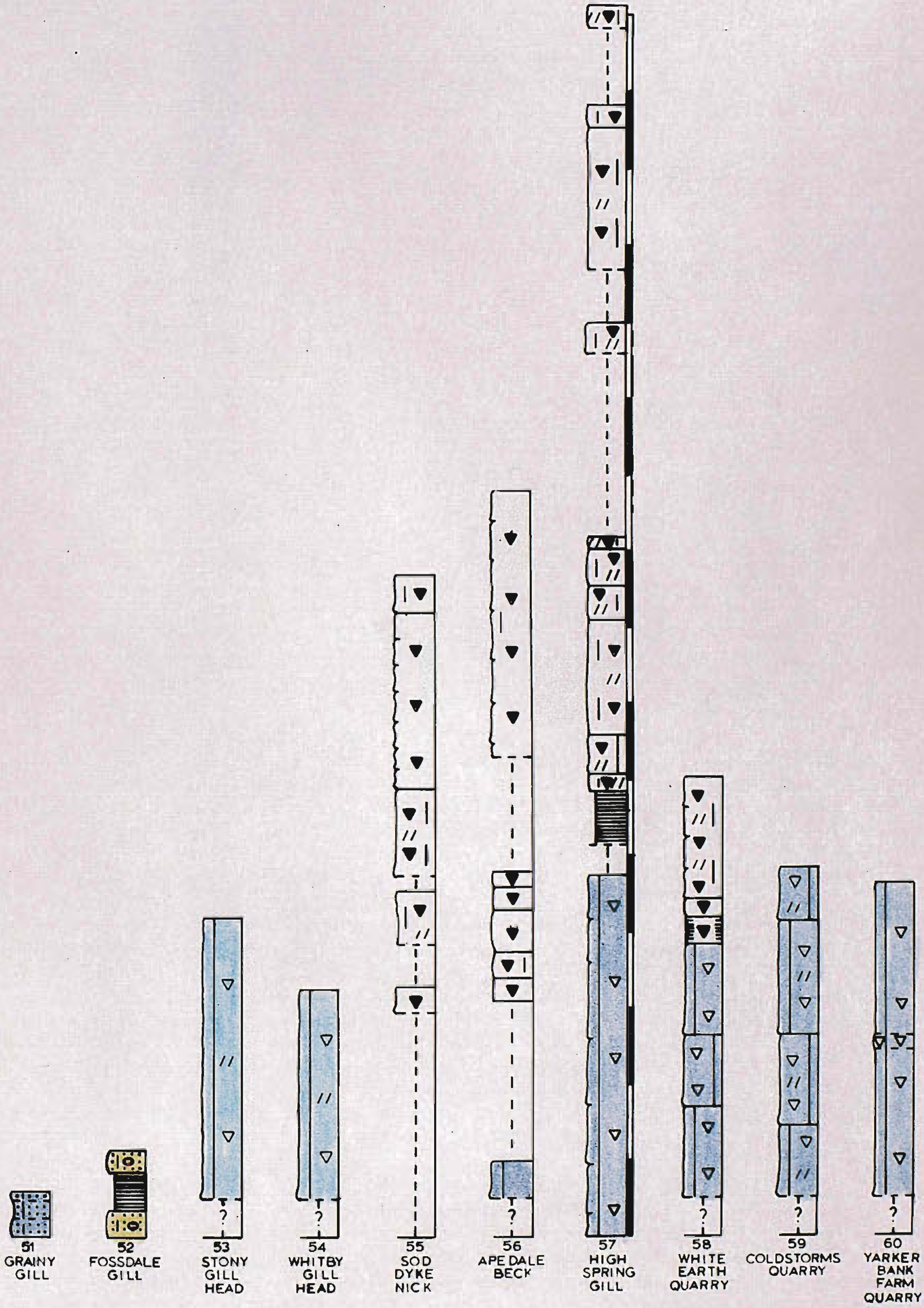

51
GRAINY
GILL
52
FOSSDALE
GILL
53
STONY
GILL
HEAD
54
WHITBY
GILL
HEAD
55
SOD
DYKE
NICK
56
APEDALE
BECK
57
HIGH
SPRING
GILL
58
WHITE
EARTH
QUARRY
59
COLDSTORMS
QUARRY
60
YARKER
BANK
FARM
QUARRY

Fig. 57.

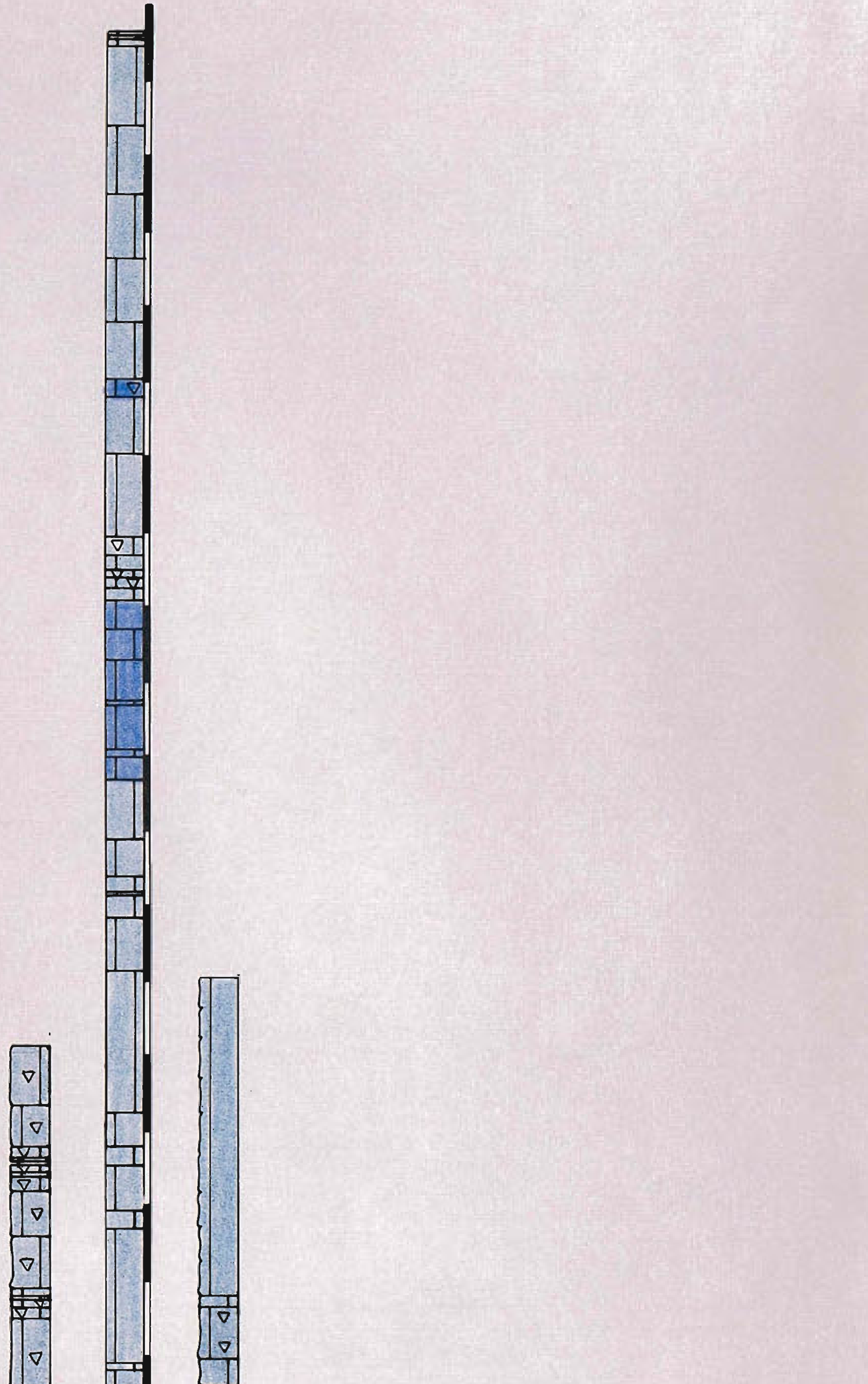


Fig. 58.

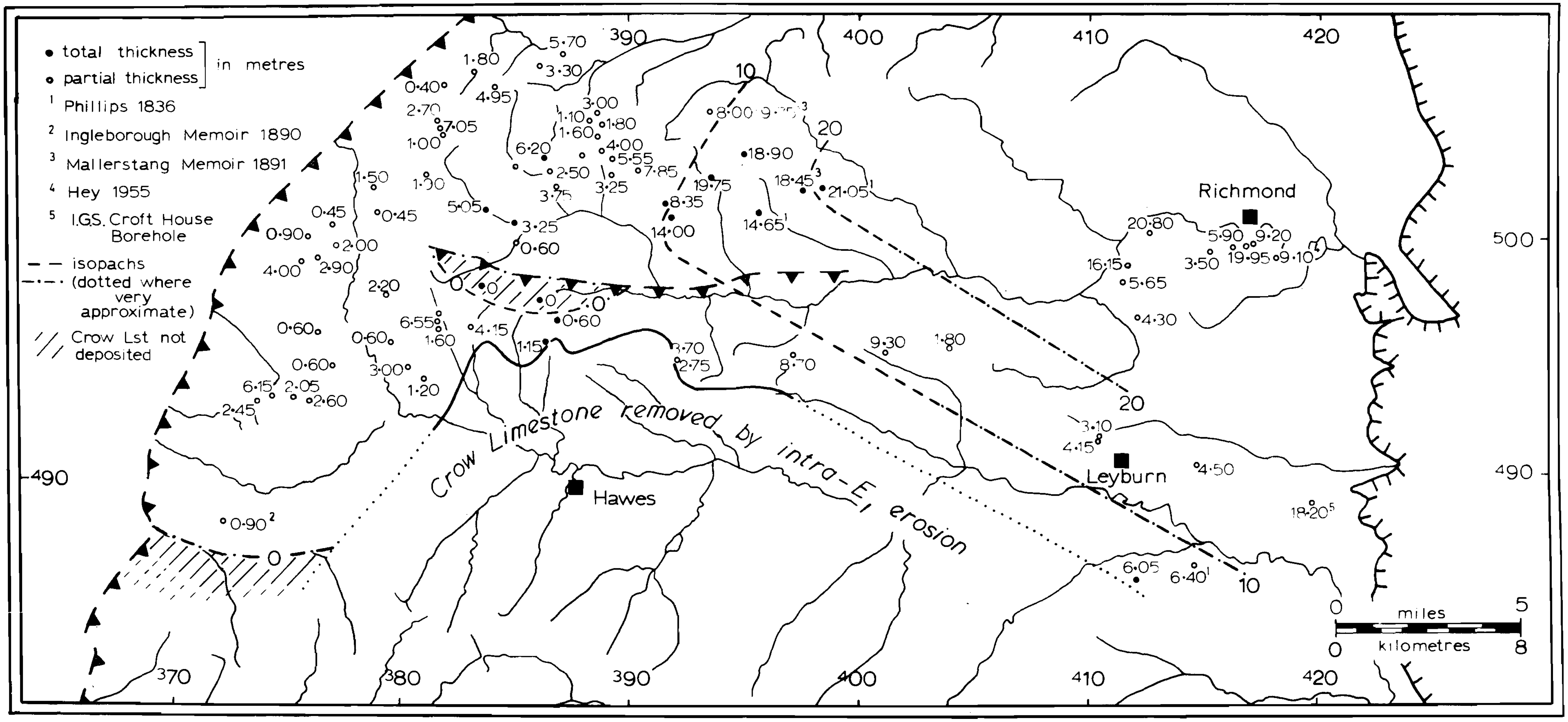


Fig. 59. Isopach map of Crow Limestone.

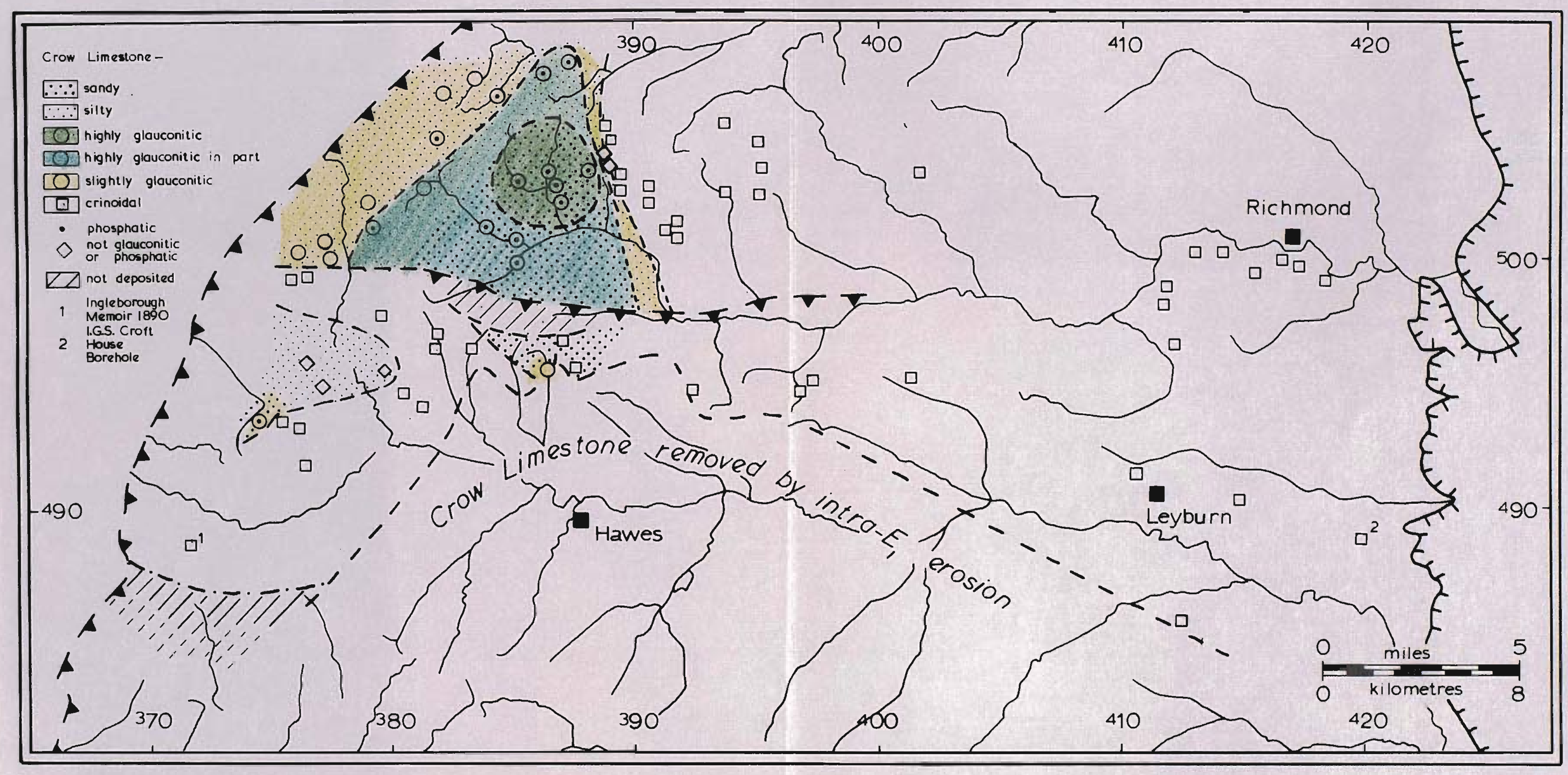


Fig. 60. Map showing lithology of Crow Limestone.

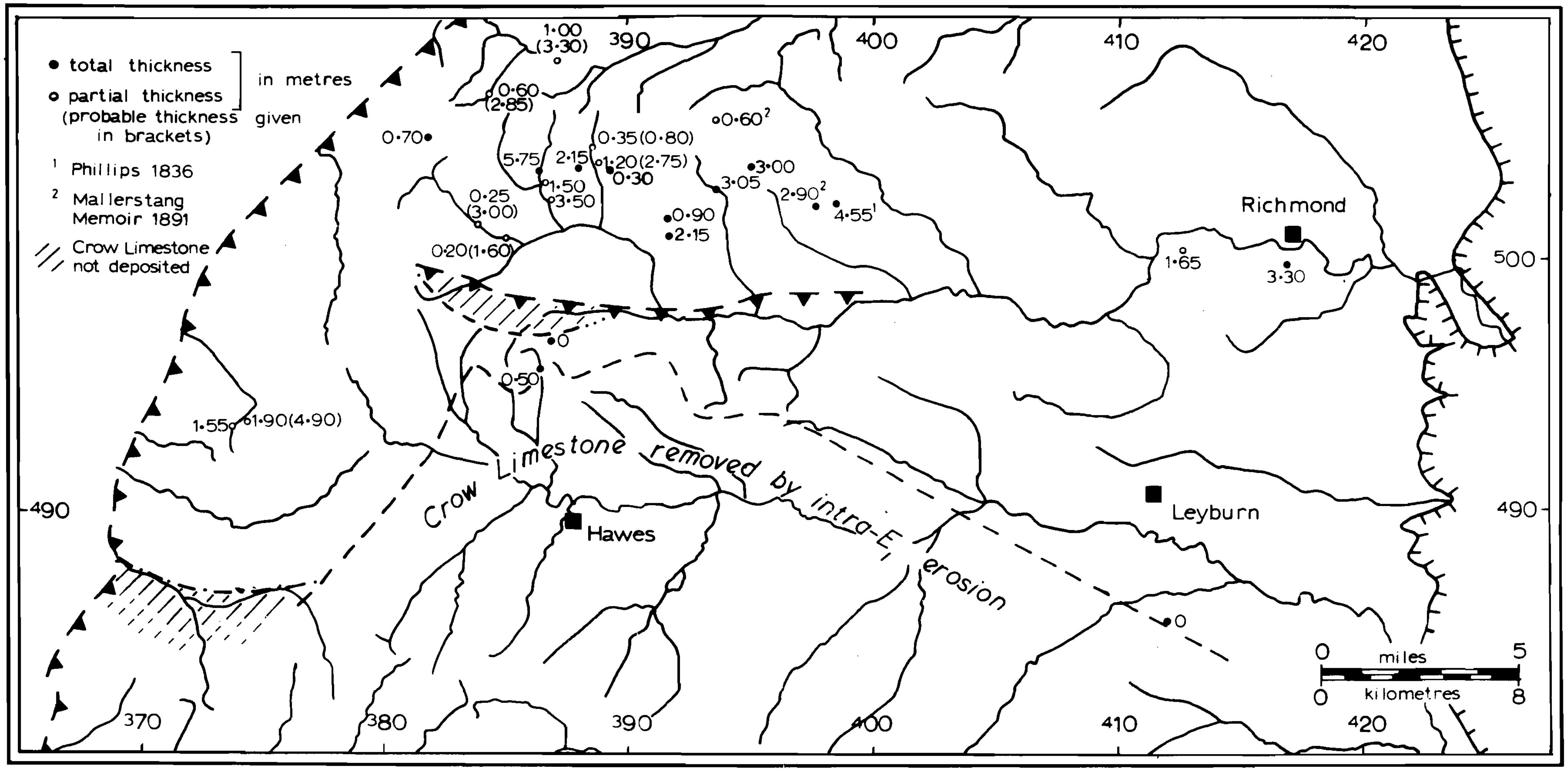
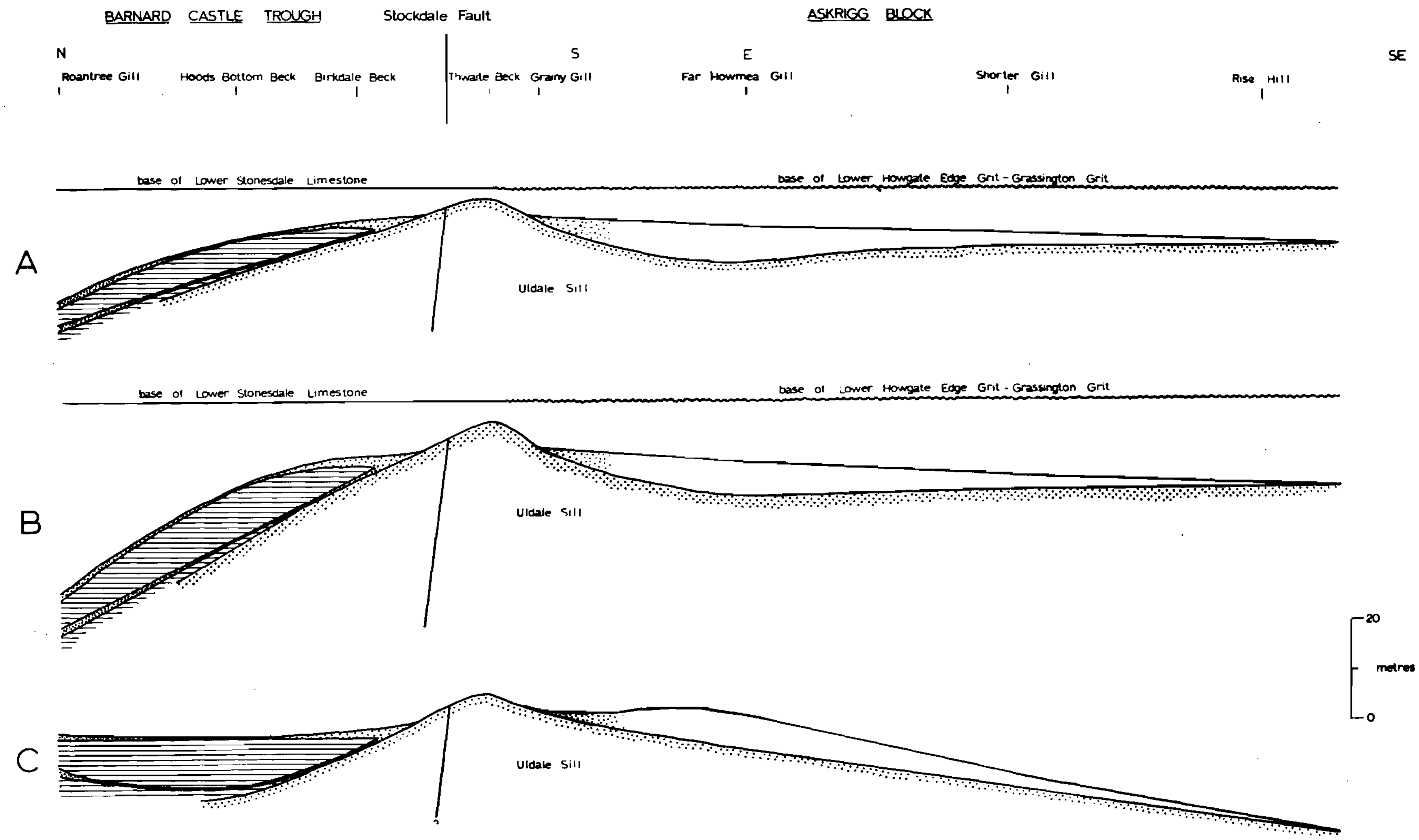


Fig. 61. Map showing thickness of main shale in Crow Limestone.



LITHOLOGY	Sandy/silty variably calcareous glauconitic chert separated by thick shale. Glauconitic sandstone	No Crow Limestone. Sparse glauconite in top of Uldale Sill	Sandy crinoid-ossicle calcarenite and calcareous sandstone	Crinoid-ossicle and -stem calcarenite and calcirudite cherty in places with siliceous sponge spicules. Crinoid - ossicle calcarenite	No Crow Limestone
ORIGIN OF SEDIMENTS	Influx of sand, silt and glauconite from sand bank during accumulation of lower and upper parts of Crow Limestone. Formation of glauconite and phosphate nodules. Siliceous sponges and zoophycos	Glauconite formation	Influx of sand from sand bank and crinoid debris from ?crinoid bank	? Crinoid bank. Prolific crinoids and siliceous sponges. Crinoid population decreasing southwards eventually disappearing	
INTERPRETATION	LOCAL BASIN. Semi-stagnant bottom with sulphate reduction and regeneration of phosphate	SHOAL. Sand bank above surge base	OPEN SHELF DEEPENING SOUTHWARDS. Subtidal just below surge base	Subtidal well below surge base. Oxygenated bottom. Wave motion directed northwards and water depth limits southerly extent of Crow Limestone	

Fig. 62. Section through the Crow Limestone: -
A. As measured with base of Lower Stonesdale Limestone and Lower Howgate Edge Grit as horizontal datum.
B. Pre-compaction allowing for 40% compaction in shales and 20% compaction in cherts.
C. As interpreted immediately after accumulation.

THE CROW LIMESTONE.

DISCUSSION.

The Crow Limestone rests on, or is separated by a thin shale from, the Uldale Sill. It is over 20m thick in the southeastern Barnard Castle Trough but thins southwestwards and is absent over the southern part of the Askrigg Block and along the south side of the Stockdale Fault in the region of Shunner Fell. In the southwest, south of Dentdale, its absence results from non-accumulation as there is no evidence of post-depositional removal. Over the central and southeastern part of the Askrigg Block non-accumulation cannot be proved because intra-E_1 erosion preceeding deposition of the Grassington Grit has cut down to a stratigraphically lower horizon. However, the southerly thinning of the Limestone shown by the isopachs (Fig. 59) and the decrease in crinoid-debris at the southern most exposure in the east, together with evidence of non-accumulation in the area south of Dentdale, suggests that the Crow Limestone did not accumulate over the southern part of the Askrigg Block.

The Crow Limestone is also absent on the northern slopes of Great Shunner Fell in a belt at least $2\frac{1}{2}$km and $\frac{3}{4}$km wide south of, and parallel to, the Stockdale Fault. The sections in Thwaite Beck (SD 860977) and Stackers Gill (SD 838984) show the Uldale Sill sandstones to be overlain directly by shale. Precise definition of the area over which the Crow Limestone is absent is impossible because outcrops are sparse but the nearest surrounding exposures of the Limestone provide maximum limits. Northern and southern limits are given by outcrops in Great Sleddale (NY 851004; 2¼km northeast Stackers Gill) and in Grainy Gill (SD 869970; 1¼ km southeast Thwaite Beck), Fossdale Gill (SD 863958; 2kms south of Thwaite Beck) and East Gill (SD 837967; 1½km southwest of Stackers Gill) respectively. Its western boundary is limited by outcrops in Mallerstang (4¼km west of Stackers Gill) but its eastern boundary cannot be fixed accurately because the River Swale has eroded to a lower stratigraphic level. Nevertheless, isopachs (Fig. 59) and distribution of facies (Fig. 60) of the Crow Limestone suggest that this area does not extend any great distance east of Thwaite Beck (SD 860977).

Around this area, but especially to the north, the Crow Limestone is sandy. The quartz sand decreases in quantity and grain size away from this area grading distally into silt before most of the quartz disappears. (Fig. 60). The Uldale Sill must, therefore, have been uplifted above surge base and eroded by currents. Sand eroded from the sandbank was transported and deposited off the bank in less turbulent environments where the Crow Limestone was accumulating. Absence of the Crow Limestone on this sandbank is, therefore, attributable to non-accumulation.

The northern limit of the shoal lies somewhere between Thwaite Beck (SD 860977), where the Crow Limestone is absent, and Great Sleddale (NY 851004), where it is present; the Stockdale Fault seems the obvious boundary. However, because there are no intermediate outcrops, it is not known whether the Crow Limestone is present or absent immediately adjacent to the Fault. As the Stockdale Fault marks the north edge of the Askrigg Block elevation of the Uldale Sill must have resulted from uplift of this northern edge. However, uplift was only local because the Crow Limestone accumulated in Mallerstang, to the west, and to the east. It occurred only in a linear belt parallel to, and along the south side of, the west end of the Stockdale Fault and terminated where the Stockdale Fault passes westwards into a plexus of smaller faults. Uplift could have resulted from local upward tectonic flexure unrelated to faulting and/or by movement on the Stockdale Fault. Both are feasible as the northern edge of the Askrigg Block is marked by a faulted monocline (the Stockdale Fault and Monocline) but as the Stockdale Fault appears to mark the northern limit of uplift, movement on the Fault seems most likely. Absence of outcrops near the Fault makes it impossible to determine whether or not it broke through to the surface. Even if it reached the surface an abrupt submarine scarp would not develop as the unlithified, waterlogged and therefore unstable sand of the Uldale Sill would be unable to maintain steep gradients. As faulting occurred the mobile sand would presumably slump although there is no evidence of slumping in the outcrops nearest the Fault.

Upward movement of the northern edge of the Askrigg Block along the west end of the Stockdale Fault is also supported by isopachs of the Uldale Sill (Fig.63 , after Rowell & Scanlon, 1957) which show it is locally thin in an east-west belt parallel to, but just south of, the west end of the Stockdale Fault. Maximum uplift occurred 1km to 1.5km south of the Fault rather than immediately to the south probably due to drag on the Fault.

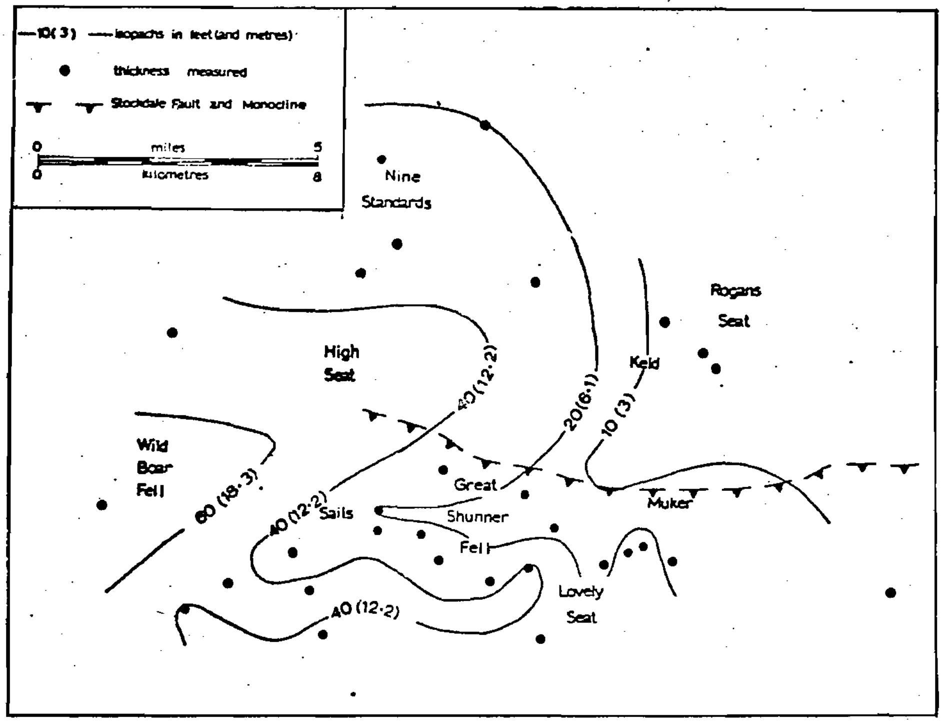


Fig. 63. Isopachs of the Uldale Sill in the vicinity of the Stockdale Fault (after Rowell & Scanlon, 1957).

Local thinning of the Uldale Sill in this area indicates post-depositional removal, attenuated deposition resulting from uplift before deposition was complete or both. Sand in the Crow Limestone derived from the Uldale Sill records at least some post-depositional removal. If all the local thinning is due to post-depositional erosion then the isopach map (Fig. 63) shows more than 6m of Uldale Sill has been removed.

The Uldale Sill was elevated during accumulation of the lower and upper parts of the Crow Limestone because both contain sand. The presence of sand only in these parts may be related to two phases of uplift, possibly two main phases of movement on the Stockdale Fault, or two periods of sand redistribution.

Deposition over the uplifted area commenced before accumulation of the Lower Stonesdale Limestone which shows no change in lithology or thickness over this area. The uniform thickness and lithology of the Lower Stonesdale Limestone suggests that it may have been accumulated approximately parallel to the geoid. If this approximation is correct then estimation of the relative movement on either side of the Stockdale Fault can be made. In Whitsundale, about 4km north of the Stockdale Fault, the distance between the top of the Uldale Sill and base of the Lower Stonesdale Limestone is about 17.4m whereas 0.75km south of the Stockdale Fault it is 2.4m in Thwaite Beck (SD 860977) and Stackers Gill (SD 838984) and only 60cm in Brian Grain (SD 841983). This gives a maximum difference in thickness of about 16.8m. If variation in thickness of the Uldale Sill is also taken into account a movement of at least 23m is obtained. This is the minimum movement because it is calculated using sediment thicknesses after compaction. As only a thin shale separates the Lower Stonesdale Limestone from the Uldale Sill south of the Stockdale Fault but thick shales occur in this position north of the Fault, total compaction must have been much greater north of the Fault. Calculation using a compaction of 50% for the shales gives a total movement of about 40m.

The lower part of the Crow Limestone is also sandy in Swere Gill (SD 744935) and silty in the area to the northwest

(Fig.60) but it is unlikely the sand and silt came from the sand bank south of the Stockdale Fault as intermediate outcrops contain no quantity of sand or silt. The distribution of sand and silt suggests a westerly source. Uplift on the Dent Fault may have raised the Uldale Sill locally and allowed redistribution of its sand by currents, similar to the uplift on the south side of the Stockdale Fault. Although speculative because there are no outcrops farther west, if a sand bank did develop in this area it would be at a similar distance from the northwest corner of the Askrigg Block as the sand bank on the south side of the Stockdale Fault. Stresses attempting to uplift the northwest part of the Askrigg Block during accumulation of the Crow Limestone may have failed to uplift the northwest corner but succeeded in uplifting its edges immediately to the east and probably immediately to the south.

In the southwest Barnard Castle Trough, immediately north of the sandbank on the south side of the Stockdale Fault, the Crow Limestone consists of two thin cherts with abundant sand, glauconite and phosphate nodules, separated by a very thick shale; the only exception is in Birkdale Beck (NY 853011) where the lowest bed is a sandstone. The shale, which reaches a maximum thickness of 5.75m in Hoods Bottom Beck (NY 863038) 5km north of the sandbank, is locally thick in this region, a result of more rapid subsidence and/or infilling of a depression in the sea floor. The unique lithology of the non-shale beds here and their extreme thinness shows the environment of deposition was much different from the surrounding area. The accumulation of sand and glauconite from the sand bank and the abundance of phosphate in this region (p. 326), suggests that this area was a small basin during accumulation of the Crow Limestone. Local uplift on the south side of the Stockdale Fault was, therefore, accompanied by downwarp on the north side of the Fault. In Swere Gill (SD 744935) the Crow Limestone also contains a thick shale (probably about 4.9m) and is similarly thought to have accumulated in a basin behind a sand bank located farther west (p.322). This is supported by the presence of only small crinoid debris in the lower part of the Limestone, even though neighbouring outcrops are coarse crinoid-stem calcarenites and calcirudites, and the presence of quartz sand and silt, glauconite and phosphate nodules.

Although scattered glauconite is seen in Swere Gill (SD 744935) it is most abundant in the centre of the basin to the north of the Askrigg Block where the lower and upper parts of the Crow Limestone are thinnest. Its overall distribution is similar to that of the sand, most abundant to the north of, and decreasing away from, the sandbank. Its distribution shows it formed on the sand bank and, like the sand, was redistributed by currents during accumulation of the lower and upper parts of the Crow Limestone. Evidence of glauconite formation on top of the bank is seen in Thwaite Beck (SD 860977) where the Crow Limestone is absent and the top of Uldale Sill is glauconitic and reworked. The oolitic structure of many of the glauconite grains (p403) also suggests formation in an agitated environment and its occurrence in small lenses in the basin records transportation. The glauconite cannot be derived from the Uldale Sill because it contains no glauconite except where its top has been reworked. The scattered grains of glauconite seen in Swere Gill (SD 744935) are thought to have formed on a sand bank farther west (p. 322).

Although rare or sparse scattered grains of glauconite are found in many of the Yoredale Limestones they are so abundant in the Crow Limestone, in places forming more than 50% of the Limestone, that they merit special consideration.

Many theories have been proposed regarding the origin of glauconite. Murray & Renard (1891) and Collet (1908) proposed the co-precipitation of Mg, Fe, Al and Si gels to which K was attracted whilst others, including Collet (1908), Takahashi & Yagi (1929) proposed the alteration of mud. The first theory to receive widespread support was that of Galliher (1935 a & b, 1936, 1939) developed from the work of Hummel (1923) and Alexander (1934) which stated that biotite could be converted to glauconite in a marine environment. The 'booklet' grains of glauconite in the Crow Limestone certainly developed from mica derived from the Uldale Sill because the mica flakes are seen in all stages of glauconisation (p.404). However, these grains form only part of the glauconite and it seems unlikely that the glauconite with an oolitic structure is an alteration product of biotite (p.403). Biotite is not the universal precursor of glauconite and the formation of glauconite from biotite is regarded best as a specific case of the modern 'layer-lattice' theory proposed by Burst (1958 a and b)

(McRae, 1972). According to Burst (1958 a and b) the formation of glauconite, essentially an illite/montmorillonite structure, required simply a degraded silicate lattice, a plentiful supply of iron and a suitable redox potential.

The only natural waters carrying significantly large quantities of iron in solution are certain bicarbonate and bicarbonate-sulphate ground waters, rare hot springs in volcanic areas and some fresh waters with iron as organically peptised ferric colloid or organic complexes. Most of the iron produced by present day erosion is transported to the ocean by colloidal ferric hydroxide as adhering oxide on clay minerals or as chemically bound ions in clastic mineral particles. Accumulation of iron-rich sediments requires only that the chemical factors governing precipitation (pH and Eh) be just right; neither the concentration nor quantity of iron in the waters at a given time need be excessive (James, 1954).

Glauconite is forming to-day in all oceans of the world, mainly on continental shelves (Cloud, 1955). Although it has been recorded from lacustrine and continental deposits (Jung, 1954; Dyadchenko & Khatuntseva, 1955, 1956; Keller 1958, 1959; Nicholas 1961; Parry & Reeves, 1966; Porrenga, 1968) it is usually found in marine sediments. It can form in moderately anaerobic (Lochman, 1949; Cloud, 1955) to strongly oxidising (Van Andel & Postma, 1954; Emery, 1960) environments but slightly alkaline conditions (pH7 - pH8) seem favourable for its genesis (McRae, 1972). The glauconite in the Crow Limestone formed above surge base in an oxidising marine environment on top of a sand bank but was transported and accumulated under reducing conditions in a semi-stagnant basin (Fig.62, p.316).

The occurrence of glauconite as casts of foraminifera or fecal pellets led many early workers to suggest an active, living organic agency was required for glauconite formation but it is now believed the presence of organisms is not absolutely necessary (McRae, 1972). Glauconite is most abundant and widespread in warm shelf areas; only rarely does it form at depths greater than the shelf margin. Temperature limits of 15°C (Porrenga, 1967) and 20°C (Takahashi & Yagi, 1929) have been given (McRae, 1972) but it is unwise to regard glauconite as a reliable temperature index (Cloud & Barnes, 1948). Its genesis is also favoured by a low sedimentation rate (Murray & Renard, 1891; Goldman, 1921, 1922; Hadding, 1932; Cloud, 1955; Muller, 1954) because it forms most readily at the sediment water interface and rapid sedimentation arrests developing glauconite grains. Such conditions are frequently encountered at unconformities and stratigraphic breaks (McRae, 1972).

Behind the sand bank in the basin centred around Whitsundale and in the basin around Swere Gill, phosphate nodules accumulated. Although rare transportation of some nodules can be proved (Plate 86) most have grown in situ because they incorporate sediment similar to the surrounding matrix, including grains of quartz and glauconite (c.f. Emery, 1960), and the surrounding sediment is compacted around them. In contrast to the matrix which contains only occasional spicules of Hyalostelia most of phosphate nodules contain abundant small monaxid sponge spicules.

Phosphate deposits have been considered to result from catastrophic killings of animals (Murray & Renard, 1891), accumulations of the phosphatic hard parts of organisms during periods of non-deposition (Miller, 1896) and in stagnant basins where regeneration of phosphate from falling organic debris cannot occur (Mansfield, 1927; Rankama & Sahama, 1950), coprolitic or fecal accumulations (Blackwelder, 1926; Amstutz, 1958) and chemical precipitates (Dietz et al, 1942; Emery, 1960, Tooms et al, 1969).

Phosphate is extracted from sea water by many living organisms and concentrated in their hard parts. Abnormal concentrations of bones, teeth, fish scales or invertebrate hard parts can produce phosphate rich beds. Phosphorus ,like iron, is present only in small amounts in sea water but can be precipitated in important quantities locally if conditions are favourable (Krumbein & Garrels, 1952). Phosphate is forming to-day mainly in areas of very slow or non-deposition on shallow water platforms near the border zone with deeper basins (Dietz et al 1942; Emery, 1960) where cold upwelling currents meet warmer water. The pH of the water in the cold upwelling currents rises as its temperature increases, the partial pressure of CO_2 decreases and the water becomes saturated with phosphate which is precipitated chemically or removed by organisms, in either case eventually resulting in phosphate deposition. The role of biogenic versus abiotic precipitation is not understood fully. Precipitation of chemical sediments may result from organic or inorganic processes but pH and Eh of the environment are the general controls on chemical sedimentation which include both inorganic reactions and biochemical processes (Krumbein & Garrels, 1952). Phosphate shows a strong tendency to migrate during diagenesis and diagenetic and metasomatic processes are often very important (Mansfield, 1927).

Rowell & Scanlon (1957) consider the phosphate nodules in the Crow Limestone are coprolites because they contain much organic debris, dominantly sponge spicules. They record two generations of phosphate, the coprolite acting as a nucleus for the second generation, which formed contemporaneously because, "minute bedding planes in the overlying glauconite rock curve smoothly over the phosphate body". If the presence of spicules in the phosphate nodule is used to suggest a coprolitic origin then the second generation of phosphate must also be considered coprolitic as it too contains spicules.

Variation in size and shape of the nodules, and the presence of quartz sand and glauconite in them, suggests they are not coprolites. The phosphate nodules formed before compaction of the sediment as laminae in the surrounding rock are distorted around them. They contain sediment identical to the surrounding rock and are thought to have grown in situ on, or just beneath, the sediment surface. Their primary or syngenetic origin is thought to result from remobilisation of phosphate under reducing conditions (pyrite is also seen in the rocks) to centres of accretion. Emery

(1960) recorded similar in situ growth of phosphate nodules off the coast of Southern California but could prove in situ growth as besides containing sediment similar to the surrounding sediment, the phosphate nodules were also encrusted by organisms.

The abundance of spicules in the phosphate and their scarcity in the surrounding rock is explained in terms of sediment preservation. The phosphate nodules, certainly early features, have preserved part of the sediment as it was immediately after deposition before compaction.

The sponge spicules, almost certainly originally siliceous (p.406), were initially abundant throughout the sediment, but, during diagenesis, the silica dissolved. The phosphate preserved most spicules as casts which were later infilled by ferroan dolomite but elsewhere, in the matrix they dissolved without trace. The silica released by dissolution of the spicules was later precipitated as chert to form the matrix of the sediment.

The features controlling the deposition of phosphorite (essentially tri-calcium phosphate) are very similar to those of calcium carbonate (Krumbein & Garrels, 1952). Neither ion is affected by Eh changes within the limits which occur in nature. The phosphate ion, however, is strongly pH dependent, consequently phosphorite solubility in sea water decreases with increasing pH, its solubility curve being essentially parallel to that of calcium carbonate, although the absolute values are much less (Krumbein & Garrels, 1952).

As the absolute solubility of calcium phosphate is considerably less than that of calcite, and because the solubility - pH curves are nearly parallel, precipitation caused by pH increase of sea water saturated with both compounds will result in a sediment composed almost entirely of calcite with only a trace of phosphate. Thus a sediment rich in calcium phosphate and low in calcium carbonate can be formed only where conditions permit the precipitation of calcium as the phosphate and in which the activity product of the carbonate is not exceeded. This could occur in a restricted basin with a relatively low pH (7.0 - 7.5) in which environment $CaCO_3$ would not be expected to form (Krumbein & Garrels, 1952). Phosphorite precipitates in the pH range 7.0 (Krumbein & Garrels, 1952; 7.1 Kazakov, 1950) to 7.8 (Krumbein & Garrels, 1952) when $CaCO_3$ becomes the major phase.

The association of glauconite, phosphate and chert is well known (Goldman, 1922; Wetzel, 1937; Kazakov & Isakov, 1940; Carrozi, 1958, 1960; Emery, 1960; Litvinenko, 1965; Rooney & Kerr, 1967; Bailey & Atherton, 1969). Although the glauconite formed in oxidising conditions on a sandbank it accumulated finally in a basin where phosphate nodules were forming under reducing conditions and a slightly lower pH than usual. Water convection in the basin was impeded but inflow of oceanic water must have been sufficient to supply the phosphorus required. The absence of an abundant varied fauna where the Crow Limestone is glauconitic and phosphatic is evidence for semi-stagnant conditions. Only sponge spicules are common and these may have been transported into the basin from the area adjacent to the sandbank. Crinoids, abundant in the Crow

Limestone elsewhere, are absent in the basin north of the Stockdale Fault although rare brachiopod shell fragments are seen. The only common fossil is that belonging to the ichnogenus Zoophycos, which, being a sediment ingesting organism, probably had a low oxygen requirement.

On the Askrigg Block the Crow Limestone contains abundant crinoid debris except in Fossdale Beck, where it is adjacent to the sand bank and consists of an upper and lower calcareous sandstone separated by shale, and in the area between Baugh Fell and Wild Boar Fell where a small basin developed (p. 323). It is also crinoidal in the northern part of the Barnard Castle Trough except in the west where the other basin developed north of the Stockdale Fault. Absence of crinoids from the basins is probably a result of unsuitable environmental conditions rather than too great a water depth. Current transported crinoid debris did not reach these areas for its absence is unlikely to result from non-preservation. The crinoid debris, therefore, appears to have undergone little transport and thick accumulations of crinoid debris probably indicate areas where crinoid growth was prolific and sustained. Their absence from the sand bank is clearly related to instability of the substrate and its susceptibility to erosion.

Although prolific crinoid growth is often associated with development of bioherms in Limestones of the Yoredale Group no bioherms have been found in the Crow Limestone although they could be present but not exposed.

In the west where the Crow Limestone is not cut out by the Grassington Grit, the crinoidal Limestone thins out completely south of Dentdale and, where last recorded on Rise Hill (Strahan, 1890), is only 90cm thick. The lack of any sign of erosion indicates its absence to the south results not from post-depositional removal but from non-accumulation. It seems that crinoids did not colonise the area south of Dentdale . Although the Crow Limestone is cut out by the Grassington Grit farther east the Limestone probably did not accumulate over any of the southern part of the Askrigg Block (p. 317).

Hyalostelia is widespread in the Crow Limestone but is especially abundant in places where the Crow Limestone is coarsely crinoidal and siliceous. Spicules are abundant in the area around the sand bank and basin south and north of the Stockdale Fault respectively, in Mallerstang, on Abbotside Common and around Blakethwaite. They seem to have accompanied the crinoids and sometimes occur in bundles on bedding planes suggesting little disturbance.

The Crow Limestone contains several shales in the northeast but a thick, persistent shale can be traced over the southern Barnard Castle Trough. It is thickest in the basin developed locally around Whitsundale and reaches 5.75m in Hoods Bottom Beck (NY 863038) but regionally thins southwards. On the Askrigg Block the shale is thickest in the basin developed locally around Swere Gill (SD 744938) where it is probably about 4.9m thick although only 1.9m is exposed. It thins away from this region and elsewhere and is thin or absent. Lack of complete exposures of the Crow Limestone makes determination of its limits impossible but it is absent in the most southerly exposures.

The Crow Limestone is cherty at least in part over the entire Askrigg Block except in the area immediately adjacent to the sand bank on the south side of the Stockdale Fault. Bedded cherts are best developed in the central and eastern parts of the Barnard Castle Trough and along the central and eastern parts of the north edge of the Askrigg Block, areas where the Crow Limestone is thickest. They are most frequent in, and commonly comprise most of, the upper part of the Crow Limestone above the thick shale. Only rarely are cherts encountered which contain no carbonate. These are bedded, sometimes laminated and often contain abundant, monaxid, siliceous sponge spicules. Most are usually at least slightly calcareous with a variable content of crinoid and bryozoan debris, small brachiopods and sponge spicules including Hyalostelia . Small horizontal burrows of Zoophycos type are common in the argillaceous and calcareous cherts but do not occur in the highly siliceous laminated cherts. The bedded cherts, more fully discussed on p. 387, are often interbedded with variably chertified shales, calcarenites and calcilutites between which there is complete gradation. Silicification of these beds varies from selective microscopic replacement, through development of isolated chert nodules and patchy silicification, to silicification of the entire rock whether carbonate or shale. Where silicification of carbonate has occurred, the beds are frequently secondarily dolomitised. The relationship between dolomitisation and silicification is described in the section on diagenesis (p.370).

THE CARBONATE ROCKS.

THE CARBONATE ROCKS.

a) Introduction.

The carbonate rocks encountered in this study consist fundamentally of three end members, skeletal carbonate (dominantly crinoid debris), micrite and sparite. A complete gradation exists between biomicrites and biosparites but whereas biomicrites are common, biosparites are rare.

Crinoids, brachiopods, corals, bryozoa and algae are sometimes seen in or near their sites of growth and occasionally form bioherms or biostromes but most of the skeletal carbonate is poor sorted crinoid and brachiopod debris with subsidiary bryozoan, molluscan and echinoderm fragments. Foraminifera, ostracods, blastoids and sponge spicules are also seen. Recognisable bioclasts range from silt to rudite size but most of the unidentifiable silt and micrite is probably also comminuted skeletal carbonate. Although pelletoids and intraclasts can be recognised, carbonate ooliths are unknown from the limestones studied.

Non-carbonate components such as quartz sand, silt, clay minerals, glauconite, phosphate and chert are sometimes abundant and there is complete gradation between carbonates and cherts, shales, mudstones, siltstones and sandstones. The transition of one lithology into another makes any division of the rocks artificial but it is convenient to divide the spectrum of rock types into carbonates (calcilutites, calcarenites, calcirudites, bioherms and biostromes; whose classification is discussed below) cherts, arenites and lutites.

b) Petrographic Classification.

As stated previously (p.21), no single classification can encompass all the features observed in carbonate rocks. It is necessary, therefore, to select or construct a classification which subdivides carbonate rocks into well defined, meaningful groups. Highly specialised classifications which incorporate a limited number of specific parameters only are of little use in a general sedimentological study of Yoredale Limestones. Similarly, genetic classifications are unsuitable because the sedimentology must be interpreted from data collected as objectively as possible, not inferred. The classification used in this study (Fig.64) is based on that proposed by Folk (1959, 1962) because it is descriptive, practical and comprehensive but incorporates some of the parameters used by Dunham (1962).

<table>
<tr><td colspan="4">Group Name</td><td>SPARITES</td><td colspan="5">MICRITES</td><td rowspan="3">Bioherm Rocks</td><td colspan="2">Replacement Dolomites</td></tr>
<tr><td colspan="4">Sparry Cement/ Lime Mud</td><td>Sparry Cement > Lime Mud</td><td colspan="4">Lime Mud > Sparry Cement</td><td>Lime Mud Only</td><td rowspan="3">Allochem Ghosts</td><td rowspan="3">No Allochem Ghosts</td></tr>
<tr><td colspan="4" rowspan="2">Allochems</td><td colspan="2" rowspan="2">Grain-Supported</td><td colspan="4">Lime Mud-Supported</td></tr>
<tr><td colspan="2">> 10%</td><td>1% - 10%</td><td>1%</td><td></td></tr>
<tr><td rowspan="5">Volumetric Composition of Allochems</td><td colspan="3">25% Intraclasts</td><td>intrasparite</td><td>packed intramicrite</td><td rowspan="5">most abundant allochem</td><td>sparse intramicrite</td><td>intraclastic micrite</td><td rowspan="5">micrite</td><td rowspan="5">biolithite</td><td>intraclastic dolomite</td><td rowspan="5">dolomite</td></tr>
<tr><td rowspan="4">25% Intraclasts</td><td colspan="2">25% Ooliths</td><td>oosparite</td><td>packed oomicrite</td><td>sparse oomicrite</td><td>oolitic micrite</td><td>oolitic dolomite</td></tr>
<tr><td rowspan="3">25% ooliths</td><td>Bioclasts: pellets 3 : 1</td><td>biosparite</td><td>packed biomicrite</td><td>sparse biomicrite</td><td>bioclastic micrite</td><td>bioclastic dolomite</td></tr>
<tr><td>Bioclasts: pellets 3:1 - 1:3</td><td>biopelsparite</td><td>packed biopelmicrite</td><td>sparse biopelmicrite</td><td rowspan="2">pelletiferous micrite</td><td rowspan="2">pelletiferous dolomite</td></tr>
<tr><td>Pellets: Bioclasts 3 : 1</td><td>pelsparite</td><td>packed pelmicrite</td><td>sparse pelmicrite</td></tr>
</table>

Fig.64. Classification of Carbonate Rocks modified after Folk (1959, 1962) and Dunham (1962).

Folk recognises three fundamental constituents in carbonate rocks, discrete carbonate aggregates (allochems), microcrystalline carbonate ooze (micrite) and sparry carbonate cement (sparite). Four types of allochems are distinguished, intraclasts, ooliths, bioclasts and pellets which, together with micrite and sparite, form the basis of his classification. Rock names are formed by combination of roots and names given to the basic components, the first referring to the allochem. the second to the interallochem material. In addition the affects of neomorphism are also recorded.

Many people have critised the weaknesses of various carbonate rock classifications but few have suggested constructive alternatives or improvements. However, the Folk classification has been modified for use in this study. The main difference between the modified classification used here and the Folk classification is the distinction between grain-supported and mud-supported carbonate rocks. This subjective distinction was stressed by Dunham (1962) and is more significant than division based on an arbitary allochem percentage as used by Folk (1962). Dunham (1962) experimentally sedimented wet grains in quiet water to determine the packing of different shaped grains. A 65% grain bulk and 60% grain solid was recorded using well sorted, rounded, highly spherical balls but 1.9cm lengths of red algae, for example, had a grain bulk of only 20% and a grain solid of 15%. Thus, although both types of grain form a framework, Folk would classify the former as packed and the latter as sparse but in the modified classification they are both described as packed. The new classes defined are approximately equivalent to those outlined by Dunham (1962);

sparites correspond to grainstones, packed micrites to packstones, sparse micrites to wackestones and micrites with less than 10% allochems to mudstones.

Although Folk defines intraclasts as "fragments of penecontemporaneous, generally weakly consolidated, carbonate sediment that have been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment" he later goes on to say "intraclast should be used as a broad class without specifying the precise origin... ..for most rocks one would have to use the non-committal term intraclast". These two statements are contradictory. The former definition for intraclast is used here. In many rocks distinction between intraclasts and pellets is impossible, a problem recognised by Folk (1962). Folk suggested that anything above 0.2mm in diameter should be termed an intraclast and anything below 0.2mm a pellet because invertebrate faecal pellets are usually less than 0.2mm in diameter. This arbitary division is totally unacceptable when the terms intraclast and pellet have been defined specifically. Clearly a term is needed for allochems of cryptocrystalline or microcrystalline carbonate, irrespective of their origin which would include unidentifiable intraclasts, pellets and micritised and coated grains. For such allochems McKee & Gutschick (1969) proposed the term 'peloid' which unfortunately has sometimes been adopted in the literature. Peloid, though admittedly concise, is not only incorrect grammatically but is of uncertain derivation. Peloid means pel-like. What is pel? Is it derived from pelite or pellet? A much better term for these allochems and used in this study is the term 'pelletoid' (Folk, 1962; Milliman, 1974).

Probably the main weaknesses of the Folk classification are the lack of emphasis on silt-sized particles and the grouping of aggregated particles such as grapestone (Illing, 1954) as intraclasts. The processes of rounding, sorting and washing were also oversimplified by Folk and require great care in interpretation. However, providing the limitations are recognised, the classification proposed here modified after Folk (1959, 1962) and Dunham (1962) provides a practical way of classifying the carbonate rocks encountered in this study. Crystal size is described according to Folk (1959).

Quantitative estimation of component percentages was achieved by point counting. The graphs produced by Dryden (1931) and later corroborated by Hutton (1950) show that a count of 400 points has a permissibly small sampling error and, on the basis of this, 400 point counts were made across the thin section along several evenly spaced traverses perpendicular to any size grading or lamination. A greater degree of accuracy than this is not warranted in quantitative analysis of most carbonate rocks because lateral differences in rock composition over distances of a few centimetres are likely to vary more than the probable sampling error (Stauffer, 1962).

CALCILUTITES.

The calcilutites include carbonate rocks with a mean allochem diameter of less than 1/16mm and mud-supported carbonates in which allochems of arenite or rudite size 'float' in a micrite matrix. The most common calcilutites are sparse biomicrites. These have greater than 10% allochems but are not grain supported. Rarely bioclastic micrites with 1% to 10% allochems are encountered but they form only a small proportion of the sediments studied. Although calcilutites are seen in the field which apparently contain no allochems, in thin section micrites with no allochems are unknown.

a) Bioclastic Micrites.

Bioclastic micrites, carbonates with 1% to 10% bioclasts 'floating' in a micrite matrix, form some of the argillaceous calcilutites in the Lower Parting (Plate 25) including parts of the bioturbated calcilutite at the top (Plate 26), small areas of the calcilutite bioherm cores in the Cockleshell, Scar and Underset Limestones and some of the upper part of the Underset Limestone where it is cherty and bioclastic debris is sparse. They are also occasionally seen interbedded with the calcareous cherts above the Underset Limestone but quantitatively bioclastic micrites constitute only a minor part of the carbonates studied.

b) Sparse Biomicrites.

Nearly all the calcilutites encountered in this study are sparse biomicrites, carbonates with more than 10% bioclasts but which are not grain supported. Most of the limestone in the Lower Parting, and the Cockleshell Limestone and lowest bed of the Scar

Limestone away from the bioherms, are of this lithology. Sparse biomicrites also form some of the calcilutite bioherm cores, the matrix of the coral biostromes where dominated by colonial corals, some of the upper part of the Underset Limestone where it is cherty and are occasionally seen in the cherts above the Underset Limestone.

The sparse biomicrites in the Lower Parting (Plate 25) like the bioclastic micrites, often contain very little crinoid debris. The allochems, frequently of silt size, are often dominated by brachiopod debris including productid spines, though crinoid, mollusc and bryozoan debris is usually present and foraminifera are sometimes common. In the bioturbated horizon at the top of the Lower Parting (Plate 26) burrowing has produced an irregular distribution of the sparse bioclastic debris. It is very sparse in the burrow infills but relatively more common outside and, near the burrows, is sometimes oriented parallel to the burrow walls. The burrow infills contain fine disseminated pyrite and goethite which on weathering produce a pink to red haematite stain giving the rock its characteristic mottled appearance. They often contain small, commonly concentric or radial, diagenetic fractures now infilled with calcite cement. Compaction structures around some of the burrow infills suggests they were lithified earlier than the surrounding sediments.

c) Sparse biopelmicrites and sparse pelmicrites.

Poorly defined, ellipsoidal, microspar, pelletoids up to 0.1mm in diameter are often seen in the bioturbated bed at the top of the Lower Parting. Their uniformity in shape, small size and association with bioturbation suggests they are likely to be fecal pellets. In places they are sufficiently abundant to form sparse biopelmicrites or more rarely sparse pelmicrites (Plate 27).

d) The Origin of Carbonate Mud.

The genesis of carbonate mud has been attributed to inorganic precipitation and the breakdown of organic skeletal carbonate and is the subject of an extensive literature.

In the Bahamas both organic and inorganic origins have been proposed. Drew (1914), supported by Kellerman and Smith (1914), first suggested that it was precipitated by the action of denitrifying bacteria but later Lipman (1924, 1929) whilst admitting that suitable bacteria exist, discounted this theory because the bacteria were not sufficiently abundant. Black (1933) considered that the high concentration of salts and the accompanying loss of CO_2 combined to induce precipitation. Lowenstam (1955) decided that bacterial breakdown of codiacean algae provided a very important source but the O^{16}/O^{18} isotope ratio studies made by Lowenstam and Epstein (1957) did not satisfactorily demonstrate an algal origin to the exclusion of inorganic precipitation. Cloud (1962), using a chemical approach, concluded that all the Bahama Bank aragonite mud could theoretically be inorganic in origin.

Work on strontium contents of carbonates in the Persian Gulf by Kinsman (1964) showed the carbonate mud was similar to inorganically precipitated aragonite and concluded that at least 80% to 90% of the mid- and inner-lagoon carbonate mud and pellets are inorganic precipitates. They cannot be derived from breakdown of calcareous algae or corals, since they are too scarce, or from disintegration of mollusc shells which have a different strontium content. Neverthless, precipitation is probably controlled physiologically by the activity of algae (Kendall and Skipwith, 1969a).

Clouds of aragonite needles (whitings) have been observed in the Bahamas and in the Persian Gulf but it has not been proved beyond doubt whether they result from inorganic precipitation or from disturbance of sea-floor carbonate mud by currents or shoals of fish.

A study of carbonate sediments off the coast of southern British Honduras by Matthews (1966) showed that biological breakdown and mechanical disintegration of carbonate skeletons are the dominant processes in the genesis of carbonate mud. Physical breakage and abrasion are most important in the agitated environments on the carbonate shoals whereas in the lagoons, although there is influx of coral and algae derived carbonate mud from the shoals, carbonate mud is forming in situ by the breakdown of carbonate skeletons, dominantly of molluscs and forams. The inherently fragile mollusc shells and hyaline foraminifera tests inhabitating the lagoons are broken down by the removal of binding material, by boring micro-organisms, mastication, ingestion and perhaps even simple movement of sediment by the vagrant benthos.

Stockman et al (1967) quantitatively estimated the annual production of carbonate mud by skeletal breakdown in Florida Bay and the nearshore part of the Florida reef tract and concluded that the rate of breakdown of indigenous skeletons, dominantly the ubiquitous codiacean Penicillus but also other algae, molluscs and corals, is more than enough to account for the total accumulation of carbonate mud.

It appears that large quantities of carbonate mud can form in a variety of ways but that in most cases organisms are involved, either directly or indirectly, in its genesis. Its origin is elusive in modern carbonate sediments but presents an even greater problem in ancient carbonates where the mineralogy, chemistry, constituents and fabric of the original sediment are obscured by diagenesis and the faunas and floras are less well known than those of the present day. Nevertheless with insight gained from the studies of modern carbonate environments it is interesting to speculate about the origin of carbonate mud in the Limestones of the Yoredale Group on the Askrigg Block.

One of the striking features of most of the carbonates encountered in this research is their high content of bioclastic material, dominantly crinoid and brachiopod debris, and carbonate mud. The abundant skeletal carbonate clearly was a possible source of carbonate mud after organic and/or mechanical disintegration. Although algae are not common in the carbonates studied, except as oncolites in a thin horizon near the top of the Scar Limestone over the north-west part of the Askrigg Block (p.140) and possibly in the calcilutite bioherm cores (p.359), calcareous algae may have been an important source of carbonate mud after post-mortem disintegration. Micritisation of allochems, although recognised, does not seem to have been responsible for production of carbonate mud in quantity. The possibility that the carbonate mud formed by inorganic chemical precipitation cannot be evaluated here.

Concluding, the abundance of organic debris in the carbonates studied and the relationship of crinoid abundance, crinoid size and bioherm development with limestone thickness shows that production of organic skeletal carbonate was the main control on the rate of carbonate accumulation. This, together with variation in size of skeletal debris down to silt grade (below which size identification of skeletal carbonate is impossible), suggests that much of the carbonate mud is a product of biological and mechanical breakdown of organic skeletal carbonate rather than a result of inorganic chemical precipitation.

CALCARENITES.

Calcarenites form the bulk of the carbonates studied and consist of a framework of dominantly arenite-sized allochems with a micrite matrix or occasionally sparite cement.

a) Packed biomicrites.

These form the largest part of the carbonates studied and consist of a framework of arenite sized bioclastic debris with interallochem areas dominated by micrite (Plate 29). Packed biomicrites comprise nearly all the Single Post Limestone, except in the extreme southeast, some of the Cockleshell Limestone where peripheral to biogenic mounds and most of the Scar Limestone. They also form the Underset Limestone except where biogenic mounds are developed and in some places where its top is cherty and most of the carbonates in the Crow Limestone except where it is very coarsely crinoidal. Packed biomicrites are also found interbedded with crinoid-stem calcirudites capping and flanking the bioherms.

The packed biomicrites consist dominantly of ill-sorted crinoid and brachiopod debris of which crinoid debris is nearly always the most abundant. Bryozoan debris is often common in the vicinity of bioherms but, like mollusc fragments, usually forms only a minor part of the skeletal carbonate. Where argillaceous the packed biomicrites often contain stylolites and frequently the constituent allochems have sutured contacts (Plate 51).

b) Biosparites.

The biosparites consist of a framework of arenite sized allochems with interallochem areas dominated by carbonate cement.

They are usually found interbedded with packed micrites capping and flanking the bioherms (Plate 30). The carbonate cements are discussed in the section on cementation (p.362) but much of the intergranular porosity is usually filled with syntaxial calcite overgrowths on crinoid fragments (Plate 45). The cement may be entirely non-ferroan calcite or initially non-ferroan and later ferroan.

Biosparites also occur in places over the northwest part of the Block where carbonate mud has been winnowed from the biomicrite adjacent to the sand lens in the Lower Parting of the Middle Limestone. Here the bioclasts are rounded, associated with scattered very fine to medium grained quartz sand and sometimes have micritic rims (Plate 31). Although non-ferroan calcite cement is seen, sometimes as syntaxial rims, most intergranular and often intragranular porosity is filled with ferroan calcite (Plates 31 and 76).

CALCIRUDITES.

The calcirudites, carbonates in which allochems of rudite size form a framework, are divisible into biomicrudites and biosparrudites depending on whether the interallochem areas are dominated by micrite or carbonate cement respectively. Both are associated with bioherms and are discussed later (p. 354).

BIOSTROMES.

a) Coral biostromes.

Well developed coral biostromes occur at the base of the Single Post Limestone, and in the lower and upper parts of the Underset Limestone. Only their lithology is described here as they have already been discussed in the sections dealing with the appropriate Limestones.

The coral biostrome at the base of the Single Post Limestone is dominated by lithostrotionid and clisiophyllid corals with an associated fauna of *Saccaminopsis* and small brachiopods (Plate 33). The corals occur in a micrite matrix with scattered crinoid debris. Where the biostrome overlies sandstone it contains scattered grains of very fine to medium quartz sand which are rarely common enough to make the biostrome truly sandy.

The coral biostromes in the Underset Limestone are also dominated by lithostrotionid and clisiophyllid corals and similarly have an associated fauna of small brachiopods (Plate 32). The corals occur in a micrite matrix with a variable content of crinoid debris. Where the biostromes contain only clisiophyllids crinoid debris is common to abundant and some of the corals have imperfect outer walls and appear to have been rolled. Where colonial corals are common crinoid debris is sparse. They occur in their position of growth and have an associated fauna of abundant small brachiopods. The coral biostromes also contain other skeletal carbonates including brachiopod, mollusc and bryozoan debris which sometimes shows varying degrees of micritisation. Occasionally poorly defined, neomorphosed pelletoids are also seen.

Selective silicification is common and varies from microscopic replacement of skeletal carbonate, through silicification of entire skeletons, to formation of chert nodules (p.373). The corals are frequently silicified either completely or in part.

Lithostrotionid corals also occur in number in parts of the Cockleshell and Scar Limestones but are not usually sufficiently abundant to form true biostromes. They occur in a micrite matrix with scattered skeletal debris, often in association with Gigantoproductus. They are commonly silicified.

b) Brachiopod biostromes.

Small brachiopods are so common in most parts of the coral biostromes that the biostromes could be referred to as coral-brachiopod biostromes. In many places, especially where colonial corals are abundant, they vastly outnumber the corals but, because of their small size, are less prominent. They are also common at the base of the Underset Limestone.

Although Gigantoproductus is very common in parts of the Cockleshell and Scar Limestones it is only sufficiently abundant to form a true biostrome in places. Most are still in their position of growth and occur in a micrite matrix with scattered bioclastic debris, consisting mainly of crinoid debris with subsidiary brachiopod, mollusc, and bryozoan detritus. Silicification is common, varying from selective replacement on a microscopic scale to patchy wholesale replacement. Chert nodules are common and are often located in the concavity of gigantoproductid valves.

c) Algal biostrome.

An algal biostrome occurs in the upper part of the Scar Limestone (Plates 38. 39 & 40). The algae occur as oncolites in a packed biomicrite. They vary from microscopic size up to about 10cm in diameter and consist of undulating, sometimes discontinuous, concentric micrite and microspar laminae a few microns to 0.5mm thick. Possible traces of algal filaments are occasionally seen in thin section but no filaments were identified after dissolution of oncolites in very dilute HCl and staining the residue for organic matter. The oncolites frequently have a nucleus of skeletal carbonate, usually a crinoid, brachiopod or bryozoan fragment, or sometimes an intraclast. Some of the bioclasts are micritised, commonly peripherally but sometimes completely.

BIOHERMS.

Two types of bioherm are recognised in the limestones studied, bryozoan calcilutite mounds and lenses of crinoid-stem calcirudite, both capped and flanked by coarse crinoid-stem calcarenites and calcirudites. The former occur in the Cockleshell, Scar and Underset Limestones whereas the latter are seen only in the Underset Limestone.

a) Calcilutite cores.

The calcilutite bioherm cores are usually unbedded sparse biomicrites but they range from bioclastic micrites to packed biomicrites. The bioclasts, dominated by crinoid and brachiopod debris, have an irregular distribution but generally increase towards the periphery of the bioherm where rudimentary bedding is sometimes developed parallel to the surface of the core. The fauna includes small brachiopods and gastropods (Plate 42) but is often dominated by trepostome and fenestellid bryozoa. Where fenestellids are abundant, the cores frequently contain numerous elongate areas of coarsely crystalline calcite cement infilling cavities with subplanar or gently undulating floors and irregular tops. The calcite cement-filled cavities are usually only a few millimetres in length but sometimes exceed a centimetre. They are frequently roofed by fenestellid fronds and sometimes contain internal sediment, now microspar (Plate 41).

Elongate areas of sparry calcite have frequently been recorded from bioherm cores similar to those described here. They are often referred to as '*Stromatactis*' or 'reef tufa' but their origins are still disputed. The literature is too extensive even to summarise briefly here but both inorganic and organic origins have been proposed. They have been described as patches of neomorphic calcite (Black, 1952) and cement-filled cavities, the cavities resulting from decomposition of soft-bodied organisms (Lowenstam, 1950; Bathurst, 1959a; Philcox, 1963), dissolution (Carrozi & Textoris, 1963; Wolf, 1963, 1965), syngenesis or diagenesis (Schwarzacher, 1961; Wolf, 1963, 1965) and 'bridging' or 'umbrella' effects of large flat fossils such as fenestellid bryozoa or foliose algae (Harbaugh, 1961).

The elongate patches of sparry calcite in the bioherms studied are certainly not neomorphic because they show fabrics typical of cavity filling cement and sometimes contain internal sediment. Their frequent occurrence directly beneath bryozoan fronds suggests fenestellids were important in their genesis. The fronds appear to have prevented accumulation of carbonate mud beneath them. This may have been achieved by growth over hollows in the sediment surface or by an 'umbrella' effect. Lithification must have been rapid before accumulation of sufficient overlying sediment to cause compaction and hence destruction of the cavities.

Most of the micrite in the calcilutite cores has neomorphosed to microspar with an average diameter of about 10 microns but patchy variation in crystal size gives the pseudobrecciated appearance sometimes seen in the field. Neomorphism, possibly of pelletoids, is responsible for the clotted texture sometimes seen in thin section. A zone of very coarse microspar with average crystal diameters of up to 50 microns frequently surrounds the elongate patches of calcite cement. Neomorphism of the micrite originally forming the cavity walls probably occurred before the cavities were completely cemented (Plate 42).

Although there is no evidence of algae it is thought they may have been present but not preserved. Their binding action would have aided cavity formation.

b) <u>Crinoid-stem calcirudite cores</u>.

Lenses of crinoid-stem calcirudite form cores to some of the bioherms in the Underset Limestone. They are packed biomicrudites and consist of a mass of coarse crinoid debris with many crinoid stems in a micrite matrix (Plate 43). Brachiopod and sometimes bryozoan debris is common and small brachiopods, notably spirifers, are often seen.

c) <u>Crinoid-stem calcirudite capping and flanking beds</u>.

Crinoid-stem calcirudites cap and flank both the calcilutite and the crinoid-stem calcirudite bioherm cores. They consist dominantly of packed crinoid-stem biomicrudites with abundant, poor-sorted crinoid debris and subsidiary brachiopod, bryozoan and mollusc detritus. Many crinoid ossicles are still articulated into lengths of stem which occasionally reach 25cm in length and 2cm to 3cm in diameter.

Occasionally crinoid-stem biosparrudites occur interbedded with the packed biomicrites, presumably where current activity was sufficient to winnow the carbonate mud (Plate 44). The allochems are ill-sorted and similar to those in the packed biomicrudites but the interallochem areas are dominated by carbonate cement which consists largely of syntaxial calcite overgrowths on crinoid debris.

d) <u>Discussion</u>.

Bioherms such as those in the Cockleshell, Scar and Underset Limestones have received much attention in the past. Bond (1950), using

Tiddeman's (1900) definition, considered the knolls in the Cackleshell Limestone north of Grassington described by Black (1950) to be true 'reef knolls' as they originated as discrete mounds on the sea floor. Black (1950), however, called them knolls and did not apply the term 'reef'. In a discussion on Bond's (1950) paper he states, "if they are to be called true reefs then the term 'reef' must be redefined to exclude organic debris as a major constituent". He was in favour of such redefinition. Joysey (1955) called the structures 'knolls' and proposed that the mound-forming calcilutite be called 'knoll limestone'.

Numerous definitions of 'reef' and other terms such as 'knoll', 'knoll reef', 'reef knoll', 'bioherm', 'biostrome', and 'bank' have been proposed in a voluminous literature (see Nelson et al, 1962; Braithwaite, 1973) but if, in the definition of 'reef', any connotation of a wave resistant, rigid, organic skeletal structure is implied then the calcilutite mounds cannot be called 'reefs'. Although bryozoa are often common and were undoubtedly important in genesis of the mounds, they could not have formed rigid, wave-resistant, skeletal frameworks like reef-forming corals.

The word 'knoll' defined here as, "a submerged elevation of rounded shape rising from the ocean floor but less prominent than a sea mount" (Dictionary of Geological Terms) can be applied to these structures providing it can be demonstrated they stood as elevations on the sea floor. It is therefore essential to distinguish present-day topography from the topography of the sediment during and just after accumulation. The crinoid-stem calcarenites and calcirudites capping and flanking the calcilutite mounds, being less resistant to weathering and erosion, are commonly removed leaving the mounds exposed. Where exposed they frequently form small hillocks but it must be emphasised that topographic hillocks, even if of bryozoan calcilutite, are not necessarily knolls as defined here. It must be proved that the calcilutite mounds stood as elevations on the sea floor. Proof comes from the capping and flanking beds which show quaquaversal depositional dips off the mounds. Post-depositional compaction cannot account for such dips because the core, with a high carbonate mud content, would compact more than the flanking beds which have a grain supported framework of skeletal carbonate and a much lower mud content. Compaction would therefore reduce any depositional dips not increase them or generate apparent depositional dips. The dips are confirmed by geopetal structures.

The mound rather than bank-like form of the calcilutite cores and the absence of any signs of current activity show they are accumulations of carbonate mud, not erosional remnants of a once continuous sheet of sediment. Initial accumulation in discrete mounds rather than uniformly over the area was probably related to sea floor or hydrographic factors. Certain sites were more favourable for carbonate accumulation than others but once mound growth started it appears to have been self-perpetuating. It is unlikely that the mounds developed initially in areas of dense bryozoan growth unless the sea floor was elevated at these places. However, once mounds became established, they would provide an ideal habitat for bryozoa providing bryozoan growth was faster than carbonate mud accumulation. Better water circulation than on the surrounding sea floor would mean a more abundant supply of planktonic food for the bryozoans to filter out in their circlets of ciliated tentacles.

Growth of the calcilutite mounds on the sea floor required either transportation of carbonate sediment and deposition at sites of mound development or in situ production and accumulation of carbonate mud. If the sediment was transported it would require selective deposition on a hydrographic prominence once the mound was established. This could occur by organic filtering and trapping of current transported carbonate mud, checking of currents carrying suspended carbonate mud by organic baffles resulting in deposition of the mud, or adhesive trapping of current transported carbonate sediment in, for example, a surficial algal ooze.

The bryozoa, especially the fenestellids, could have acted as both current baffles and sediment traps but their populations do not appear sufficiently dense in many mounds to have had a marked effect. The possibility of sediment adhesion to an algal slime cannot be eliminated; algae may have been present but are not preserved.

The circular plan of most of the mounds suggests that accumulation of transported sediment was not the main mound forming process. They are considered to result from mainly in situ production and accumulation of carbonate mud. The filtering feeding mechanisms of the bryozoans would not be inhibited by deposition of transported carbonate mud and, providing their growth could at least keep pace with in situ accumulation of carbonate sediment, the environment would be very suitable for bryozoan habitation.

From quantitative estimates of the production of aragonite by codiacean algae (Stockman et al., 1967) and study of trapping and stabilisation of carbonate mud by Thalassia (Ginsburg & Lowenstam, 1958) it appears that carbonate mud mounds can develop as largely self-supporting systems (Bathurst, 1971). They supply their own sediment from the calcareous benthos which is trapped among the sea grass blades and stabilised by their roots and rhizomes. The tightly packed roots can support steep slopes in potentially unstable waterlogged carbonate mud and enable the mound to maintain its relief. Additional resistance to erosion is provided by subtidal algal mats, the low threshold velocity of mud-sized particles and low bed roughness (Bathurst, 1971).

Unfortunately the origin of the carbonate mud in the Yoredale calcilutite bioherm cores is unknown. Calcareous algae may have been major contributors but they have not been recognised. Pray (1958) considered much of the carbonate mud in bryozoan calcilutite cores in Mississippian bioherms of southern New Mexico was of algal origin but similarly found no algal structures preserved. Binding organisms are also conspicuously absent. Bryozoa may have partially bound the sediment but they are not numerous enough to have been the main binders. Sea grasses cannot have fulfilled this role either because angiosperms did not spread extensively until the Lower Cretaceous. Although speculative it appears that algae, of which there is now no trace, may have been not only a source of carbonate mud but also important sediment binders. "It would be interesting to know if the algae alone, calcareous and non-calcareous, were able to support the development of mud banks unaided" (Bathurst, 1971).

Although similar bioherms up to 350 feet (107m) in height have been recorded in the literature (Pray, 1958), in the rocks studied termination of calcilutite mound development and colonisation by crinoids occurred after growth to a height of only a few metres. The reason for this is unknown but it could be related to many environmental factors including water depth. Once crinoids colonised the mounds they soon became very abundant and grew to a large size. This environment, with good water circulation and hence an improved supply of nutrients, enabled prolific crinoid growth. After death most of the crinoids appear to have accumulated more or less in situ as coarse crinoid-stem calcarenites and calcirudites with depositional dips on the mound flanks of up to 20^{o}. Dips of this magnitude are not rare for Pray (1958) recorded depositional dips of up to 35^{o} in beds flanking Mississippian bioherms in southern New Mexico. The crinoids must have formed dense thickets and have been effective current baffles. They would not only trap sediment produced in situ by mechanical and biological breakdown of carbonate skeletons and stabilise it with their root systems but also be a potential trap for any passing suspended sediment. Evidence of current activity is usually absent although occasional biosparites and biosparrudites interbedded with the biomicrites and biomicrudites show that in places carbonate mud has been winnowed. Rarely, as at Binks (SD 709836), preferred orientation of crinoid stems also indicates current activity.

In the Underset Limestone lenses of unbedded crinoid-stem calcirudite with a carbonate mud matrix are seen in addition to bryozoan calcilutite mounds. Like the calcilutite mounds, they are capped and flanked by crinoid-stem calcarenites and calcirudites and are also considered to be in situ accumulations. Initial development must have occurred at sites especially favourable for crinoid growth for, as in the beds capping and flanking the bioherms, the crinoids grew to a much larger size than elsewhere. Once their debris had accumulated, the mounds formed seem to have offered ideal habitats for further prolific crinoid growth but, like the calcilutite mounds, they attained heights of only a few metres before they too became covered with thin bedded crinoid-stem calcarenites and calcirudites.

The evidence suggests that the calcilutite mounds and the lenses of coarse crinoid debris, both capped by thin bedded crinoid - stem calcarenites and calcirudites, result from biogenic production and accumulation of carbonate in situ rather than accumulation of transported sediment. They are therefore bioherms in the sense of Cumings (1952) i.e. a reef, bank or mound of strictly organic origin embedded in rocks of a different lithology.

LITHIFICATION AND DIAGENESIS.

a) Introduction.

The fabric and mineralogy of carbonate rocks result not only from the original characteristics of the sediment but also from complex syngenetic, diagenetic and epigenetic changes. The high susceptibility of carbonate sediments to these changes often makes determination of their original characteristics difficult. Recent studies have not only increased our knowledge of modern carbonate environments but have also led to a greater understanding of ancient carbonate rocks. However, even with this knowledge the sedimentology, lithification and diagenesis of ancient carbonate rocks are still often very difficult to interpret.

Three processes can be recognised in the lithification and diagenesis of carbonate rocks, 1) cementation, the filling of interparticle and intraparticle voids by passively precipitated cement, 2) dissolution and 3) neomorphism, which embraces two in situ processes a) polymorphic transformation and b) recrystallisation (Bathurst, 1971). Although these three processes can be recognised they are frequently inter-related. For example, aggrading neomorphism, the process whereby a mosaic of finely crystalline carbonate is replaced by a coarser mosaic of carbonate (Folk, 1965), involves in the neomorphic processes of polymorphic transformation and recrystallisation both dissolution and precipitation.

b) Cementation.

By comparison with modern carbonate sediments the carbonates of the Yoredale Group probably had porosites of 40% - 70% (Ginsburg, 1964; Bathurst, 1971; Choquette & Pray, 1970). Absence of considerable compaction in all but the argillaceous carbonates and reduction of their porosity to less than 5% requires early cementation, very large sources of $CaCO_3$ and a highly efficient means of transporting the calcium carbonate and precipitating it in the pores. As most of the carbonates studied are bioclastic micrites, cements are usually best studied in cavities within carbonate skeletons where they are often well displayed. However, it must be realised that micro-environments within these intraparticular cavities can differ from those in the surrounding intergranular porosity. Cavities also occur beneath allochems where bridging occurs, dominantly under fenestellid fronds in the calcilutite bioherm cores and beneath shell debris. Only in the biosparites and biosparrudites can intergranular cements be studied easily.

b) Cementation.

To aid study of the carbonate cements the rocks were stained with an acidified solution of alizarin red S and potassium ferricyanide to differentiate the various carbonate minerals (see appendix p. 421). This not only allowed easy distinction between calcite and dolomite but also enabled recognition of ferroan calcite and ferroan dolomite. Differences in mineralogy and ferrous iron content and the spatial relationships of the carbonates enabled at least part of the history of cementation to be established.

The earliest recognisable cement consists of non-ferroan calcite. It rims calcareous bioclasts and fossils in the biosparites and biosparrudites and cavities, including those in the calcilutites, but is seen best lining cavities within calcareous bioclasts and fossils. Most of the crystals are in optical continuity with their substrate.

On finely polycrystalline substrates, such as lithostrotionid corals (Plate 61) the first crystals to nucleate are small and fibrous. They are oriented perpendicular to the substrate and are commonly overgrown by later, larger, often scalenohedral, non-ferroan calcite crystals with a similar orientation. Where these crystals do not entirely fill the cavity they are terminated by well developed planar crystal faces. The remainder of the cavity may be filled with equant non-ferroan calcite which abuts against these faces.

Where the earliest recognisable generation of non-ferroan calcite cement is nucleated on monocrystalline substrates it is usually very coarse. Such is the case in the biosparites and biosparrudites where nucleation on crinoid debris has resulted in formation of large syntaxial overgrowths (Plate 45) which are occasionally poikilitic.

Nucleation and growth of cement is sometimes prevented where bioclasts are peripherally micritised or coated with micrite. On partly coated or micritised grains cement occurs selectively on those parts which are not micritised or micrite covered.

This earliest generation of non-ferroan calcite cement is clear and free from inclusions. It does not coat fractured surfaces and therefore pre-dates compaction of the sediment sufficient to break bioclasts.

Post-dating this non-ferroan calcite cement is a ferroan calcite cement which, unlike the first generation of non-ferroan calcite, coats fracture surfaces and therefore post-dates compaction of the sediment sufficient to break bioclasts. Although its appearance may be marked by nucleation of new crystals continued growth of the non-ferroan cement crystals already established but with an increased iron content is more usual. The stain imparted by the potassium ferricyanide shows the ferroan/non-ferroan junction in the crystals is either abrupt or transitional. The ferroan calcite cement sometimes stains uniformly (Plate 45) but usually, after its first appearance, there is an alternation of variably ferroan and non-ferroan zones (Plate 46) Several of these zones may occur within a single cement crystal (Plate 46). They have planar boundaries which represent old crystal faces and can often be correlated from crystal to crystal. They are therefore time planes useful in studying evolution of the cement. Zones of this type have been interpreted as recording changes in the iron content of the pore fluids (Bathurst, 1971) but they may also reflect other changes in pore fluid chemistry aiding or inhibiting incorporation of ferrous iron into the calcite crystal lattice. Ferroan calcite cements usually post-date earlier non-ferroan calcite cements although exceptions have been recorded (Colley & Davis, 1969).

The ratio of ferroan to non-ferroan calcite is highest in the argillaceous limestones and lowest in the clay-free limestone where nearby shales are absent. It seems likely that clay minerals provided the source of iron, either within their lattice or as an adsorbed iron-oxide film, or that they, possibly with other insolubles, prevented early cementation by decreasing permeability and preventing nucleation cement crystals.

A similar distribution of ferroan calcite is recorded by Oldershaw & Scoffin (1967) in the Lower Carboniferous Halkyn and Silurian

Wenlock Limestones. They noticed a pre-compactive fracture, non-ferroan calcite cement (<200 ppm Fe^{2+}) and a later post-compactive fracture, ferroan calcite cement (200 ppm - 500 ppm Fe^{2+}); the ferroan calcite cement occurring uniformly in the argillaceous limestones but only in the clay-free limestones where adjacent to an underlying shale. They concluded that clay minerals were the source of the iron and the calcium carbonate for the ferroan calcite cement was derived by pressure solution of the argillaceous limestones and from calcium carbonate released from the shale.

The slight sedimentary compaction sufficient to break only occasional bioclasts in the non-argillaceous limestones shows that lithification sufficient to produce a rigid framework occurred before burial deep enough to break most of the delicate skeletons. Compaction however, is greater in the argillaceous limestones where delicate bioclasts are often distorted, broken and frequently displaced (Plate 28). Lithification of the argillaceous carbonates must have occurred later than lithification of the non-argillaceous carbonates, a conclusion supported by the high ferroan to non-ferroan cement ratio in the argillaceous limestones. Clay minerals, organic matter and other insolubles would not only decrease permeability but would form envelopes around the carbonate grains inhibiting both nucleation, and therefore growth of carbonate cement crystals, and neomorphism (Bausch, 1968; Marschner, 1968).

Evidence of pressure solution is shown by tightly packed grains with sutured contacts and stylolites. Although stylolites are seen in nearly all the carbonates they are most common in the argillaceous limestones; the same is true for sutured grains. Preferential solution of the argillaceous limestones is caused by several factors. High insoluble residues inhibit lithification and neomorphism, and clay minerals themselves may have also been instrumental in pressure solution. Clay films between grains increase pressure solution because diffusion in the clay layer is greater than in a solution film between clean carbonate grains. Where the carbonates contain thin shale films pressure solution is concentrated, grain boundaries are highly sutured and stylolites are frequently developed. (Plate 29).

The cements in the caliche at the top of the Single Post Limestone merit special attention. The apparently accretionary concentric laminations of some of the microspar clasts (Plate 48) suggests they were originally composed of micritic carbonate cement precipitated in a subaerial environment. Fractures within the clasts are usually filled with calcite but sometimes siderite and ferroan calcite, whereas the intergranular porosity is filled with siderite or ferroan calcite. The siderite post dates the early non-ferroan calcite cement and consists of brown, lens-shaped crystals with their long axes oriented perpendicular to the substrate (Plates 49 & 50). It usually forms a fringe around clasts, sometimes lines fractures within clasts and occasionally fills the intergranular porosity completely. It also occurs as a replacement. The siderite cement is followed by ferroan calcite cement which fills the remaining porosity with large crystals.

c) Neomorphism.

Neomorphism embraces "all transformations between one mineral and itself or a polymorph. It does not include simple pore-space filling;

older crystals must have been gradually consumed and their place simultaneously occupied by new crystals of the same mineral or a polymorph" (Folk, 1965). Although passive dissolution and precipitation are excluded from this definition they are inevitably involved in neomorphic processes (Bathurst, 1971).

Distinction between clay and silt-sized carbonate grains in the matrix is important. Mud-sized carbonate grains result either from skeletal breakdown or from direct precipitation as aragonite or high Mg calcite whereas silt-sized grains, except those resulting from aggrading neomorphism, are chiefly from breakdown of organic skeletal carbonate (Matthews, 1966). Micrite and silt resulting from breakdown of skeletal carbonate have been differentiated from neomorphic carbonate on the basis of grain shape, the former is often polyhedral whereas the latter consists of interlocking grains. In ancient carbonates such genetic interpretation is very difficult to make because of the complex diagenetic history.

In the non-argillaceous carbonates most of the calcilutite matrix consists of silt-sized, non-ferroan calcite crystals between 4 microns and 30 microns in diameter, commonly about 10 microns. As few crystals are less than 4 microns in diameter, if the matrix was originally dominated by micrite, most of the crystals must have undergone aggrading neomorphism. Two types of aggrading neomorphism seem to have occurred, a general crystal enlargement (Plate 25) and a patchy enlargement, crystals expanding in some areas leaving patches of smaller crystals (Plate 26). This suggests the matrix was originally of smaller grain size, probably dominated by micrite and very fine silt.

The calcilutite matrix of the relatively clay-free limestones has neomorphosed to a coarser fabric than the matrix of the argillaceous limestones. Clay minerals and probably other insolubles seem to have inhibited neomorphism (Bausch, 1968; Marschner, 1968). In some of the argillaceous limestones the originally non-ferroan calcite matrix has neomorphosed almost entirely to ferroan calcite (Plate 28). Where neomorphism to ferroan calcite is less extensive, a single neomorphic crystal may grade centrifugally from non-ferroan calcite to ferroan calcite.

Neomorphic fabrics resulting from sub-aerial exposure are seen in the Single Post Limestone over the northwest part of the Askrigg Block and the southwestern Barnard Castle Trough. Here the Limestone, a mottled biomicrite, contains irregular areas of neomorphic ferroan and non-ferroan microspar with sparse, often corroded, bioclasts and small irregular vugs infilled with ferroan calcite cement which truncate bioclasts (Plate 47). Percolation of rainwater through the most permeable parts of the sediment is thought to have caused dissolution on both microscopic and macroscopic scales. Macroscopic dissolution resulted in the formation of vugs whereas microscopic dissolution was more selective and increased both intergranular and intragranular porosity. After dissolution, probably during burial, the leached areas seem to have suffered more intense neomorphism than the surrounding areas, possibly because of their enhanced porosity. Like leaching, neomorphism tended to destroy original fabrics and may be responsible for destruction of much of the bioclastic debris in these areas.

Although the matrix of the Limestones is considered largely a product of breakdown of skeletal debris, comparison with modern carbonate muds suggests it originally had porosities of 40% to 70%. Absence of considerable compaction in all but the argillaceous limestones shows that a high percentage of the now lithified matrix, with porosities of less than 5%, must be carbonate cement.

Neomorphism of the first formed cements in carbonates usually occurs during the early stages of diagenesis and is very difficult to identify in ancient carbonate rocks. Although speculative, some of the very fine, fibrous, non-ferroan calcite seen on originally aragonite fossils and bioclasts may be a calcitised aragonite cement.

Neomorphism may preserve original fabrics in detail, in general form only, or may obliterate them completely. Aragonitic fossils such as molluscs are preserved where they have been calcitised or where, after dissolution, their mold has remained intact and been infilled by calcite cement. Many molds, however, must have collapsed after dissolution of the aragonite shell leaving no trace. Where the neomorphic fabric cuts across fossils or bioclasts their structure may be preserved as dusty inclusions. More commonly, the structure of the bioclast or fossil controls the neomorphic fabric as, for example, in some brachiopod shells where neomorphic calcite is oriented parallel to the original fibres. During neomorphism, calcite crystals within bioclasts or fossils may grow outward into the adjacent micrite matrix and replace it. Large syntaxial neomorphic overgrowths are sometimes seen on echinoderm fragments. They frequently contain dusty inclusions inherited from the replaced micrite and can therefore be differentiated from overgrowths of cement which are usually clear. The overgrowths may be monocrystalline or polycrystalline but both reflect the optical orientation of the host.

Some of the allochems are micritised either completely or peripherally but in others it is not obvious whether the peripheral micrite is a coating or a replacement. Bathurst (1966) described micrite replacing allochems and showed it resulted from precipitation of carbonate in algal borings. Some of the micritisation in the Yoredale carbonates almost certainly results from algal boring because micrite filled tubes penetrating allochems are visible in thin section. Whether or not all the micritised allochems have undergone this process is debatable . Purdy (1968) suggests a relationship between micrite and organic matter either as an organic matrix in skeletal carbonate, dispersed in fecal pellets or as algal inclusions in bored allochems. Decomposition of the organic matter by bacteria and fungi is thought to cause dissolution and replacement of the allochem by cryptocrystalline carbonate simultaneously.

Micritisation in the carbonates is not intense. It may have been inhibited by fast accumulation of carbonate and by the interstitial mud which decreases both pore space for bacterial inhabitation and inhibits diffusion of metabolic products. The degree of micritisation, if purely algal, should also be a function of water clarity and hence at least partly related to water depth as light is required for photosynthesis. Friedman et al (1971) found no such relationship and conclude that fungi also play a major role.

d) Dolomitisation.

Dolomite is common as a minor component of the carbonates studied but forms a major component of the calcarenites at the base of the Underset Limestone and some of the siliceous calcarenites and calcareous cherts associated with the Underset and Crow Limestones. It is also frequently associated with mineralisation and faulting.

Recent work has shown that dolomites can form in marine environments from solutions with high Mg:Ca ratios under conditions of high salinity or during diagenesis by reaction of interstitial waters with high Mg:Ca ratios with the carbonate sediment. It can also be epigenetic.

In the Yoredale carbonates dolomite occurs as both a cement and a replacement. It is most common as a replacement and post-dates the first ferroan calcite cement. Staining shows it to vary from non-ferroan to ferroan and, as in the ferroan calcite cement, non-ferroan and ferroan zones are sometimes seen within the same crystal.

Replacement dolomite usually occurs as isolated euhedral rhombs (Plate 64, 65 & 66) except where dolomitisation in intense and the rhombs have grown together forming an interlocking mass of anhedral crystals (Plate 54). Dolomitisation tends to be selective replacing micrite matrix, bioclastic debris and calcite cement in that order. Schmidt (1965) showed the micrite matrix in some carbonate sediments was completely dolomitised whereas the allochems were only slightly or not dolomitised. He noticed intraclasts, ooliths and originally aragonitic bioclasts were more susceptible to dolomitisation than calcitic allochems of which those of high Mg calcite were more susceptible than those of low Mg calcite. Lucia (1968) established a similar sequence but noted this strict order was not always observed. Other factors besides pre-dolomitisation mineralogy are important including particle size, small particles being most susceptible, and permeability. Organic matter may also play a significant role favouring dolomitisation. Favourable Eh-pH conditions can be created by organic decay and may be the link between the common association of silicification and dolomitisation.

Dolomitisation seems to have had a long history. Its first appearance post-dates the first ferroan calcite cement but in most places appears to pre-date silicification because where rhombs of dolomite occur in a chertified carbonate, their edges are sometimes corroded and etching has occurred along their cleavage (Plate 64). This suggests that dolomitisation occurred before silicification for where dolomite rhombs replace unsilicified carbonate their edges are not corroded. In other places, however, there is no evidence of such etching and dolomite formation may post-date silicification. Replacement of silica by dolomite can be demonstrated where siliceous sponge spicules are replaced. This is best illustrated where rhombs of dolomite are seen replacing _Hyalostelia_ spicules (Plates 71 & 72). Dolomite formation post-dating silicification can also be proved where dolomite veins cut silicified carbonate fabrics.

e) Carbonate veins.

Veins of non-ferroan and ferroan calcite and non-ferroan and ferroan dolomite have been recorded. They vary considerably in age and may be complex having, for example, an early generation of non-ferroan calcite followed by a later generation of ferroan calcite. Some, like those filling tension fractures confined to burrow infillsat the top of the Lower Parting and those in the clasts of the caliche at the top of the Single Post Limestone, seem to have developed soon after the sediment was coherent enough to crack. Others, particularly those associated with faults and mineral veins, must have formed much later. Although veins of dolomite are frequently associated with mineralisation elsewhere they are much less common than calcite veins and appear, in general, to have developed later.

f) Silicification.

Although scattered chert nodules show local silicification is widespread, more intense silicification is restricted to certain parts of specific limestones. It is common in parts of the Lower Parting, in the Cockleshell and Scar Limestones in certain areas, in places at the top of the Underset Limestone, in much of the Crow Limestone and in the cherts associated with the Underset and Crow Limestones.

Silica occurs as both a cement and replacement. Its first appearance post-dates the earliest generation of ferroan calcite cement and the first formed dolomite. The cement is best studied in cavities in skeletal carbonates such as the body cavities of corals and brachiopods where they have not been completely infilled by carbonate mud or earlier carbonate cements. The remaining cavity is sometimes lined or completely filled by colourless to yellowish-brown, colloform chalcedony with the fibres oriented perpendicular to the cavity wall (Plates 57 and 58). Where chalcedony only lines the cavity or is absent, the remaining cavity is frequently infilled by granular quartz (Plates 59 and 60).

Replacement by cryptocrystalline to microcrystalline quartz or chalcedony is also common. It varies from selective replacement of minor parts of the rock to complete silicification. Where there is only limited replacement the silicified components are nearly always carbonate skeletons (Plates 32 & 61). Silicification may begin at a single point or several different places within the same skeleton, either partly or completely replacing it. The fabric of the replaced skeleton may be pseudomorphed by oriented chalcedony fibres or, where the replacement silica shows no orientation, by lines of dusty inclusions within the silica but often the fabric of the host is destroyed. Where there is only minor silicification, replacement is usually restricted to the carbonate skeletons; only rarely does it invade the matrix.

The carbonate skeletons are silicified selectively but the degree of preservation is not related to the extent of replacement. Corals, often silicified in the coral biostromes, are most susceptible followed by brachiopods and echinoderms. Molluscs, foraminifera, algae and bryozoa are least susceptible but whereas silicification of molluscs and foraminifera can be proved, silicification of algae and bryozoa can only be inferred where the carbonate rock is completely silicified. Nowhere are silicified algae or bryozoa recognised. Similar orders of susceptibility to silicification were recorded by Newell et al (1953) and Chillingar et al (1967) with the exception of bryozoa which they found preferentially replaced. Susceptibility to silicification is related to many factors including mineralogy, fabric, permeability and content of organic matter. Of these fabric seems the most important. Carbonate skeletons with a fine fibrous structure are replaced first followed by skeletons with small granular crystals. With increasing silicification the larger skeletal crystals and the matrix is replaced, probably starting with the smallest crystals. There is therefore an inverse relationship between silicification and crystal size. Organic matter also seems important. This is shown best by the preferential location of many chert nodules in gigantoproductid valves in the Cockleshell and Scar Limestones and the association of silicification with the coral biostromes.

Intense silicification leads to replacement of the rock by microcrystalline and cryptocrystalline quartz and chalcedony either locally as nodules, stringers or patches, or wholesale. Sometimes there is complete replacement but commonly some of the carbonate survives, usually bryozoa and often at least some of the crinoid debris. Silica replacing carbonate skeletons frequently cuts across their boundaries and invades the matrix.

i) Chert nodules

Chert nodules are widely distributed although they are more common in some limestones and certain areas than in others. They may be absent or abundant and vary from a microscopic size to large irregular masses, stringers and extensive tabular cherts. The nodules frequently occur in zones parallel or subparallel to the bedding and in places form tabular masses. In the field their contact with the surrounding limestones seems abrupt. Most are medium to dark grey with a bluish tint, but sometimes they are brownish-black, and usually have a lighter coloured porous outer zone commonly about a centimetre thick. They contain a variable quantity of unreplaced carbonate which usually increases towards the periphery of the nodule and is often dominated by crinoid debris. On weathering the unreplaced carbonate often dissolves leaving chert molds. Calcite veins, both ferroan and non-ferroan, sometimes fill fractures transecting the nodules and may or may not extend into the surrounding matrix. (Plate 55).

In thin section the contact between the chert nodules and surrounding limestone is microscopically irregular (Plate 55). It sometimes follows shell fragments and other bioclastic debris although patches of silica often occur outside the megascopic periphery (Plate 56). The chert nodules consist of colourless to yellow or brown, cryptocrystalline to microcrystalline quartz with inclusions of organic matter, pyrite, iron-oxide and carbonate. Chalcedony is also common and, like quartz, occurs as both a replacement and cavity filling cement. Cavities are often lined or completely filled with colourless to yellowish-brown, colloform chalcedony with fibres oriented perpendicular to the cavity walls (Plates 57 & 58). Where chalcedony only lines the cavity its central part is frequently filled by granular quartz (Plates 59 & 60). Calcareous fossils may be preserved as carbonate (Plate 63), as chert pseudomorphs (Plates 59 & 60), or as dusty inclusions in chert (Plates 65 & 66). Many have been completely destroyed especially where silicification is intense. Sometimes they have only a chertified margin (Plate 63). The matrix of the carbonate is nearly always replaced.

The chert nodules are clearly replacement features. They contain bioclasts of similar type and orientation to those in the surrounding rock. Within the nodules the carbonate rock is seen in all stages of silicification and bioclasts which transect the periphery of the nodule may be silicified inside but not outside. Occasionally structures within the limestone, such as very thin shale laminae, can be traced into the nodules.

ii) Chert nodule formation.

During early lithification and diagenesis variations in the amount of carbon dioxide derived from decaying organic material causes fluctuations in pH. Concentrations of carbon dioxide resulting from an irregular distribution of decaying organic matter such as that noted by Emery & Rittenberg (1952), Van Andel & Postma (1954) and Siever et al (1961) in modern sediments would locally reduce the pH of the highly alkaline interstitial water and cause dissolution or carbonate and precipitation of silica. A concentration gradient of HCO_3^- and Ca^{2+} between the sites of organic decay and surrounding areas where less carbondioxide was being produced would enable diffusion of dissolved carbonate away from the site of organic decay. A similar concentration gradient but in the opposite direction would allow migration of silica from the surrounding areas to the sites of organic decay.

Siever (1962) considered the appearance of silica at sites of organic decay could not be explained in terms of pH because at published pH values for most sediments (below pH 9) a decrease in pH would result in solution of calcium carbonate but would not affect the solubility of silica which is essentially independent of pH between pH 2 and pH 9. Walker (1962) however, suggested variations of pH within the diagenetic environment could account for silicification. It has now been shown experimentally that pH's greater than pH 9 can exist in natural environments (p.381).

A further mechanism suggested by Emery & Rittenberg (1952) and expanded by Siever (1962) is the effect of organic matter on the solubility of amorphous silica. Emery & Rittenberg (1952) proposed that at sites of organic decay silica solubility is lowered by adsorption of silica onto organic matter. Silica is immobilised by the formation of organic-silica complexes whereas in the surrounding area without organic adsorbates silica is free to dissolve. A concentration gradient of dissolved silica would continue to immobilise the silica producing insoluble organic-silica complexes. This process would continue, carbonate dissolving and silica precipitating at these sites until the organic matter was either completely oxidised by bacteria, complexed with silica, or until bacterial activity producing the carbon dioxide ceased. Siever (1962) also uses this model to explain the replacement of SiO_2 by $CaCO_3$ if it is assumed that bacterial decay was completed at some sites before others.

The concentration of chert nodules in certain beds and at certain horizons may be related to permeability but their common association with a rich fauna suggests that organic matter was important.

The chert nodules often contain pyrite, usually finely disseminated but sometimes as small cubes, and rhombs of ferroan and non-ferroan dolomite. The pyrite and dolomite are often restricted to the nodule or are more abundant than in the surrounding limestone. Absence, or less common appearance, of dolomite and pyrite outside the nodule does not appear to result from non-preservation. Formation of both seems to pre-date silicification. This can be proved for the dolomite because the rhombs sometimes have corroded edges. The formation of dolomite and pyrite, like chert, is favoured by organic decay which may be the main factor linking their association.

iii) Source of silica.

Biogenic amorphous silica originally distributed throughout the carbonate sediment is considered to be the source of silica for silicification. Redistribution and concentration of this silica is thought to have taken place by dissolution and precipitation in highly alkaline interstitial fluids. Siliceous sponges are thought to have been the main contributor of silica but radiolarians may also have been important.

It is unlikely that non-carbonate detrital material supplied any significant quantity of silica because it usually forms only a minor part of the limestone. A volcanic or non-biogenic origin is also unlikely (p. 393). Siliceous sponge spicules, now replaced by chalcedony or cryptocrystalline to microcrystalline quartz, occur in the chert nodules but not in the surrounding limestone. This implies migration of biogenic amorphous silica outside the sites of nodule formation to those sites.

A fuller discussion on the source of silica is given in the section on the bedded cherts (p. 392).

iv) Replacements within the chert-carbonate system.

Although the dissolution and precipitation of calcium carbonate and silica are well known from laboratory experiments, actual replacements have not been demonstrated. The solubility of $CaCO_3$ is highly dependent upon pH, the dominant independent variable in natural environments being the activity of CO_2, pH being the dependent and not the controlling factor. Calcium carbonate dissolves in acid and precipitates in alkaline solutions, the precise value of precipitation depending mainly on the activity of CO_2, $CaCO_3$, pressure and temperature. Recent work has shown that the solubility of silica is essentially independent of pH between pH 2 and pH 9 but increases greatly in alkaline solutions of pH greater than pH 9 (Alexander et al, 1954; Iler, 1955; Krauskopf, 1956; Okamoto et al, 1957). These results differ from the now suspect experimental data obtained earlier by Correns (1941), which showed a progressive increase in the solubility of silica with pH at all values greater than pH 3.

As a result of this recent data, Walker (1962) suggested that chert-carbonate replacements may take place where fluctuations of pH occur under conditions of high alkalinity (above pH 9). In highly alkaline water even a slight increase in pH would favour solution of silica and the simultaneous precipitation of calcium carbonate whereas a decrease in pH would favour the reverse, solution of calcium carbonate and precipitation of silica. Accordingly, carbonate replacement of chert would result under conditions of increasing pH, chert replacement of carbonate under conditions of decreasing pH, and chert-carbonate reversals under conditions of fluctuating pH. In environments where interstitial water has a normally high alkalinity, fluctuations in pH could be caused by variations in the amount of dissolved carbon dioxide, possibly derived from decaying organic matter.

This explanation by Walker (1962), a modification of Correns (1950) theory, assumes that interstitial waters of high alkalinity are common in nature, because the proposed replacement mechanism depends on the inverse solubility relationship that exists between silica and carbonate at pH values above pH 9. Siever (1962) noted that the assumption that high pH values are present in interstitial waters is not supported by most published data (Baas-Becking, 1960) and indeed Walker in an earlier paper (1960) stated a similar opinion. However, although published data shows that pH's greater than 9 are not common in nature, it now appears that natural waters of high alkalinity are more common than published analyses indicate.

Especially significant is the work of Garrels (1960) who showed that pure de-aerated water in equilibrium with calcium carbonate has a theoretical pH value between pH 9.88 and pH 10.00 and that values of the same order of magnitude can be obtained experimentally. Gavish & Friedman (1969) have also shown that upon the addition of aragonite to de-ionised water the pH may climb to pH 9.4 within 2½ hrs at 25°C. Jansen & Kitano (1963) obtained a pH of 9.4 after one minute of adding finely-ground marine carbonate to distilled water.

This data suggests the infrequency of high pH values reported in published literature may reflect inaccuracies of analytical methods of pH determination rather than a near absence of high pH waters in nature. More likely, however, the absence is due to the extreme difficulty in determining the pH of interstitial fluid uncontaminated by other waters or atmospheric CO_2.

The tendency for replacements to take place might also be influenced by variations in the temperature of interstitial waters during burial (Walker, 1962). The solubility of silica increases with temperature (Okamoto et al, 1957; Siever, 1962) whereas the solubility of calcium carbonate decreases with an increase in temperature (Miller, 1952). An increasing temperature resulting from burial might therefore lead to solution of silica and precipitation of calcium carbonate. This mechanism presumably would only apply to sediments that have suffered burial sufficiently deep to cause a significant increase in temperature.

g) Discussion.

Lithification and diagenesis of carbonate sediments can occur in shallow marine environments (Alexandersson, 1969; De Groot, 1969;

Shinn, 1969), deep marine environments (Milliman, 1966; Fisher & Garrison, 1967), subaerial environments (Friedman, 1964) and subsurface environments (Friedman, 1968). The low porosity of most of the carbonates encountered in this study (usually less than 5%) is the result of elimination of both the primary pore volume of the sediment and the secondary pore volume due to dissolution and fracturing. Besides a reduction in porosity, there have also been mineralogical and textural changes. Some of the original characteristics of the sediment are preserved, some have undergone fabric and/or mineralogical changes but are still recognisable or can be interpreted, whereas others have disappeared during lithification and diagenesis leaving no trace.

Marine cements of recent carbonate sediments are usually aragonite or high Mg calcite. Commonly aragonite forms fibrous cements whereas high Mg calcite is often micritic (Friedman, 1968; Shinn, 1969; Alexandersson, 1969) but aragonite and high Mg calcite can also form micritic and fibrous cements respectively (Ginsburg et al, 1967). Recognition of micritic cement in ancient carbonates is difficult as it is similar in appearance to micrite produced by breakdown of organic debris (Alexandersson 1969). The only criterion which can be used to identify any early aragonite or high Mg calcite cements in the carbonates studied is the presence of fibrous, low Mg calcite cement because aragonite and high Mg calcite are no longer preserved. Whether aragonite or high Mg calcite cement forms depends on many factors including ion concentration and the presence of organic compounds (Mitterer, 1971) and salinity and the Mg/Ca ratio (Taylor & Illing, 1971; MacKenzie & [illegible], 1971). The mineralogy of the substrate may also control the type of cement developed (Glover & Pray, 1971) or not (Glover & Pray, 1971; Land, 1971; Ginsburg et al, 1971). Neomorphism of carbonate sediments, including any cements, can occur relatively early. Fibrous cements may be replaced by low Mg calcite mosaics (Shinn, 1969).

Lithification and diagenesis in the meteoric water environment is discussed by Bathurst (1971) who gives an idealised scheme of lithification and diagenesis. The scheme, based mainly on work by Land (1966), Land et al (1967), Friedman (1964) and Gross (1964), is developed from studies of limestones in Bermuda, Eniwetok, Guam and Funafuti which have all been more or less lithified in a freshwater environment. In all these cases the original unconsolidated carbonate sediment is dominated by aragonite and high Mg calcite skeletons. The first sign of change is for the grains to cohere. Low Mg cement can be seen in the intragranular pores and in the intergranular pores around the points of grain contact but, as there is no evidence of dissolution, the cement must be allochthonous. The next change is the loss of Mg^{++} from the high Mg calcite. When all the high Mg calcite has become stabilised considerable mineralogical and fabric changes occur as the aragonite is dissolved and precipitated as calcite in both primary and secondary pores formed by dissolution. Calcitisation of aragonite and recrystallisation of aragonite and calcite also occurs without development of a passive cavity. Calcitisation is a wet polymorphic transformation of aragonite to calcite and affects both aragonite skeletons and aragonite cement. Recrystallisation is a growth of certain crystals at the expense of smaller ones of the same mineral species. Both are neomorphic processes and result in growth of neomorphic spar. These processes lead to a rigid but still porous entirely low Mg calcite rock. Any further reduction in porosity in the subaerial meteoric water environment can take place only on the delivery of allochthonous carbonate.

Diagenetic environments are highly complex in thick carbonate sequences but must be even more complicated in carbonates such as those in the Yoredale Group where they are relatively thin and interbedded with non-carbonate lithologies. Connate water in the Yoredale Group must have varied from marine in the carbonates to fresh water in the channel sandstones and to stagnant acid water in the swamps where coals formed. During burial and compaction migration of this connate water must have produced complex diagenetic changes. Diagenesis is also complicated by differences in mineralogy and hence chemistry of the various members of the sediment pile which includes in addition to carbonates, cherts, sandstones, shales, gannisters, fireclays and coals.

The Single Post Limestone shows clear evidence of subaerial exposure over the northwest part of the Askrigg Block and was probably partly lithified in a subaerial environment. Evidence of dissolution is shown by its irregular corroded top and corroded bioclasts and vugs within the Limestone. The highly neomorphosed areas producing the mottling are thought to be areas where rainwater percolated through the sediment and dissolution enhanced porosity. The local development of a caliche in the southwest part of the Barnard Castle Trough is evidence of carbonate precipitation in a subaerial environment but elsewhere the cements are similar to those in the other limestones.

The other limestones show no evidence of subaerial exposure and are considered to have been lithified in submarine and burial environments. Cementation began rapidly in the non-argillaceous limestones, before compaction sufficient to break bioclasts, and is thought to have started in a submarine environment soon after accumulation of the sediment. Proof that the initial non-ferroan calcite cement is submarine is impossible though it may be noted that some of the cement in the calcilutite bioherm cores is cloudy and similar to that described by Pray (1958) which he proved was precipitated in a marine environment.

The first generation of ferroan calcite cement is assumed to have occurred during burial of the sediment. Incorporation of Fe^{2+} in the calcite lattice requires a reducing environment (Evamy, 1969). Evamy (1969) noted that reducing conditions under which ferrous iron is stable in carbonate provinces occur widely below the water table but only rarely above it.

Dolomitisation and silicification are thought to have occurred during burial while carbon dioxide was still being produced by decaying organic matter, though dolomitisation associated with mineralisation occurred much later.

THE BEDDED CHERTS.

THE BEDDED CHERTS.

Bedded cherts occur at the base and top of the Underset Limestone and in the Crow Limestone predominantly in the upper part. Although some are non-calcareous most contain at least a small component of carbonate. With increasing carbonate the cherts pass into siliceous limestones, with increasing clay content into cherty shales and, locally in the Crow Limestone, with increasing glauconite into glauconite sandstones. Many divisions could be made on the basis of component percentages but they would be artificial because the lithologies are gradational. The cherts here are divided into those which are non-calcareous and those which are calcareous, a distinction which can be made in the field. Two types of calcareous chert can be recognised, those which contain bioclastic carbonate as an important component and those which do not, the latter being divisible into argillaceous and non-argillaceous types.

NON-CALCAREOUS CHERTS.

These cherts have a high SiO_2 content up to 95% (determined by X-ray fluorescence). They occur at the top of the Underset Limestone and in the upper part of the Crow Limestone but form only a small part of the cherts. They have a matrix of cryptocrystalline and microcrystalline quartz with patches of chalcedony (Plate 73). It is colourless to various shades of yellowish-orange, yellowish-brown, brown and greyish-orange and contains inclusions of organic matter, pyrite, clay minerals and carbonate. Scattered, silt-sized quartz and grains of glauconite are sometimes seen.

The most obvious component of many of the non-calcareus cherts is sponge spicules which are sometimes so abundant that they form a framework to the rock (Plates 67 and 68). Nearly all are monaxid types averaging 0.05mm in diameter but varying between 0.01mm and 0.05mm in dameter and up to 2mm in length. They are oriented with their long axes parallel to the bedding. The spicules are colourless and have a radial chalcedonic structure in cross section or are composed of cryptocrystalline to microcrystalline quartz. Their central canal may or may not be preserved. Where preserved it is infilled by chalcedony or cryptocrystaline to microcrystalline silica which may be colourless or similar to the matrix of the rock with small inclusions. Sometimes it can be recognised where infilled by chalcedony but more usually it cannot because the chalcedony filling the canal has grown in optical continuity with the chalcedony of the spicules. Hyalostelia spicules, commonly 1mm but up to 1.5mm in diameter, are often sparsely scattered and become locally common but they are most abundant in the calcareous cherts and siliceous limestones. Rarely small triaxons are seen.

The non-calcareous cherts including those with abundant sponge spicules, are sometimes laminated (Plates 67 and 68). The lamination results from alternations of light and dark coloured chert laminae. The darkest laminae are thin, less than 2mm thick, and rich in organic matter and clay minerals. The lighter laminae are thicker and contain less organic matter and clay minerals. The colour of the chert laminae seems related to content of insolubles. Where sponge spicules occur in the laminated cherts they are most abundant in, and form nearly all of, the light coloured laminae whereas in the darker laminae they are less abundant. Although the contacts between the laminae are poorly defined the lamination is too regular to be a diagenetic feature. Its regularity and attitude parallel to the bedding suggests it is a sedimentary feature related to regular changes in environmental conditions. Bradley (1929), Rubey (1929), Bramlette (1946) and Anderson (1960, 1964), considered climatic changes were the most probable causes of such laminations. Both diurnal and seasonal cycles can produce lamination but diurnal cycles would be too short to produce the lamination seen in the cherts. Annual cycles are known to produce laminations of comparable thickness. The light coloured laminae with abundant sponge spicules probably represent seasonal proliferation of organic production, comparable with seasonal planktonic blooming resulting in the formation of varves. The darker laminae, containing amongst other insolubles, clay minerals, probably represent seasons less favourable for organic production and associated reduced accumulation.

CALCAREOUS CHERTS.

The calcareous cherts contain carbonate as an important component either as carbonate mud, carbonate silt, skeletal debris, carbonate cement or several of these components and form the bulk of the cherts. With increasing carbonate mud and carbonate silt they pass into cherty calcilutites, with increasing bioclastic debris into cherty bioclastic calcilutites, bioclastic calcarenites and occasionally bioclastic calcirudites and with increasing clay minerals into cherty shales.

The calcareous cherts contain a fauna dominated by small brachiopods and, at the base of the Underset Limestone, by fenestellid bryozoa and a variable content of bioclastic debris, in a matrix of cryptocrystalline to microcrystalline quartz and chalcedony. The skeletal carbonate includes crinoid, brachiopod, bryozoan and mollusc debris, sponge spicules and foraminifera. With the exception of bryozoa, which where preserved are never silicified, it may or may not be silicified. Both small monaxid sponge spicules and Hyalostelia spicules are seen though the former are more common in the non-calcareous cherts. Hyalostelia spicules are sometimes abundant (Plate 70) and are most common where the chert is crinoidal. They are usually preserved as cryptocrystalline to microcrystalline quartz and chalcedony though may be replaced, usually only partly, by calcite, ferroan calcite, dolomite or ferroan dolomite (Plates 70, 71 & 72). The small monaxid spicules are preserved as cryptocrystalline to microcrystalline quartz, chalcedony, non-ferroan and ferroan calcite, and dolomite or ferroan dolomite. Like the Hyalostelia spicules they are thought to have been originally siliceous because the structure of the spicule, notably the central canal, is preserved best in those which are siliceous. Where preserved, the canal in both the small monaxid and Hyalostelia spicules may be infilled with cryptocrystalline to microcrystalline quartz or chalcedony, though sometimes it is infilled with ferroan calcite and often appears enlarged. In some spicules where the central cavity is infilled with cryptocrystalline to microcrystalline quartz or chalcedony the form of the cavity is not preserved.

The calcareous cherts have a matrix of cryptocrystalline to microcrystalline quartz, chalcedony, mud to silt-sized carbonate, clay minerals, organic matter and sometimes pyrite, quartz silt and glauconite. Frequently dolomite rhombs occur in matrix. Cavities in the rock are filled with a variety of cements including calcite, ferroan calcite, dolomite, ferroan dolomite, chalcedony and granular quartz which are thought to have had a similar history to the cements in the limestones (p. 362).

Often the calcareous cherts contain Zoophycos. Wells (1955) first described Zoophycos ('cauda galli') from the Yoredale Group in the Main and Richmond Cherts but concluded, "there is not enough evidence to decide whether they are due to an organism or sedimentary effect". Zoophycos has been interpreted as the burrows of sediment ingesting organisms (Hantzschel, 1960, 1962; Seilacher, 1967a, 1967b; and others) and imprints of abandoned prostomial parts of sabellarid polychaetes (Plicka, 1965, 1966, 1968). However, the majority of ichnopalaeontologists consider that while some traces may be imprints most are burrow systems.

Zoophycos in the calcareous cherts are clearly burrows. The burrow systems are up to 30cm in diameter and consist of arcuate, radiating, spreite burrows 1mm to 2mm wide usually parallel, but sometimes sub-parallel, to the bedding. They are preserved as cryptocrystalline to microcrystalline silica darker than the surrounding matrix, with their spreite as thin arcuate laminae perpendicular to the burrow walls. Occasionally where the burrows cut one another their relative ages can be established.

Systematic exploitation of certain layers of sediment shows that the burrows are those of a sediment ingesting organism. This is supported by their preferential location in the finer, relatively bioclastic free, layers of sediment which were probably rich in organic material. Sometimes coarse bioclastic debris encountered by the burrowing organism has been pushed to the side of the burrow. Finer debris in the burrow infills is often oriented parallel to the spreite (Plate 74).

Although the burrowing organism producing Zoophycos is unknown Zoophycos has been used as an environmental indicator. Its use in this role can be questioned as it is known from intertidal (Hecker, 1970) and shallow water sediments (Bandel, 1967; Häntzschel, 1970; Hecker, 1970) and has been found in a deep-sea core from a depth of 3,800 ft (1160m) in the southeast Pacific (Seilacher, 1967). However its presence as a feeding trace shows the sediment had enough organic material to support the organism. The mechanism of burrowing allowed complete exploitation of laminae rich in organic matter within a certain radius. The 'cauda galli' (Zoophycos) described by Wells (1955) are also burrow systems; the burrow spreite are clearly illustrated (Wells, 1955, p.184, Fig. 4.)

The argillaceous cherts contain an important clay mineral component and may be shaly. They are best developed at the base of the Underset Limestone but also occur above the Underset Limestone and are sometimes seen in the Crow Limestone. They often occur adjacent to shales. Both the argillaceous cherts and the shales are calcareous.

SOURCE OF SILICA FOR FORMATION OF BEDDED CHERTS.

Theories regarding the origin of chert can be divided fundamentally into those which propose an inorganic origin and those which suggest an organic origin. Both inorganic (Sargent, 1929; Wells (1955; Hey, 1956) and organic origins (Hinde, 1887) have been suggested for cherts of the Yoredale Group.

The outstanding feature of natural waters is their apparent undersaturation with respect to silica. Except for hot spring waters and exceptionally rare waters from evaporite basins, surface and ground waters in nature contain far less silica than would be expected from laboratory experiments. Krauskopf (1959) showed experimentally that the solubility of amorphous silica in water is 50ppm at $0^{o}C$, 100ppm to 140ppm at $25^{o}C$ and 360 to 420ppm at $100^{o}C$. Most river waters and ordinary ground waters contain less than 35ppm SiO_2 (Clarke, 1924) whilst connate waters commonly have 20ppm to 60ppm SiO_2 (Meents et al, 1942).

The low concentrations of silica in sea water (0.1ppm to 10ppm) indicate some effective process or processes of removal must be operating, since rivers are continually adding water with silica concentrations many times greater. The principal process cannot be coagulation of colloidal silica by electrolytes as postulated by Tarr (1926) and Twenhofel (1950) because most of the silica brought by rivers is in true solution (Krauskopf, 1959). Nor can the process involve direct chemical precipitation because sea water is undersaturated with respect to silica and laboratory experiments show the solubility of amorphous silica in sea water to be the same as in fresh water.

Direct precipitation of gelatinous silica can only take place locally where volcanic activity produces abnormally high concentrations of silica. Such silica saturated solutions, which become supersaturated on cooling, may come from hot springs or be derived from decomposition of hot lava and ash by reaction with sea water. There is no evidence of contemporaneous volcanicity associated with the bedded cherts studied so a volcanic origin for the silica seems unlikely.

The adsorption of silica onto suspended particles in the presence of electrolytes was considered to be an important process by Bien et al (1959) in and around the east Mississippi delta, at least in the initial stages of removal of silica from solution. The adsorption of silica onto clay minerals or organic matter has often been suggested since as an important process in the removal of silica from sea water. However, recently Boyle et al (1974), after studying silica removal in the Merrimach River, Massachusetts and previous data on this subject, concluded that inspection of data presented by previous authors shows that in no case has it been unambiguously proved that silica exhibits non-conservative behaviour during estuarine mixing. Mixing of fresh and coastal waters in the estuaries themselves, or in the vicinity of fresh water plumes, is in all cases conservative within uncertainty of the data. The behaviour of silica in the overall mixing of river water with deep ocean surface water is non-conservative but this is not a consequence of, nor related to, mixing. It is presumably caused by processes common to surface water globally. "While it is conceivable that in placid estuaries of long residence time silica could be removed by diatom growth, the rapid inorganic removal hypothesised by Bien et al (1959) and others with all its implications of geochemical mass balance has not been unambiguously substantiated", (Boyle et al, 1974).

Diagenetic alteration of sediments, or the introductiion of silica by later solutions, has been proposed to account for chert formation. Clay mineral diagenesis may release silica. For example, the change from montmorillonite to illite involves a silica excess but the amounts released are too small to account for large scale chert formation.

To-day, amorphous silica is precipitated in the open ocean by organisms such as diatoms, radiolarians, sponges and silicoflagellates. Accumulation of biogenic silica has often been proposed as a source of silica for chert formation (Hinde, 1887; Correns, 1926; Cressman, 1955; Siever, 1962).

Relatively little work has been done on the silica secreting organisms of which most has been concentrated on the diatoms. It is useful to take the diatoms as an example to try to establish their relationship with silica because similar relationships may apply to other siliceous organisms.

The ability of diatoms to remove silica from sea water is impressively shown by the experiments of Jørgensen (1953) in which two species of diatom reduced silica concentration from initial values of 0.65ppm to 125ppm to the range 0.065ppm to 0.085ppm. These organisms, which build their tests out of opal, have the ability to utilise minute concentrations of silica and to maintain their shells in contact with a medium which should dissolve them. Iler (1955) suggests this is accompanied either by adsorption of cations that form insoluble silicates or by formation of organic-silica complexes on their surface; the latter seems most likely.

This does not mean biogenic removal of silica is not conditioned by changes in silica content of the water. Local diatom blooms may occur as a result of high silica concentrations from volcanic products. Indeed the association of radiolarian cherts with volcanoes indicates a similar relationship. Diatom productivity is determined by many organic and inorganic nutrients, among them silica (Harvey, 1957) but their use of silica is dependent on the silica content of the water. This is especially well illustrated by fresh-water diatoms living in lakes of varying SiO_2 content where, other things being equal, there is a direct relationship between population size and available silica (Siever, 1962). Silica deficient shells are produced in cultures grown in low silica nutrient solutions (Harvey, 1957). Diatoms can precipitate silica from solution even at very low concentrations (less than 1ppm) but they cannot be abundant unless there is enough SiO_2 in solution to support the population. Thus a higher productivity of diatoms and resulting faster accumulation of siliceous sediments is the consequence of a greater quantity of dissolved silica supplied to the environment.

We know most about the diatoms but available knowledge of present and ancient environments suggests that radiolaria and siliceous sponges act and acted in the same way. Fundamentally, it is the contribution of silica from inorganic sources that determines the presence, or absence of biogenic siliceous sediments.

Diatoms, which date from the Mesozoic Era, and silicoflagellates, which are known to exist from Upper Cretaceous times (Siever, 1962), obviously could not have contributed silica to Carboniferous rocks but siliceous sponges and radiolaria are known back to the beginning of the Palaeozoic and may have existed earlier. Microscopic examination of the cherts, including transmission and scanning electron microscopy, revealed abundant siliceous sponge spicules but no trace of radiolarians. Radiolarians may have been absent during accumulation of the sediment but it seems more probable that they were present and have been destroyed during diagenesis. It is considered, therefore, that the cherts resulted from accumulations of siliceous organisms or remobilised organic silica.

The development of thick cherts at particular stratigraphic horizons suggests either primary accumulation of silica at these horizons or remobilisation and precipitation of silica at these levels. The bedded and laminated nature of many of the thick cherts and the common abundance of siliceous sponge spicules indicates primary accumulation. As the source of silica is thought to be organic the presence of bedded chert must reflect greatly increased and prolific growth of siliceous organisms which, after death, accumulated on the sea floor. The productivity of diatoms is related to the abundance of many organic and inorganic nutrients including silica content of the water (Harvey, 1957) and providing the environment can supply the other requirements for growth there is a direct relationship between population size and available silica (Siever, 1962). This is also true for radiolarians and probably for siliceous sponges. Dense populations of siliceous organisms cannot be supported unless there is an adequate supply of silica. The thick cherts encountered in this study are thought to result from population explosions of siliceous organisms resulting from an increase of silica in the environment.

Bedded chert occurs in an east-west belt across the southern part of the Askrigg Block at the base of the Underset Limestone and across the northern part of the Askrigg Block and southern Barnard Castle Trough at the top of the Underset Limestone and in the Crow Limestone. It is not confined to either the Block or the surrounding basins but spans the Block edges. Its absence along the southern edge of the Askrigg Block at the base of the Underset Limestone is considered to result from non-accumulation due to too great a water depth for siliceous sponge habitation (p.417).

The distribution of chert around or near the faults bounding the Askrigg Block, especially well shown by the chert at the top of the Underset Limestone which is developed around, and is thickest near, the Stockdale Fault, suggests the faults were important in chert formation. Association of bedded chert with periods of fault movement (discussed later p.417) confirms this. The bedded chert at the base of the Underset Limestone is related to downward movement of the southern edge of the Askrigg Block, probably along the Mid Craven Fault, whereas the chert at the top of the Underset Limestone accumulated during downward movement of the northern edge of the Askrigg Block along the Stockdale Fault. The bedded cherts in the Crow Limestone are associated with upward movement of the northern edge of the Askrigg Block along the Stockdale Fault. Their location, dominantly at the top and to a lesser extent at the base of this Limestone, can be related to two phases of uplift. This is substantiated by two periods of erosion of the Uldale Sill on the south side of the Stockdale Fault during accumulation of the lower and upper parts of the Crow Limestone. The faults are thought to have acted as channels of escape for connate water with a relatively high silica content, expelled by compaction of the thick succession of siliceous deltaic sediments. Its release into the sea water resulted in proliferation of siliceous sponges and probably other siliceous organisms now not preserved which, after death, accumulated to form biogenic chert.

LITHIFICATION AND DIAGENESIS OF THE BEDDED CHERTS.

During lithification and early diagenesis the siliceous organisms trapped in the sediment would tend to slowly dissolve as the interstitial fluid, essentially sea water, would be undersaturated in silica. The rate of dissolution depends on many factors including the rate of decomposition of organic matter which protected the siliceous organisms during life and the concentration of silica in solution. It tends to slow as the concentration of silica in solution increases. Dissolution of very small siliceous organisms, points and thin edges of siliceous skeletons and areas of grain contact, would occur first. The large surface areas of the siliceous organisms gives rise to high solubilities and rates of solution that can lead to supersaturation and consequent precipitation of silica or replacement of non-siliceous components such as bioclastic carbonate.

Emery & Rittenberg (1952) have shown by analyses of interstitial waters of modern sediments that increases in dissolved silica can occur beneath the sediment surface and both they and Bruevich (1953) give evidence of approximate saturation.

THE ARENITES.

THE ARENITES.

The arenites encountered are all sandstones. They can be subdivided into calcareous, micaceous and glauconitic quartz sandstones and glauconite sandstones.

MICACEOUS SANDSTONES.

Micaceous sandstones comprise part of the Lower and Upper Partings in the southwest Barnard Castle Trough but only reach the northwest edge of the Askrigg Block where they become calcareous. They form part of a sequence coarsening upwards from shales, through siltstones into sandstones and are considered to be the distal sands of a delta located farther north. A detailed study of these beds has not been made but the sandstones consist of very fine to medium, dominantly angular to subangular quartz with muscovite. They are poor to moderately well sorted and, besides accessory minerals including feldspar and heavy minerals, often contain carbonaceous material. Parallel or ripple cross-lamination is common.

CALCAREOUS SANDSTONES.

Calcareous sandstones locally form the base of the Single Post Limestone on the north slope of Whernside and the Lower Parting in an around Garsdale and in a small area near Cam Houses (Fig. 16). They consist of poor sorted, angular to subangular, very fine to medium quartz sand and quartz silt in a ferroan calcite cement (Plate 75). Absence of the non-ferroan calcite cement which pre-dates the ferroan calcite cement in the carbonates, shows lithification of the sands started after initial lithification of the carbonates, probably during burial (p. 363). The sandstones contain scattered bioclastic debris which increases in abundance where they pass laterally or upwards into sandy limstones (Plate 76).

GLAUCONITE AND GLAUCONITIC SANDSTONES.

Glauconite and glauconitic sandstones form the upper and lower part of the Crow Limestone around the sandbank on the south side of the Stockdale Fault and in the basin to the north. To the south they pass into coarsely crinoidal limestones and to the north into sandy and silty glauconitic cherts.

Quartz sand and silt derived from the Uldale Sill forms the fine to medium grained sandstones at the base of the Crow Limestone in Birkdale Beck (NY 837018) and the lower and upper parts of the Crow Limestone in Fossdale Gill (SD 863958). They contain glauconite, pyrite and small phosphate nodules in a matrix of cryptocrystalline to micro-crystalline quartz and ferroan dolomite. Sparse bioclasts, including Hyalostelia spicules, crinoid ossicles and brachiopod fragments, are also seen.

In the basin developed locally around Whitsundale, north of the sandbank, glauconite becomes abundant and replaces quartz as the dominant mineral. Here the upper and lower beds of the Crow Limestone are glauconite sandstones which, in places, show traces of cross-lamination (Plates 77, 78, 79 & 80). The glauconite is associated with scattered silt to fine quartz sand in a matrix of cryptocrystalline to micro-crystalline silica and phosphate. Nodular phosphate is also common (Plate 78) and the sediments, rich in organic matter, often contain Zoophycos and disseminated pyrite.

In thin section the glauconite grains are pale green, usually rounded and average 0.15mm in diameter, though grains up to 0.3mm are seen. Some are aggregates of randomly oriented, microcrystalline glauconite platelets but others have an oolitic structure or a micaceous cleavage.

The oolitic grains (Plates 80, 81 & 82) usually have a nucleus of randomly oriented microcrystalline glauconite platelets surrounded by concentrically oriented glauconite platelets with their c-axes perpendicular to the grain surface. The outer zone varies from being absent to comprising nearly all of the grain. It is paler than the nucleus, very pale green to very pale yellowish-green, with higher birefringence and is characterised by a black extinction cross in cross-polarised light. The oolitic structure is developed best in spherical grains where the outer zone is thick. It is also well developed on well rounded grains but on elongate or irregular grains oolitic rims are poor or absent.

The oolitic structure suggests these grains developed in agitated water but whether they are true ooliths or merely coated grains is not known. It is unlikely they are glauconitised carbonate ooliths because they have a nucleus of glauconite. If they had been originally carbonate accretion around some of the associated quartz grains would be expected. The possibility that the structure is that of a reaction rim is unlikely because, though well developed on spherical grains, they are poor or absent on those which are irregular. It seems likely that aggregates of glauconite platelets acted as nucleii for additonal glauconite accretion.

Many glauconite grains show a cleavage which may be pronounced.

They are platy, ellipsoidal, or vermicular and have a parallel or sub-parallel cleavage. The origin of these grains can be traced through a series of transitional stages to a precursor, biotite. Glauconitisation of biotite is well known (Galliher, 1935, 1936 & 1939). The scattered flakes of biotite in the glauconite sandstones are colourless, very pale green or pale brown and are often pleochroic from almost colourless or very pale green to very pale brown. The first sign of transformation to glauconite is the appearance of a greenish alteration around the periphery and along the cleavage of the biotite flake. This is accompanied by expansion perpendicular to the cleavage which results in an expanded green platy crystal with decreased pleochroism and birefringence. Expansion is often irregular and the cleavage becomes sinuous. As glauconitisation proceeds centripetally from the periphery of the grain, and preferentially along the cleavage, the edges of the biotite flakes frequently expand before, or more than, their centres, producing flared ragged ends. Although many grains of glauconite still show a well developed cleavage in other grains it is only just recognisable. Further glauconitisation destroys the cleavage and the grain is replaced centripetally by non-pleochroic, microcrystalline glauconite of low birefringence. Total glauconitisation leads to a grain composed of an aggregate of microcrystalline glauconite with no preferred orientation.

Although some of the more glauconitised grains are rounded many are not. Whereas the oolitic glauconite formed in the agitated environment on the shoal along the south side of the Stockdale Fault (p.323) many of the inherently fragile glauconitised biotites, especially those with expanded ragged edges could not have survived such conditions. It seems the biotite was glauconitised more or less in situ in the basin after derivation and transportation from the sandbank. Glauconite formation in the basin can be proved where glauconite contained within phosphate nodules is of a smaller size than in the surrounding sediment. The in situ formation of phosphate arrested development of glauconite within the nodule whereas outside it continued to grow.

The glauconitic rocks contain rounded phosphate nodules commonly 1cm to 5cm but up to 10cm in diamater (Plates 83, 84 & 85). In thin section the phosphate is dark to light brown. Several generations can be recognised. The oldest parts of the nodules, usually the centres, are darkest and form accretionary nucleii for later generations (Plate 85) which may join several older nodules. Besides the general colour difference, the periphery of each generation of phosphate is darker than the rest of the nodule (Plate 84). This suggests the rate of accretion was not uniform.

The phosphate nodules contain abundant sponge spicules (Plates 83 and 84) and variable quantities of quartz and glauconite. Nearly all the sponge spicules are monaxid types. Excluding Hyalostelia spicules, which are sparsely scattered, they are usually about 25 microns but up to 50 microns in diamater and form up to 20% of the nodules. Most are phosphatised but some are glauconitised whilst others are preserved as one or two crystals of dolomite cement, usually ferroan dolomite, or are siliceous. The siliceous spicules consist of cryptocrystalline to microcrystalline quartz or chalcedony and usually have their central canal preserved,often with an infilling of phosphate or ferroan dolomite.

The central canal in the spicules preserved as ferroan dolomite, phosphate or glauconite is not usually recognisable. Although calcareous spicules can be silicified and well preserved, the good preservation of the central canal and spicule wall in the siliceous spicules suggests they were originally siliceous.

Hyalostelia spicules are seen occasionally outside the phosphate nodules in the chert matrix of the rock but small monaxid sponge spicules are absent. It seems probable that the spicules were originally abundant throughout the sediment rather than occurring in very localised dense concentrations but that during diagenesis only those entombed in phosphate were preserved. The spicules outside the phosphate nodules appear to have dissolved without trace whereas many of those within the nodules were preserved as silica, by glauconitisation or phosphatisation, or, after dissolution, as molds which later became infilled with dolomite, ferroan dolomite and possibly phosphate. The silica dissolved from the spicules seems to have replaced, or have been precipitated in, the sediment outside the phosphate nodules and now forms the siliceous matrix.

The phosphate nodules contain glauconite and quartz. Both increase in abundance towards the periphery of the nodules and are more abundant in the later than the earlier generations of phosphate (Plate 85). This shows phosphate accretion occurred during compaction of the sediment but compaction structures around the nodules shows they lithified before final compaction of the surrounding sediment (Plate 78).

Ferroan dolomite is common in the glauconitic rocks as both a cement and a replacement. Glauconite grains are often replaced preferentially, either partly or completely, by one or sometimes a few rhombohedral ferroan dolomite crystals (Plates 81 and 82). In many cases dolomite growth ceased at the edge of the glauconite grain but in others it extends beyond and replaces the cryptocrystalline to microcrystalline siliceous matrix. Ferroan dolomite also pseudomorphs spicules in the phosphate nodules and sometimes replaces those which are glauconitised. Fractures which transect the nodules are usually filled with ferroan dolomite. It is coarsely crystalline and post-dates lithification sufficient to allow brittle fracture. Restriction of many fractures to the nodules, like the compaction structures around the nodules, shows the surrounding sediment was lithified after lithification of the phosphate.

THE LUTITES.

LUTITES.

The lutites comprise shales and mudstones which are usually calcareous,but whereas shales are common mudstones are rare. Their mineralogy has not been studied.

Non-calcareous to slightly calcareous shales occur in the Lower and Upper Partings in the northwest where they consist dominantly of deltaic sediments. The shales, often micaceous and sometimes with small siderite nodules, pass upwards into siltstones and sandstones. Poorly calcareous shales also occur in the Crow Limestone . In the basin developed north of the Stockdale Fault around Whitsundale they contain siderite and phosphate nodules; elsewhere they are often silicified.

The most common lutites encountered within the limestone formations are calcareous shales. They are common in the Lower Parting and form nearly all the Upper Parting on the Askrigg Block. They also occur in the cherts below and above the Underset Limestone, between the Underset Limestone and overlying chert, and in the Crow Limestone. A fauna including brachiopods, and crinoid and bryozoan debris is often present. Where shales occur in cherts or cherty limestones they are usually silicified. Besides well developed shales thin shale partings or films are seen. They are common in the Lower Parting, the Cockleshell Limestone, the Scar Limestone, the cherts above the Underset Limestone and the Crow Limestone. Mudstones occur only in the Lower Parting and the chert above the Underset Limestone. Calcareous mudstone infills the irregular surface of the Single Post Limestone in Whitfield Gill (SD 930923) and forms the lowest bed of the Lower Parting. In Birkett

Railway Cutting (NY 774029) a thin mudstone also occurs in the Lower Parting underlying a thin coal. The mudstones in the chert above the Underset Limestone seen in the north are often shaly.

GENERAL CONCLUSIONS

CONCLUSIONS

The carbonates of the Yoredale Group investigated in this study, the Middle, Underset and Crow Limestones, consist dominantly of micrite with skeletal carbonate debris and a marine fauna including crinoids, brachiopods, corals, bryozoa, molluscs, algae, foraminifera and sponge spicules. The prolific but varied fauna, the occurrence of bioherms and biostromes and the absence of evidence of hypersalinity suggests they accumulated under shallow marine conditions of normal salinity.

Dominance of carbonate mud has often been taken to indicate accumulation in quiet water conditions but work on modern carbonate sediments has shown the ratio of matrix to cement is not always a reliable environmental indicator. Carbonate mud can accumulate in relatively high energy conditions where marine grasses locally restrict current flow and eventually stabilise it by the binding action of their roots and rhizomes (Ginsburg & Lowenstam, 1958). Crinoids probably played a similar role in the Yoredale times especially in the vicinity of bioherms where growth was dense. Not only would they restrict current flow but they would also trap mud in their debris and stabilise it with their anchoring 'roots'. It must be remembered, however, that carbonate mud can also infiltrate clean-washed calcarenites and calcirudites after initial accumulation during periods of reduced current activity or by bioturbation.

Conversely, absence of carbonate mud from rocks retaining their original depositional textures does not always indicate non-accumulation or removal due to water turbulence. Micrite-free calcarenites can accumulate where only coarse carbonate sediment is being produced. Currents need only be sufficient to by-pass fine sediment.

The size, sorting and rounding of allochems is often used in environmental interpretation but the assumption cannot be made that in a turbulent environment the sediments will be coarse, well sorted and well rounded. Allochem size depends on other factors in addition to sorting, including the size of allochems potentially available for accumulation and the sizes to which they break down. If allochems are initially of similar size the sediment will give the false impression that it is well sorted. Equation of sorting with grain size is also misleading. Sorting is related to hydraulic properties of the grain of which size is only one factor. Other features of great importance are shape and density. Pore space is obviously important especially in skeletal carbonate.

Rounding has often been used as an indicator of mechanical abrasion and therefore energy of the environment but its interpretation is extremely complex (Ham & Pray, 1962). Breakdown of skeletal carbonate, for example, is frequently biological. This can also produce rounded allochems.

Evidence of current activity is seen in all three Limestones. The locally sandy base of the Single Post Limestone shows the underlying sand was locally redistributed during accumulation of the lower part of the Limestone. Later, after uplift, the Single Post Limestone was removed in an area west of the northwest part of the Askrigg Block and the underlying sand eroded and transported into and around Garsdale where it accumulated to form the Lower Parting. Further evidence of current activity is shown by non-accumulation of the Crow Limestone along the south side of the Stockdale Fault in the region of Great Shunner Fell. Here uplift of the north edge of the Askrigg Block along the Stockdale Fault elevated the Uldale Sill above surge base, causing erosion and transportation of the eroded sand into the surrounding less turbulent areas where the Crow Limestone was accumulated. Cross-lamination of the sand is not widespread though it can be recognised in all these cases.

Oncolites in the Scar Limestone with concentric algal coatings around nucleii, the 'oolitic' structure of glauconite in the Crow Limestone and the presence of apparently rolled and abraded corals in the coral biostrome at the base of the Underset Limestone show that movement of particles by currents did occur.

However, the absence of widespread cross-lamination, the presence of a large number of fossils in situ, especially colonial corals and Gigantoproductus, and the abundance of carbonate mud suggest the environment was not highly turbulent.

Water depths are difficult to quantify. The abundant fauna suggests the sea was shallow, though stromatolites and carbonate ooliths are absent. As the bioherms stood as primary elevations on the sea floor and show no evidence of ever having been subaerially exposed, their relief of up to 10m indicates a minimum water depth. The factor limiting their growth may have been surge base.

It seems the carbonates accumulated in a shallow to deep subtidal marine environment of normal salinity. Water depths are considered generally to have increased from north to south, an increase responsible for non-accumulation of the Underset and Crow Limestones over the southern part of the Askrigg Block.

The abundant skeletal carbonate in the limestones shows they are essentially biogenic. Most of the finer carbonate mud and silt is probably also skeletal carbonate which has undergone biological or mechanical breakdown. Bioherms were major sources of carbonate sediment. They locally swell the thickness of the limestones and mark places exceptionally favourable for carbonate production.

Comparison of the distribution of bioherms in the three Limestones studied shows they moved progressively northwards with time. Their location must have been controlled by numerous environmental factors, amongst them water depth. Their lateral displacement with time is thought to result from changes in relative water depth caused by tilting of the Askrigg Block. Using this and other sedimentological information, part of the tectonic history of the Askrigg Block can be established.

Although no bioherms are exposed in the Single Post Limestone, the coarse crinoid-stem calcirudites seen in the extreme southeast probably indicate their close proximity. Accumulation of the Single Post Limestone was terminated, at least in the northwest, by uplift which subaerially exposed the Limestone and resulted in widespread formation of an emersion surface, internal dissolution and local development of caliche. After resubmergence deltaic shales, siltstones and sandstones invaded the area from a northerly direction. A thick sequence of deltaic sandstones and shales were deposited in the southwestern part of the Barnard Castle Trough forming the Lower Parting. The Lower Parting thins southwards across the Askrigg Block where marine rather than deltaic conditions prevailed. Only the shales persist any distance onto the Block becoming calcareous and interbedded with calcilutites before failing completely. Still farther south the calcilutites also fail and the Lower Parting is absent over the southern part of the Askrigg Block. The reason for its absence here is unknown though resubmergence of the northwest part of the Askrigg Block may have been accomplished by a hinge movement which uplifted the southern area but there is no evidence to suggest this region was ever subaerially exposed.

While the Single Post Limestone was subaerially exposed it was completely removed in an area west of the Dent Fault, to the west of the northwest part of the Askrigg Block, exposing the sandstone beneath. After resubmergence the exposed sand was eroded and transported by currents eastsoutheastwards into Garsdale where it accumulated to form the Lower Parting.

After accumulation of the Lower Parting, carbonate accumulation became established over the entire area and resulted in formation of the Cockleshell Limestone. The bioherms in this Limestone, located in the area north of Grassington, suggest the optimum habitat for bioherm growth had moved slightly northwestwards from that in the Single Post Limestone, a result of slight downwarp of the southeastern corner of the Askrigg Block.

Accumulation of the Cockleshell Limestone was halted by re-establishment of a deltaic influence and accumulation of the Upper Parting. A thick sequence of deltaic shales, siltstones and sandstones was deposited in the southwestern Barnard Castle Trough but only the shales persist any distance onto the Askrigg Block where marine rather than deltaic conditions prevailed. The shales represent the distal deposits of the delta to the north and fail over the southern part of the Block where the Upper Parting is absent.

After the main influx of terrigenous sediment, carbonate accumulation became re-established and resulted in formation of the Scar Limestone. Bioherms developed around Redmire, Penhill and Plover Hill about 20km north and northwest of the bioherms in the Cockleshell Limestone. Their location suggests further deepening of the sea over the southern area caused by tilting of the Askrigg Block down to the south. The oncolites in the Scar Limestone grew where the sea was shallowest over the northwest part of the Block.

In the Underset Limestone location of bioherms across the northern part of the Askrigg Block and in the southeastern Barnard Castle Trough shows another shift of optimum water depth to the north. Tilting of the Block to the south is supported by absence of the Limestone over the southern part of the Block due to too great a water depth preventing production of carbonate.

No bioherms are exposed in the Crow Limestone but its coarsely crinoidal character along the north edge of the Askrigg Block around the sandbank developed on the south side of the Stockdale Fault suggests further tilting of the Block. Uplift of the north edge of the Block along the west end of the Stockdale Fault resulted in elevation of the Uldale Sill above surge base to form a sandbank on which the Crow Limestone did not accumulate. The sandbank was eroded by currents and its sand transported off the bank. The abundance of sand at the base and top of the Crow Limestone records two phases of uplift.

The bedded cherts associated with the Limestones are biogenic.

They mark proliferation of siliceous organisms during periods of release of silica-rich connate water along faults. Not only does their distribution show a relationship to faults but their appearance coincides with periods of fault movement. The bedded chert at the base of the Underset Limestone marks downward movement of the southern edge of the Askrigg Block, probably along the Mid Craven Fault whereas the bedded chert at its top marks downward movement of the Askrigg Block along the Stockdale Fault. The bedded cherts in the Crow Limestone are associated with upward movement of the northern edge of the Askrigg Block along the Stockdale Fault. Their location, dominantly at the top but also at the base of the Crow Limestone, can be related to two phases of uplift. This is substantiated by two periods of erosion of the sandbank formed by uplift of the Uldale Sill on the southside of the Stockdale Fault.

The repetitive nature of the beds of the Yoredale Group has been known since Phillips' (1836) time. It results from interplay between two broad environments, a shallow sea in which carbonate accumulation was normal and a delta which periodically invaded the sea depositing terrigenous sediment and preventing carbonate accumulation.

Many theories have been proposed with regard to cyclothemic sedimentation (Westoll, 1962). They can be divided fundamentally into those which propose a tectonic origin and those advocating climatic control. Cyclical uplift, followed by erosion to base level, then marine transgression after regional subsidence was favoured by Hudson (1924, 1933), Dunham (1950) and Bott & Johnson (1967) whereas eustatic changes have been proposed by Wanless & Sheppard (1936) and Ramsbottom (1973). Moore (1958) considered the cyclothems resulted from invasion of a shallow sea in which carbonate was accumulating by a delta, build-up of deltaic sediments and eventual abandonment of the delta by diversion of the main distributaries. Regional subsidence eventually caused submergence of the delta top below sea level and allowed carbonate to accumulate once more before re-establishment of deltaic conditions over the area. As many limestones directly overlie delta tops with seat earths and coals, carbonate accumulation presumably began in very shallow water which gradually increased in depth, at least during the early stages of accumulation. It seems likely that delta abandonment, a well documented feature of modern deltas, and tectonic movement, for which there is abundant evidence, were most important.

Whichever theory or theories are correct the carbonates studied contain abundant evidence of tectonic movement. The major cause of these movements is related to differential subsidence along the faults bounding the Askrigg Block. The surrounding basins were generally subsiding faster than the Block. Locking or increased drag on the faults caused tilting or downwarp of the Block edges. Tilting was sometimes compensatory, downward movement of one edge being accompanied by uplift of the opposite edge. Movements on the Block, not directly related to motion on the boundary faults, shows that, contrary to popular belief, the Askrigg Block is not monolithic (see Moore & Cousins discussion on Burgess & Mitchell, 1976). The movements altered the sedimentary environments and are recorded by variations in thickness and lithology, the location of, and relationships between, certain lithologies and the presence and position of erosion surfaces.

Further detailed documentation of the Yoredale Group viewed in regional perspective will no doubt enable a much greater understanding of the sediments, the environments in which they accumulated and the tectonic history of the area. The limestones, so often described merely as 'crinoidal limestone' in the past contain a wealth of information for interpretation by the active researcher. At this stage detailed field work seems essential. The carbonates need to be examined carefully and described and interpreted in the light of recent advances in carbonate sedimentology. After working on these rocks one is left with an awesome feeling of how much there is still to be done.

APPENDIX

APPENDIX.

Thin Sections.

a) Manufacture.

The large area thin sections used in this study were manufactured using standard techniques. Most rock slices were cut perpendicular to the bedding and mounted on 3" x 2" glass slides, then ground to a thickness of about 30 microns and stained with an acidified solution of alizarin red S and potassium ferricyanide to differentiate the various carbonate minerals (see below). After staining they were sprayed with 'Trycolac', a quick drying liquid cover glass which has a refractive index similar to that of glass, does not affect the stain and is unaffected by water and immersion oil. This eliminated the tedious and time consuming task of remounting the thin slice in Canada Balsam under a cover slip and the risk of damaging the stained surface.

b) Staining.

i) Method

Each thin section was stained with an acidified solution of alizarin red S and potassium ferricyanide following the method outlined by Dickson (1965). Besides differentiating dolomite from calcite it also enabled detection of variations of ferrous iron content within them.

First each thin section was washed thoroughly in distilled water and etched in 1.5% HCl for 10 seconds to remove any carbonate dust still adhering to its surface. The etched thin section was them immersed in an acidified mixture of the two stains (0.2 grams of alizarin red S per 100cc of 1.5% HCl and 2.0 grams of potassium ferricyanide per 100cc of 1.5% HCl mixed in a ratio of alizarin red S solution to potassium ferricyanide solution = 3 : 2) for 45 seconds, each stain working independently and without mutual interference. The now partially stained thin section was them immersed for 10 seconds in an acidified solution of alizarin red S only (0.2 grams of alizarin red S per 100cc of 1.5% HCl) to enhance colour differentiation. After rapid but careful washing with distilled water, the thin section was dried as quickly as possible because the stain is relatively soluble in water. Care was taken not to touch the stained surface as the stain, only a surface precipitate, is easily rubbed off. Distilled water was used for making up all the solutions and washing off the surplus stain from the thin sections after each stage of the proceedure.

The staining technique outlined above enables recognition of calcite, ferroan calcite, dolomite and ferroan dolomite by positive colour differentiation as shown in Fig. 65.

STAGE	PROCEDURE	TIME	CARBONATE	RESULT
1	Etching 1.5% HCl	10 secs.	Calcite Ferroan Calcite	Considerable etching
			Dolomite	Neglible etching
			Ferroan Dolomite	Some etching
11	Staining 0.2g alizarin red S per 100cc 1.5% HCl + 2.0g potassium ferri-cyanide per 100cc 1.5% HCl mixed in ratio 3:2	45 secs.	Calcite	Very pale pink to red (depending on optical orientation)
			Ferroan calcite	Very pale pink to red + Pale blue to dark blue (Two superimposed give mauve, purple to royal blue
			Dolomite	No colour
			Ferroan dolomite	Pale to deep turquoise depending on ferrous content.
111	Staining 0.2g alizarin red S per 100cc. 1.5% HCl	10 secs	Calcite Ferroan calcite	Very pale pink to red
			Dolomite Ferroan dolomite	No colour
RESULTANT STAINS			Calcite	Very pale pink to red (depending on optical orientation)
			Ferroan calcite	Mauve, purple to royal blue
			Dolomite	No colour
			Ferroan dolomite	Pale to deep turquoise depending on ferrous content.

Fig.65. Staining proceedure for differentiation of carbonate minerals. (after Dickson, 1965).

ii) Discussion.

It was thought at one time that dolomite could be distinguished from calcite on the basis that dolomite alone contained ferrous iron and would, therefore, stain with potassium ferricyanide but work by Evamy (1963) has shown this to be incorrect. It is now known that any carbonate mineral containing small quantities of ferrous iron will stain providing the carbonate can be made to react with an acid medium.

The intensity of the staining precipitate imparted by potassium ferricyanide (Turnbull's Blue) to the ferroan carbonate has often been taken to reflect the amount of iron present. This is not strictly true as the intensity of the stain depends on the rate of liberation of Fe^{++} from the carbonate via an acid solution to the stain. Ferroan calcite and ferroan dolomite which stain with the same intensity indicate the presence of much more iron in the dolomite for it has a much slower reaction rate. Even in a single zoned ferroan dolomite crystal the depth of the stain is not proportional to ferrous iron content, for the reaction rate increases with increasing $FeCO_3$ (Dickson, 1965). Other substances such as zinc, cadmium, manganese, copper, nickel and cobalt give a variety of yellow and brown precipitates whilst ferric iron produces a red lake (Dickson, 1965). Fortunately the colours of these precipitates do not remenble that of Turnbull's Blue and, therefore, no confusion can arise.

At room temperature alizarin red S is most selective as a stain in a concentration of HCl between 1% and 2%. At the 1.5% plus level the thickness of the thin section is greatly reduced and the staining becomes pale, whilst adherence of gas bubbles to the surface being treated sometimes yields unreliable results. Lower concentrations produce a stain so thick that it obscures the fine detail of the thin section and desiccation cracks are likely to develop over the stained surface as it dries. An important feature of the stain at the 1.5% acid concentration (which does not affect the Lakeside mounting medium) is that with calcite a surface parallel to the c-axis is more deeply stained than one normal to that axis. This is especially important in fabric analysis where optic orientations are required.

The difference in solubility between calcite and dolomite in dilute HCl means that in a thin section of 30 microns calcite is etched to approximately 15 microns whilst dolomite remains at 30 microns. The difference is easily observed under the microscope.

Acetate Replicas.

a) Carbonate replicas.

A flat surface of the rock was polished, washed, dried and then etched with 1.5% HCl for 1 minute. When dry, after washing with distilled water, the etched surface was coated with acetone and a piece of acetate sheeting carefully smoothed onto the surface. The specimen was then left for at least 1 hour to dry, after which the acetate was peeled off carefully. In order to remove any carbonate grains adhering to the peel it was washed in 5% HCl, then rinsed in distilled water, dried and mounted. Acetic acid can be used instead of HCl in the etching process but it tends to etch selectively along intergranular boundaries.

b) Stained carbonate replicas.

A flat surface of the specimen was polished and etched as in the preparation of carbonate replicas. This surface, after washing in distilled water, was stained for 2 minutes in an acidified solution of alizarin red S and potassium ferricyanide (0.2 grams of alizarin red S per 100cc of 0.5% HCl and 2 grams of potassium ferricyanide per 100cc of 0.5% HCl, mixed in a ratio of alizarin red S solution to potassium ferricyanide solution of 3 : 2). A lower concentration of HCl than in the thin section staining was used to produce a more intense stain. After careful washing with distilled water, but before the surface was completely dry, the stained surface was held horizontally and covered with acetone. Acetate sheeting was then rolled onto the surface and left for at least an hour before it was removed bringing the surface precipitate on the rock off with it. The resulting stained peel was then mounted.

c) Chert replicas.

Acetate replicas of cherts were prepared in a similar manner to that outlined above for carbonates except that hydrofluoric acid was used as the etching agent instead of HCl. The etching time required proved variable depending upon the type of chert but examination of the specimens under a binocular microscope during the etching process showed when they were suitably etched.

Thin Sections or Acetate Replicas?

To access the relative advantages and disadvantages of stained thin sections and stained acetate replicas both were made in the initial stages of this research.

The main advantages of acetate replicas over thin sections is that they are much quicker to make and, if required, can be made to replicate large areas of the rock relatively easily. They can show greater textural detail than thin sections after application of careful selective etching and can be used directly as negatives in an enlarger. Non-stained and stained replicas can be made from a rock surface with only slight further grinding and etching and, if required, several different staining techniques can be applied.

Despite these advantages acetate replicas have serious disadvantages. They only replicate the rock surface and do not allow direct observation of its mineralogy. Addition of the solvent to the stained rock surface can cause diffusion of the stain and, as the stain is a surface precipitate, some detail of the underlying fabric is inevitably lost. For these reasons thin sections were preferred to acetate peels. Even though their manufacture was more time consuming than that of peels it was felt that the extra effort was well spent.

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PHOTOMICROGRAPHS.

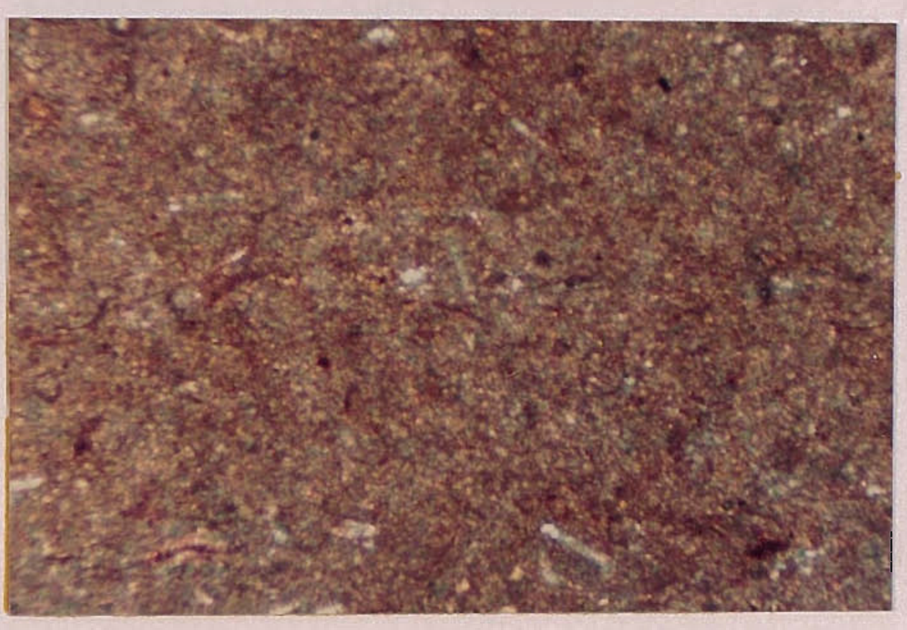

Plate 25. Bioclastic micrite with poorly preserved brachiopod debris. The matrix has neomorphosed to microspar which is ferroan in places. (stained thin section, p.p.l., x 40) Lower Parting, Whitfield Gill (SD 930923), Wensleydale.

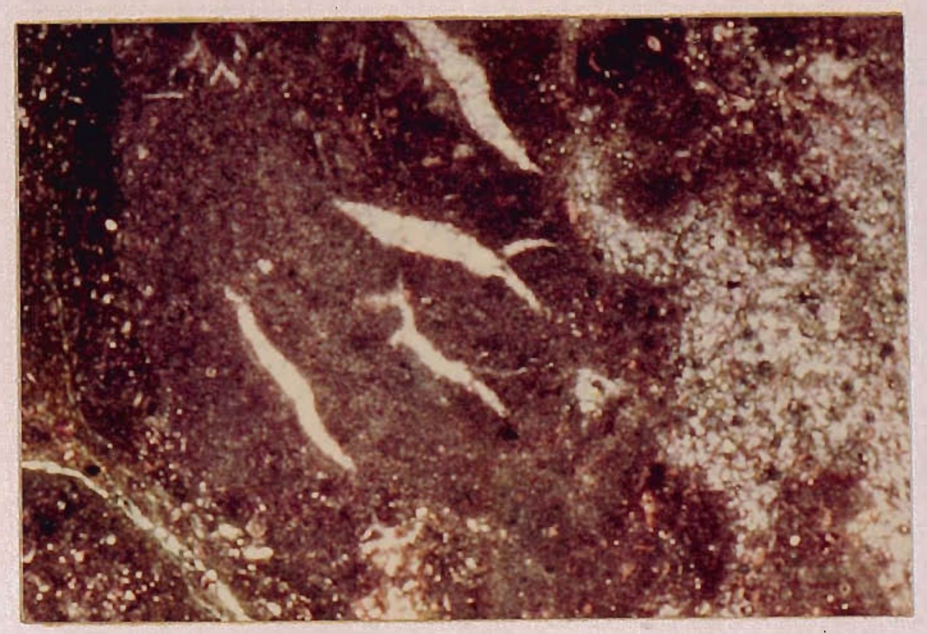

Plate 26. Bioclastic micrite with burrow infill containing tension fractures filled with non-ferroan calcite cement. The matrix of the biomicrite has neomorphosed to microspar and pseudospar. (stained thin section, p.p.l., x 40) Lower Parting, Whitfield Gill (SD 930923), Wensleydale.

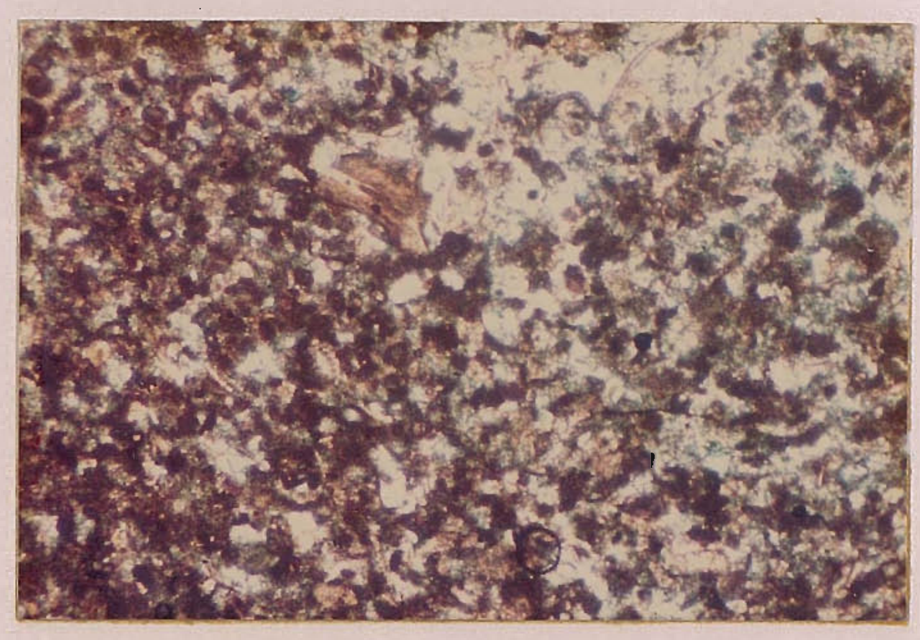

Plate 27. Sparse pelmicrite with poorly defined micrite and microspar pelletoids and sparse bioclastic debris. The micrite matrix has neomorphosed to microspar and pseudospar.
(stained thin section, p.p.l., x 40)
Lower Parting, Whitfield Gill (SD 930923), Wensleydale.

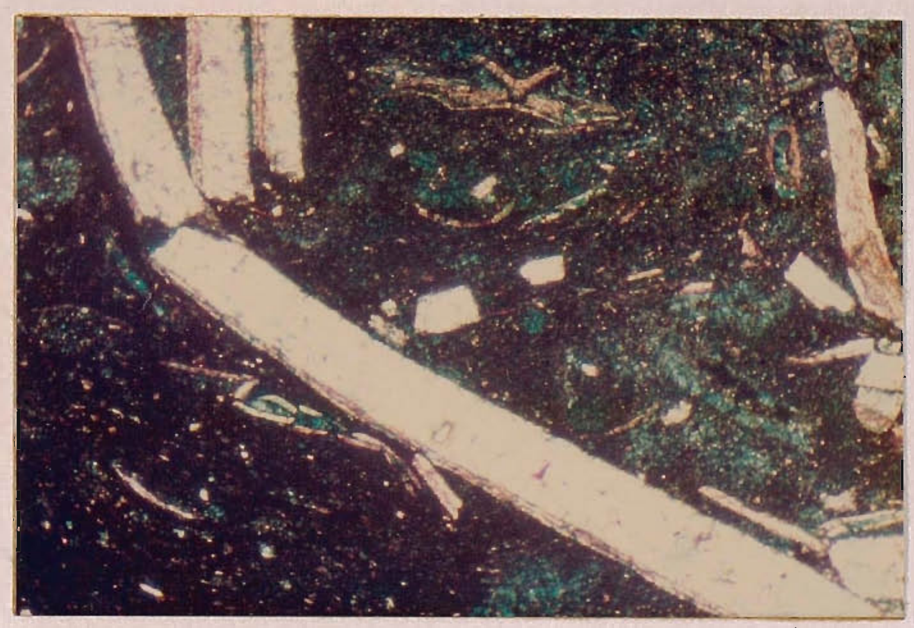

Plate 28. Argillaceous sparse biomicrite. The bioclasts, dominated by brachiopod debris, show evidence of compactive fracture. The matrix has neomorphosed to ferroan microspar.
(stained thin section, p.p.l., x 40)
Lower Parting, Whitfield Gill (SD 930923), Wensleydale.

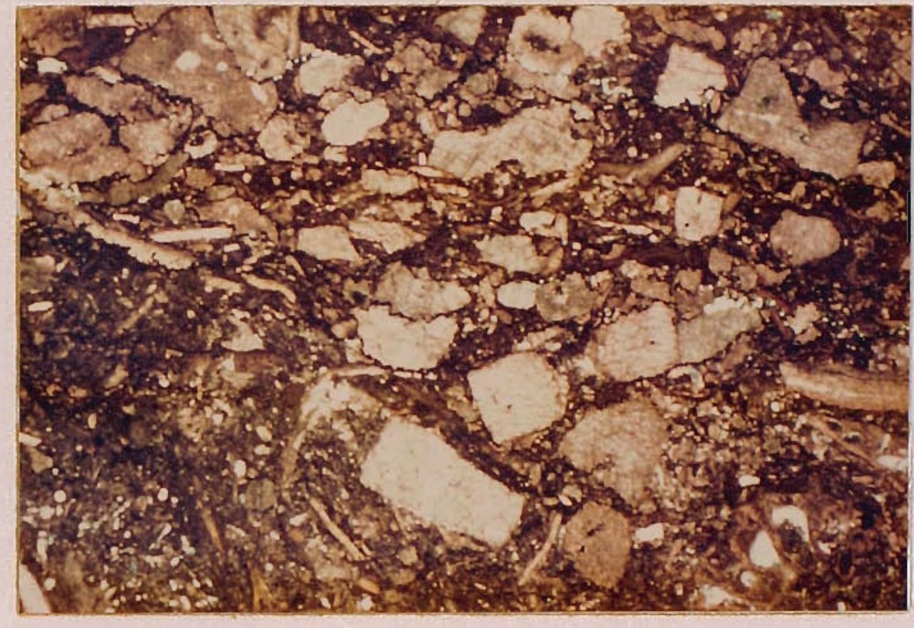

Plate 29. Argillaceous packed crinoid-ossicle biomicrite. The crinoid debris shows well developed sutured grain contacts.
(stained thin section, p.p.l., x 40)
Underset Limestone, Greenside Quarry (SD 748905), Garsdale.

Plate 30. Crinoid-ossicle biosparite from the calcarenites capping a calcilutite bioherm core. The cement forms syntaxial overgrowths on the crinoid debris and consists of an early non-ferroan and later ferroan calcite cement.
(stained thin section. p.p.l., x 7)
Scar Limestone, west of Yarnbury (SE 075659), near Grassington.

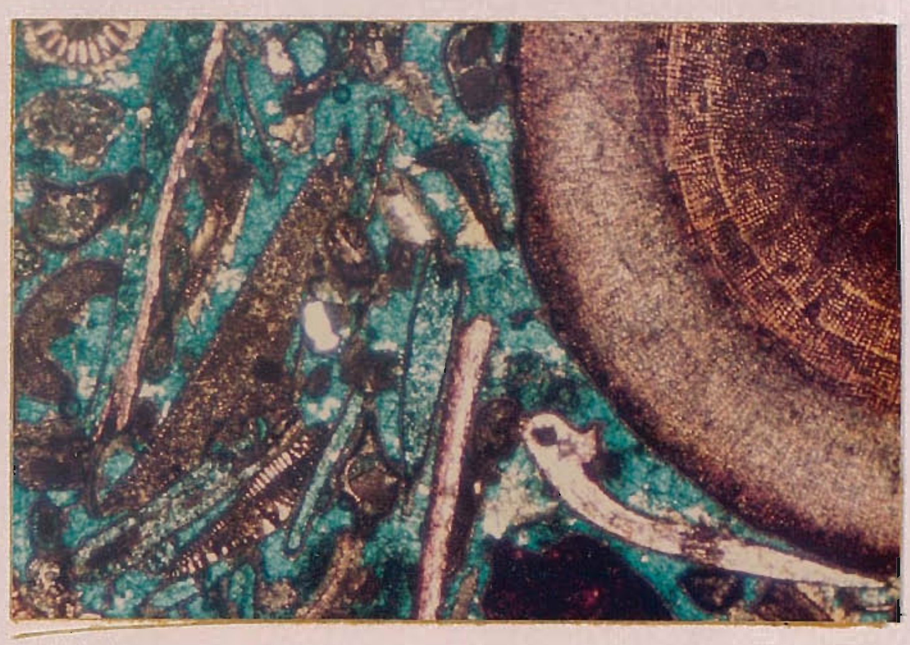

Plate 31. Biosparite with scattered quartz sand cemented by a poorly developed early generation of non-ferroan calcite followed by a later generation of ferroan calcite.
(stained thin section, p.p.l., x 40)
Lower Parting, River Clough (SD 782922), Garsdale.

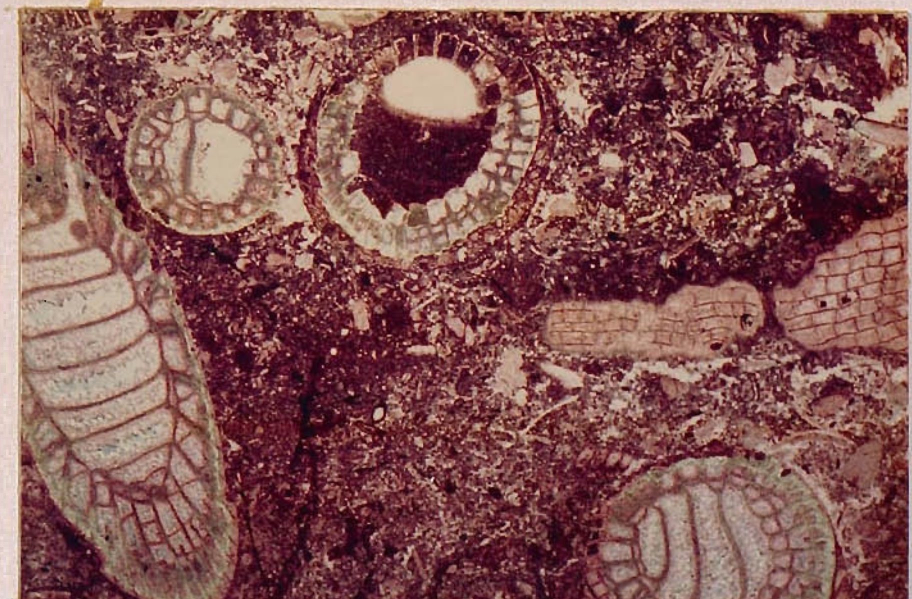

Plate 32. Coral biostrome with Diphyphyllum and Dibunophyllum in a micrite matrix containing comminuted bioclastic debris. The partly silicified Diphyphyllum corallites are usually filled with calcite and quartz cement; the calcite being initially non-ferroan but later ferroan. The corallite just above the centre of the photomicrograph displays a well developed geopetal structure. (stained thin section, p.p.l., x 5)
Underset Limestone, Grisedale (SD 760938).

Plate 33. Coral biostrome with partly silicified Lithostrotion and small brachiopods in a sparse biomicrite. They are infilled with an early generation of non-ferroan calcite cement followed by ferroan calcite cement (see Plate 46) then a granular quartz cement. Late stage veins of non-ferroan calcite cut all fabrics. (stained thin section, p.p.l., x 2.5)
Single Post Limestone, Park Gill Beck (SD 987753), Wharfedale.

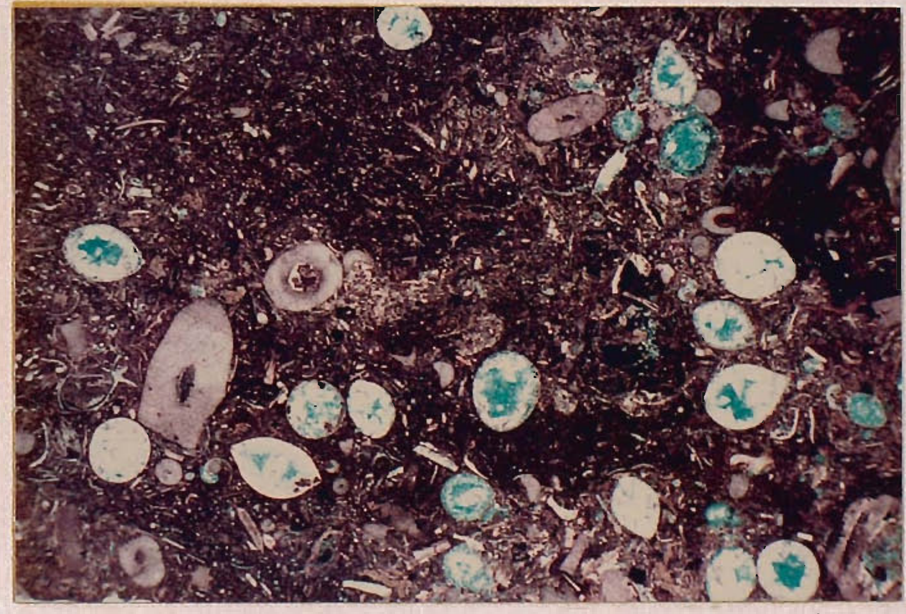

Plate 34. Saccaminopsis carteri (Brady) in a sparse biomicrite. (stained thin section, p.p.l., x 3.5)
Single Post Limestone, Hesleden High Bergh (SD 871751), Littondale.

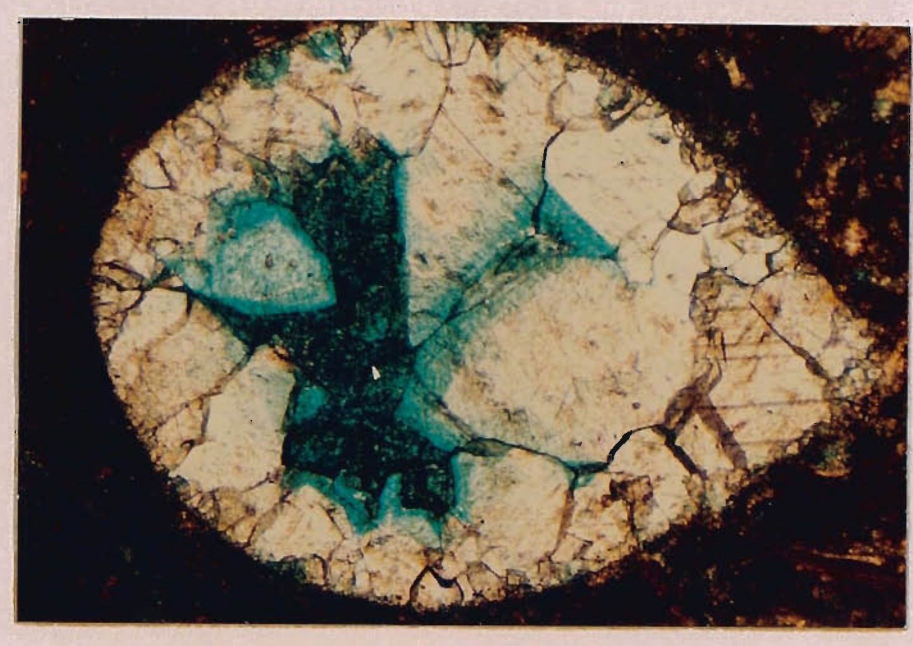

Plate 35. Saccaminopsis carteri (Brady) figured in Plate 34 (bottom right) infilled with calcite cement. The calcite cement is initially non-ferroan but becomes ferroan.
(stained thin section, p.p.l., x 40)
Single Post Limestone, Hesleden High Bergh (SD 871751), Littondale.

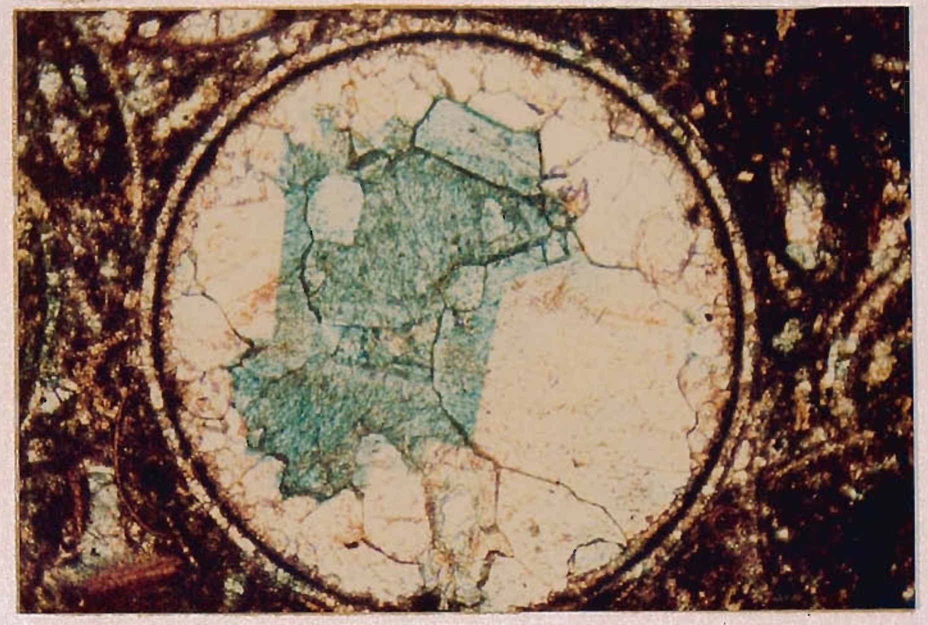

Plate 36. Saccaminopsis carteri (Brady) with test wall preserved. The test occurs in a sparse biomicrite and is infilled by calcite cement which is initially non-ferroan but later ferroan.
(stained thin section, p.p.l., x 40)
Single Post Limestone , Hesleden High Bergh (SD 871751) Littondale.

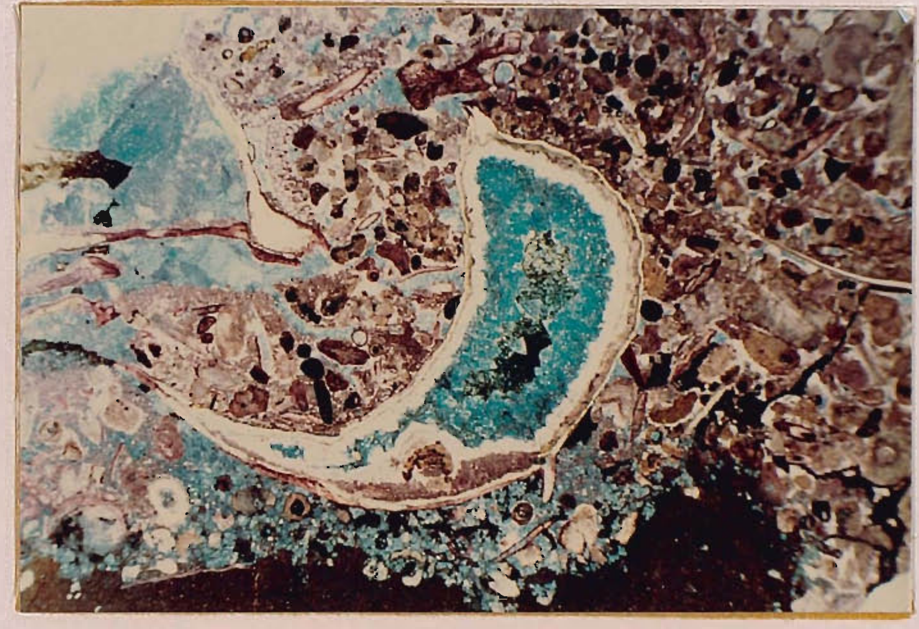

Plate 37. Brachiopod biostrome with spinose productid with geopetal structure in a packed biosparite. The shell is silicified and infilled with an early non-ferroan calcite cement followed by a ferroan calcite cement then a ferroan dolomite cement. (stained thin section, p.p.l., x 4)
Scar Limestone , north of Grassington (SE 007653).

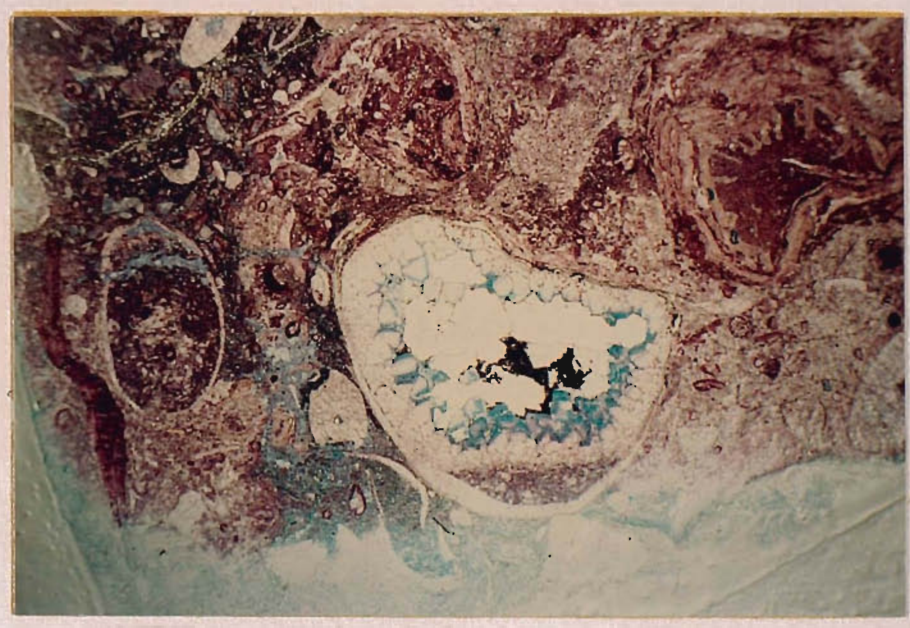

Plate 38. Algal biostrome with concentric algal coatings around allochems including coral fragments (top right). The brachiopod contains internal sediment which forms a good geopetal structure. The rest of its body cavity is filled with non-ferroan calcite cement followed by a ferroan calcite cement then granular quartz. The centre of the cavity is filled with dolomite.
(stained thin section, p.p.l., x 4)
Scar Limestone, Fossdale Gill (SD 861938), Wensleydale.

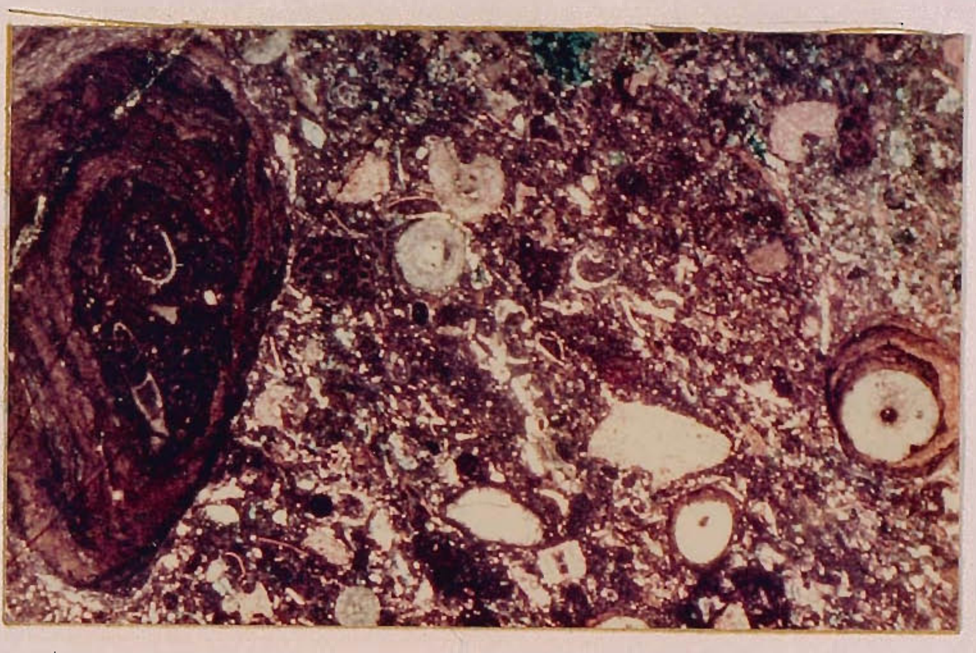

Plate 39. Algal biostrome. The oncolites occur in a packed biomicrite and frequently have an allochem as a nucleus. Concentric algal laminations are seen around an intraclast (centre left) and a crinoid ossicle (centre right).
(stained thin section, p.p.l., x 5)
Scar Limestone, Hazel Bottom Gill (SD 770839), Dentdale.

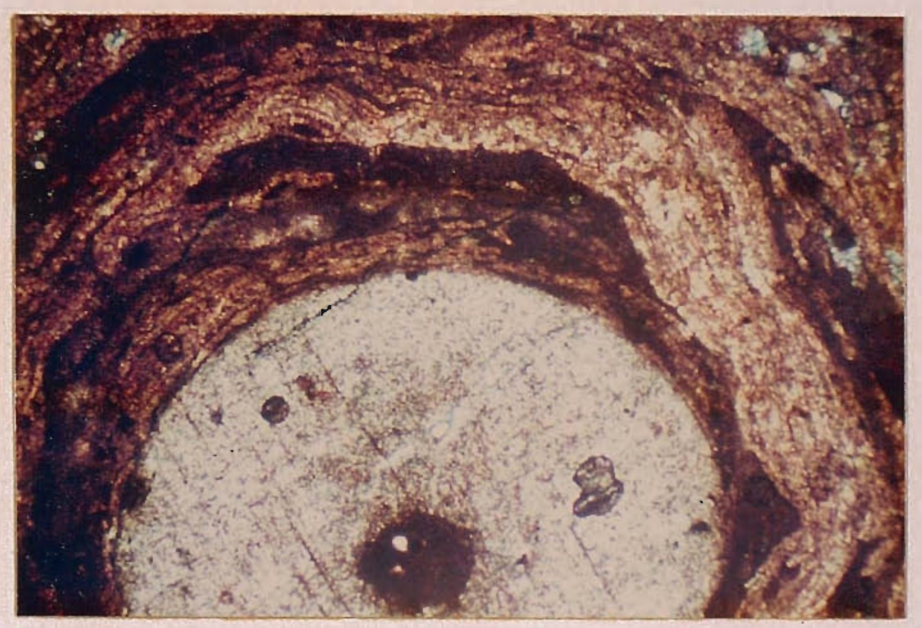

Plate 40. Oncolite figured in Plate 39 showing concentric algal laminations around a crinoid ossicle.
(stained thin section, p.p.l., x 40)
Scar Limestone, Hazel Bottom Gill (SD 770839), Dentdale.

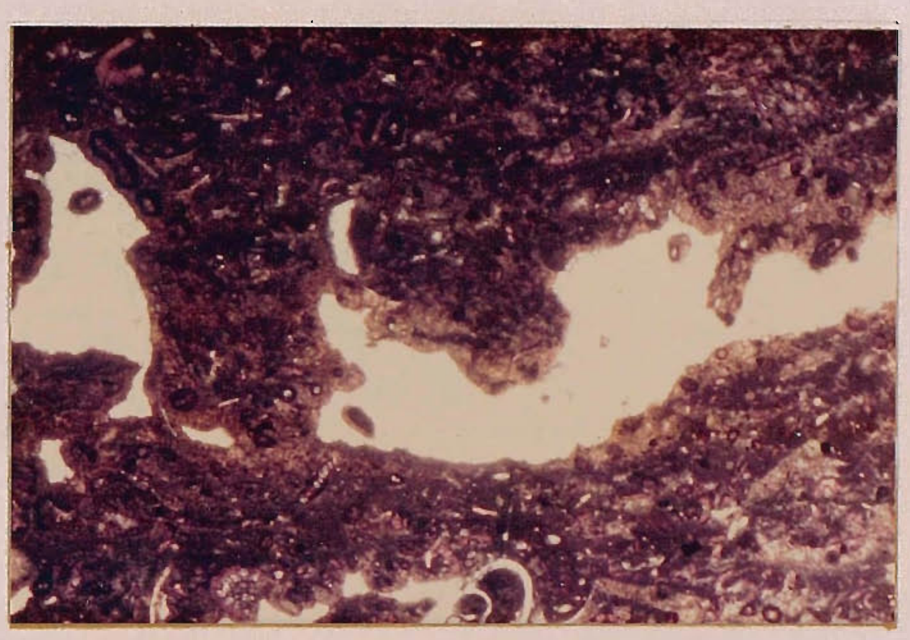

Plate 41. Sparse biomicrite bioherm core with abundant fenestellid bryozoa. The cavity filled with non-ferroan calcite is roofed by a fenestellid frond and is thought to have formed due to a bridging or 'umbrella' effect.
(stained thin section, p.p.l., x 5)
Cockleshell Limestone, west of Yarnbury (SE 075659), near Grassington.

Plate 42. Gastropod partly filled with sediment in a sparse biomicrite bioherm core. The shell and the cavity (lower right) are filled with calcite cement which becomes slightly ferroan. The micrite adjacent to the cement filled cavities has neomorphosed to microspar coarser than the rest of the matrix.
(stained thin section, p.p.l., x 12.5)
Cockleshell Limestone, west of Yarnbury (SE 075659), near Grassington.

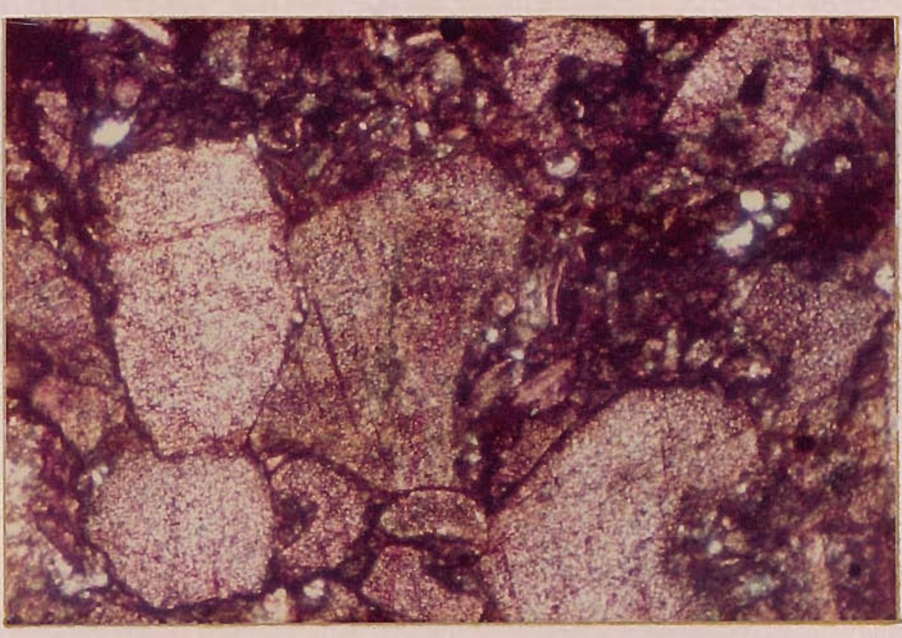

Plate 43. Packed crinoid-stem biomicrudite with crinoid debris showing sutured and interpenetrating grain contacts. (stained thin section, p.p.l., x 4.5)
Underset Limestone, Kidstones Scar (SD 946813), Bishopdale.

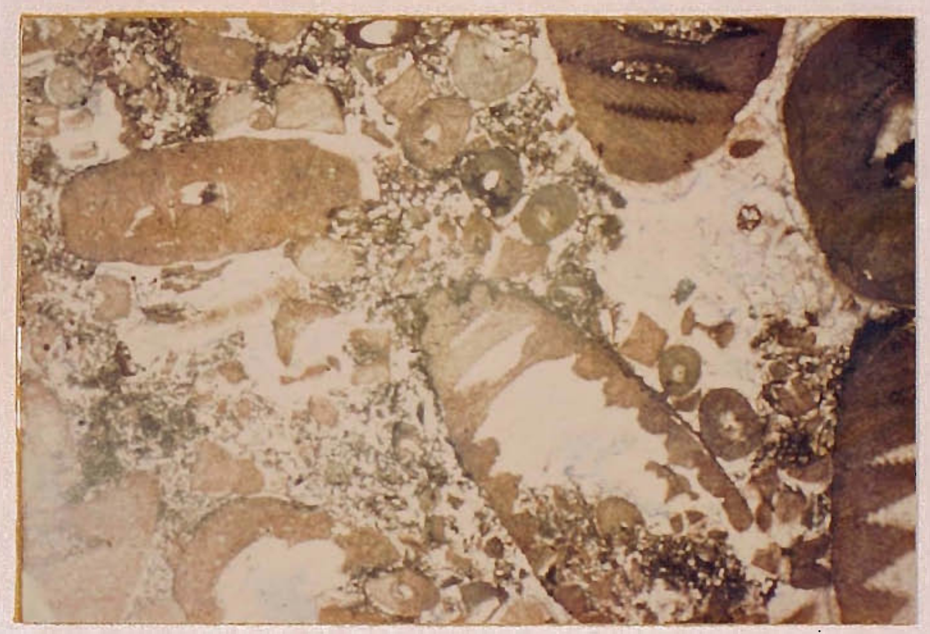

Plate 44. Poorly sorted crinoid-stem biosparrudite. The calcite cement is mainly non-ferroan and consists of syntaxial overgrowths on crinoid debris.
(stained thin section, p.p.l., x 4.5)
Underset Limestone, Barton Quarry (NZ 216083), near Melsonby.

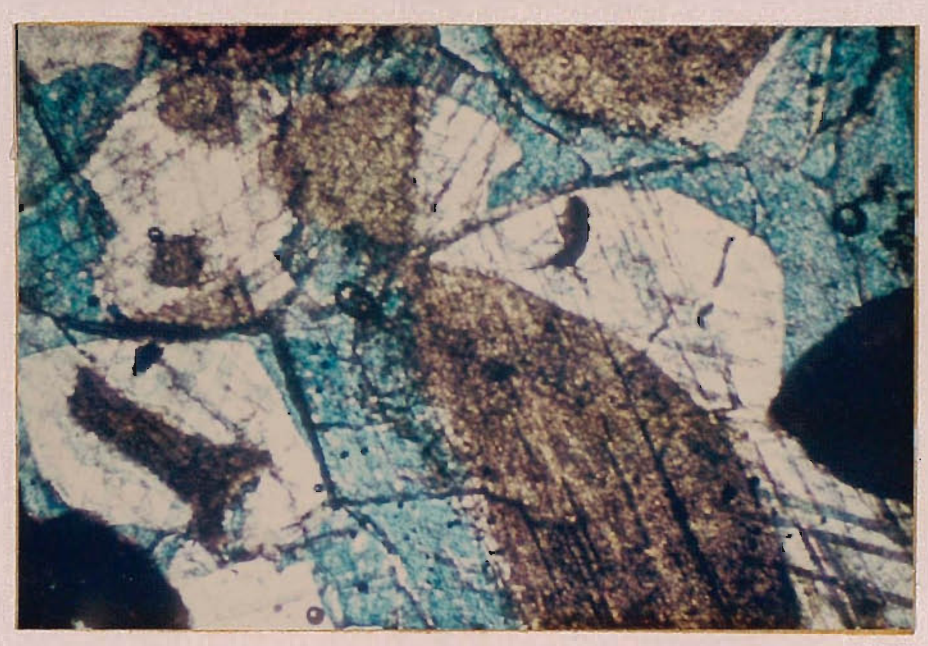

Plate 45. Large monocrystal overgrowths of non-ferroan and later ferroan calcite cement on crinoid debris in a biosparite.
(stained thin section, p.p.l., x 40)
Scar Limestone, west of Yarnbury (SE 075659) near Grassington.

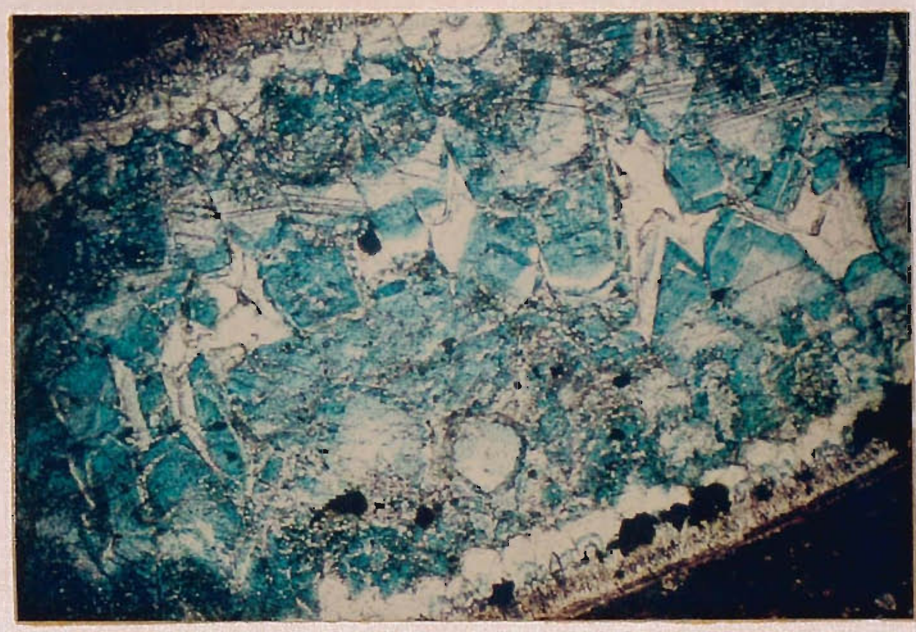

Plate 46. Silicified brachiopod (figured in Plate 33, bottom right) lined with pyrite and infilled with calcite cement. The first formed cement is non-ferroan but the later cement consists of alternating zones of variably ferroan and non-ferroan calcite which can be correlated from crystal to crystal.
(stained thin section, p.p.l., x 40)
Single Post Limestone, Park Gill Beck (SD 987753), Wharfedale.

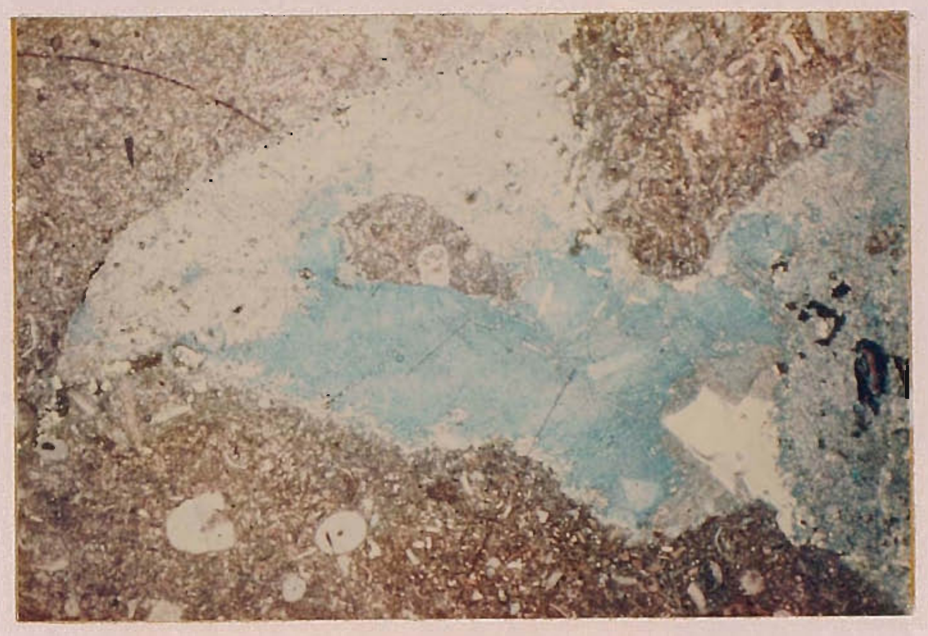

Plate 47. Mottled packed biomicrite in places showing neomorphism to ferroan microspar (top right). The vugs infilled with coarsely crystalline ferroan calcite truncate bioclasts.
(stained thin section, p.p.l., x 3)
Single Post Limestone, Whitfield Gill (SD 930923), Wensleydale.

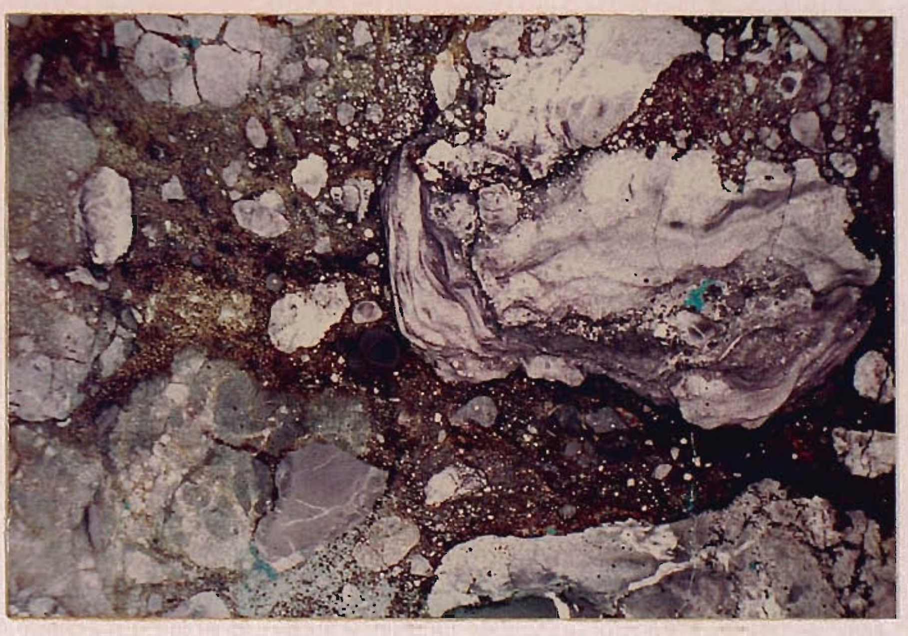

Plate 48. Caliche ? Clasts of microspar, sometimes laminated, with fractures infilled with non-ferroan calcite cement, siderite cement and non-ferroan calcite cement, in a matrix of siderite.
(stained thin section, p.p.l., x 3.5)
Single Post Limestone, Birkett Railway Cutting (NY 774029), Mallerstang.

Plate 49. Fractures within a clast of microspar (see Plate 48, top left) infilled with siderite then ferroan calcite cement.
(stained thin section, p.p.l., x 40)
Single Post Limestone, Birkett Railway Cutting (NY 774029)
Mallerstang.

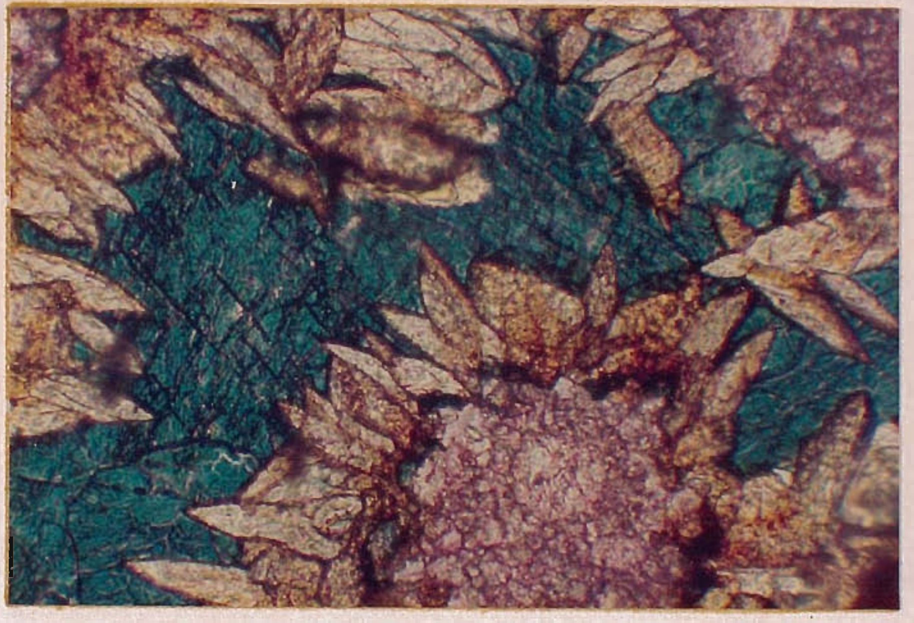

Plate 50. Lens shaped crystals of siderite cement coating clasts of microspar. The siderite is post-dated by a coarsely crystalline ferroan calcite cement.
(stained thin section, p.p.l., x 150)
Single Post Limestone, Birkett Railway Cutting (NY 774029)
Mallerstang.

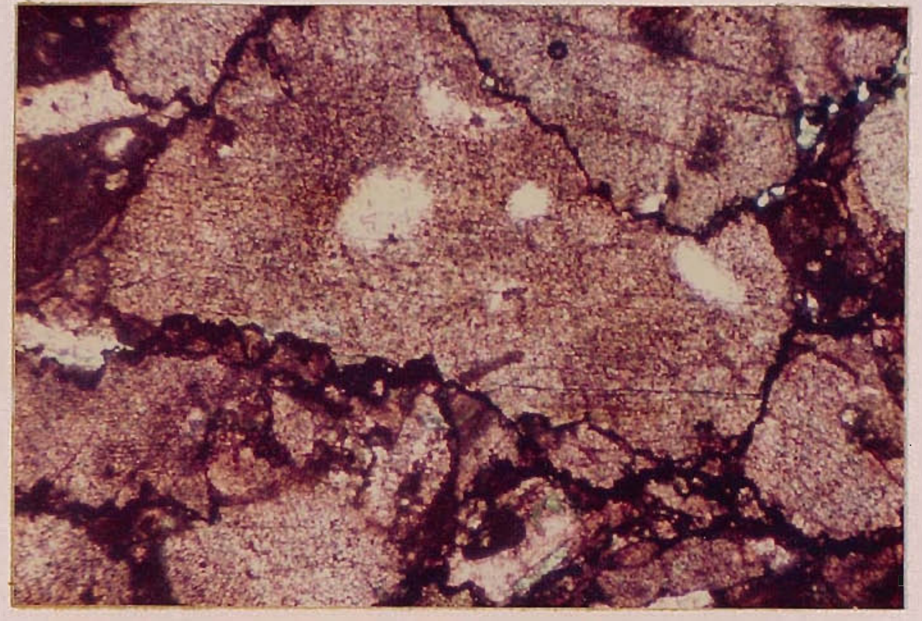

Plate 51. Crinoid debris in an argillaceous packed biomicrite showing well developed sutured grain contacts and microstylolites. (stained thin section, p.p.l., x 40)
Underset Limestone, Greenside Quarry (SD 748905), Garsdale.

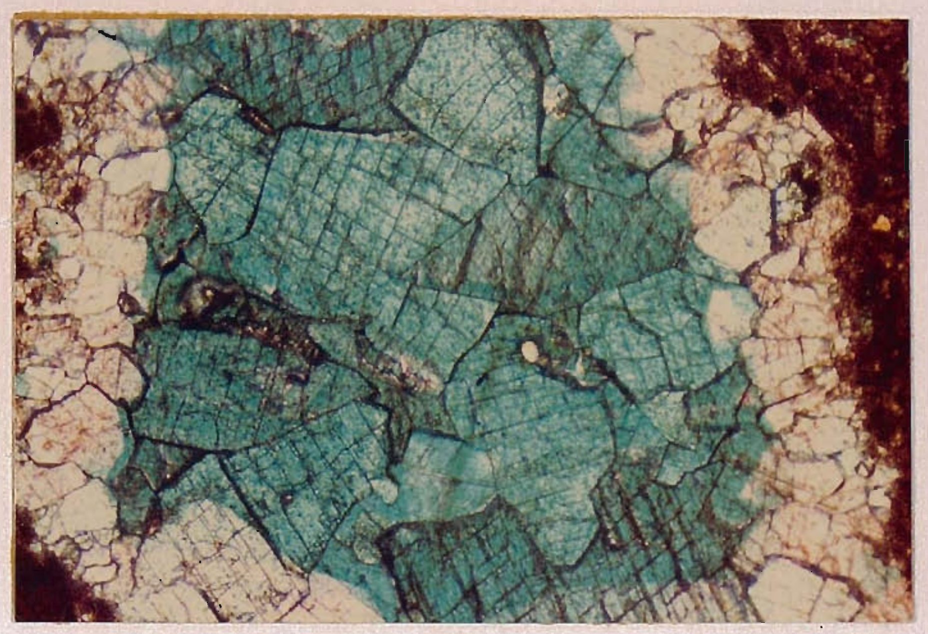

Plate 52. Carbonate vein consisting of an early generation of non-ferroan calcite followed by a later generation of ferroan calcite cutting a biomicrite.
(stained thin section, p.p.l., x 40)
Single Post Limestone, Mere Gill (SD 745753), Ingleborough.

Plate 53. Partly dolomitised packed crinoid-ossicle biomicrite with some coarsely crystalline calcite left unreplaced. (stained thin section, p.p.l., x 40) Single Post Limestone, southwest of Bare House (SE 003665), near Yarnbury.

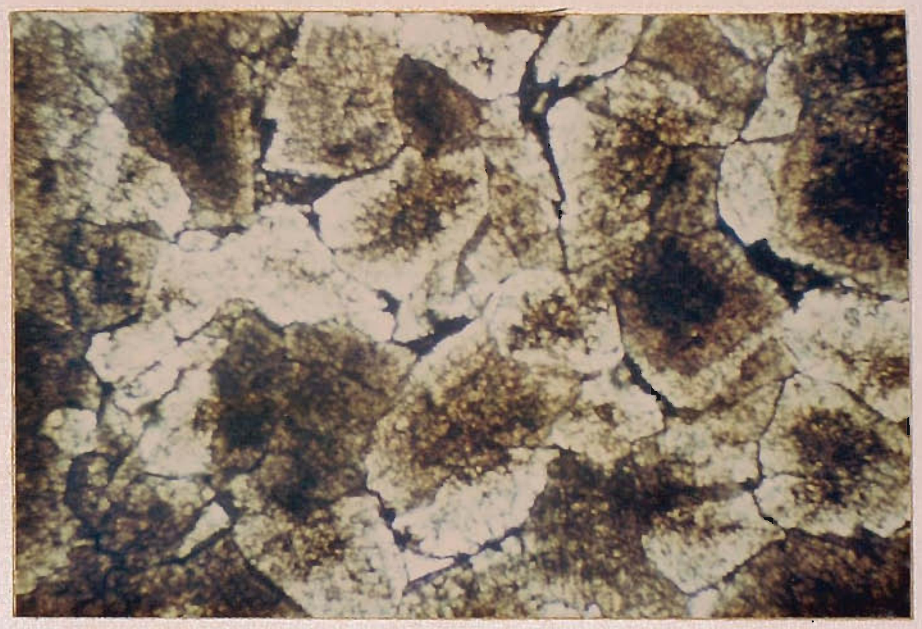

Plate 54. Completely dolomitised packed biomicrite showing sometimes zoned dusty inclusions within the dolomite. (stained thin section, p.p.l., x 40) Single Post Limestone, southwest of Bare House (SE 003665), near Yarnbury.

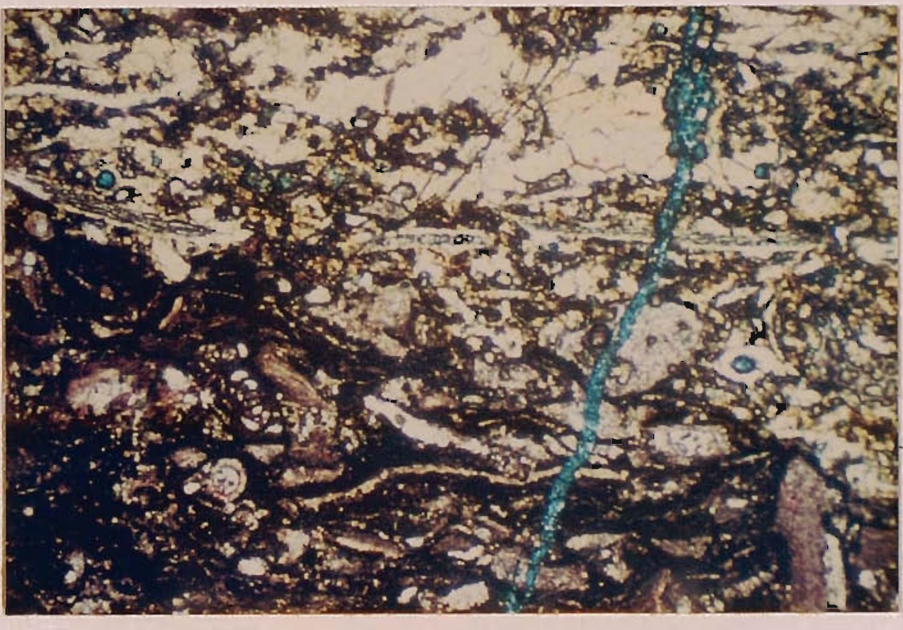

Plate 55. The chert nodule in the upper part of the photomicrograph has a gradational rather than abrupt contact with the sparse biomicrite it has replaced. Both are cut by a late stage ferroan calcite vein.

(stained thin section, p.p.l., x 40)

Lower Parting, Whitfield Gill (SD 930923), Wensleydale.

Plate 56. The chert nodule in the lower part of the photomicrograph has a microscopically irregular but fairly abrupt contact with the packed biomicrite it replaces. The chert/limestone contact can be seen to follow the brachiopod shell near the centre of the field of view.

(stained thin section, p.p.l., x 5)

Underset Limestone, West Gill (SE 011791), Coverdale.

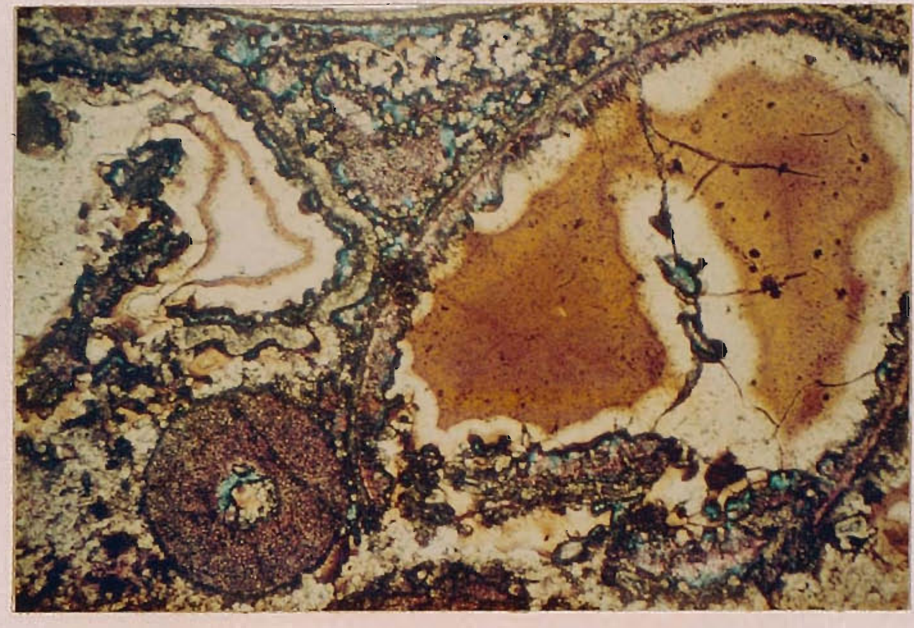

Plate 57. Part of the chert nodule illustrated in Plate 56 showing cavities infilled with colloform chalcedony. An earlier fibrous carbonate cement lines the large brachiopod shell on the right. It consists of non-ferroan calcite followed by ferroan calcite and in places has been replaced by chalcedony.
(stained thin section, p.p.l., x 40)
Underset Limestone, West Gill (SE 011791), Coverdale.

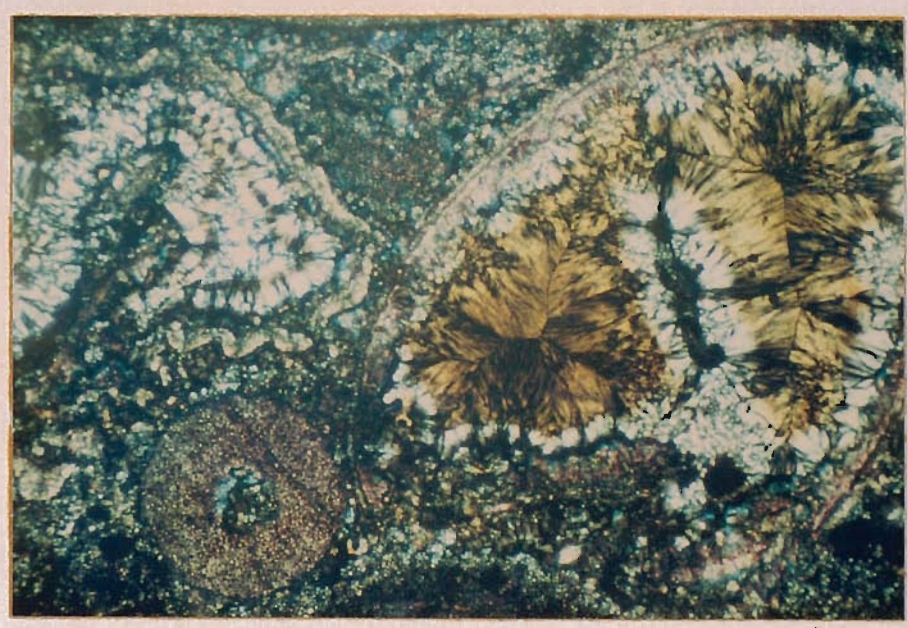

Plate 58. View as in Plate 57 showing fibrous nature of the chalcedony cement.
(stained thin section, x.p.l., x 40).
Underset Limestone, West Gill (SE 011791), Coverdale.

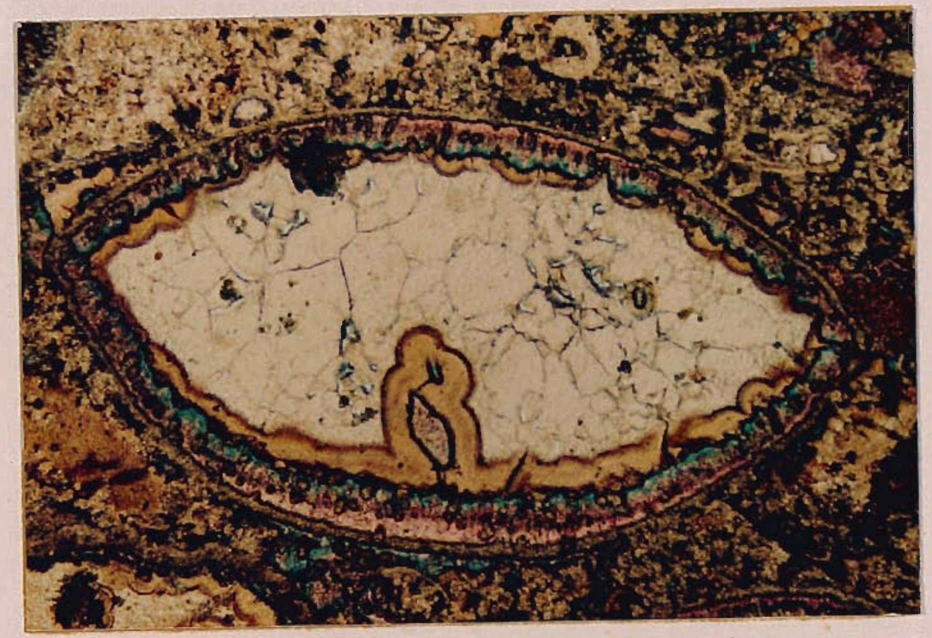

Plate 59. Brachiopod in the cryptocrystalline to microcrystalline quartz and chalcedonic matrix of the chert nodule figured in Plate 56. The shell is silicified and infilled with four generations of cement, first non-ferroan calcite then ferroan calcite followed by chalcedony and granular quartz.
(stained thin section, p.p.l., x 40)
Underset Limestone, West Gill (SE 011791), Coverdale.

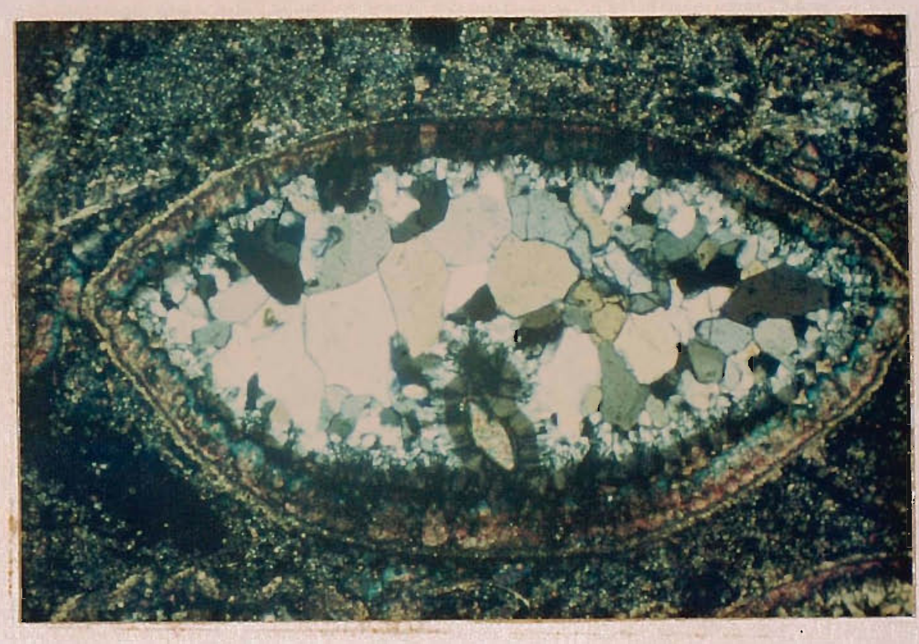

Plate 60. View as in Plate 59.
(stained thin section, x.p.l., x 40)
Underset Limestone, West Gill (SE 011791), Coverdale.

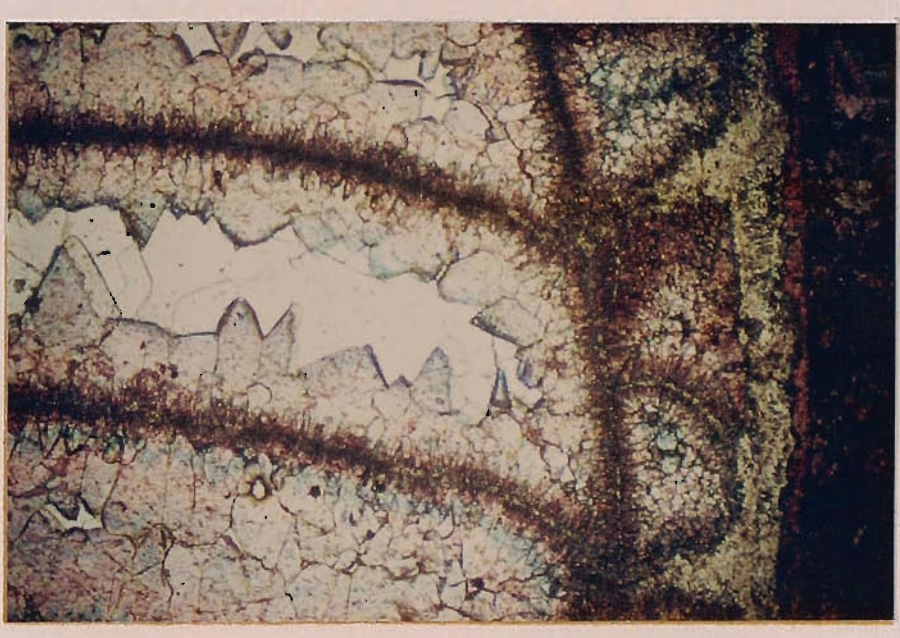

Plate 61. A portion of the partly silicified Diphyphyllum corallite figured in Plate 32 (lower left). Small fibrous non-ferroan calcite cement crystals nucleated on the coral skeleton line the body cavity. In places they become ferroan and are overgrown by larger crystals of non-ferroan and variably ferroan calcite. The central part of the cavity is filled with granular quartz which has replaced parts of the adjacent calcite cement. (stained thin section, p.p.l., x 40). Underset Limestone, Grisedale (SD 760938).

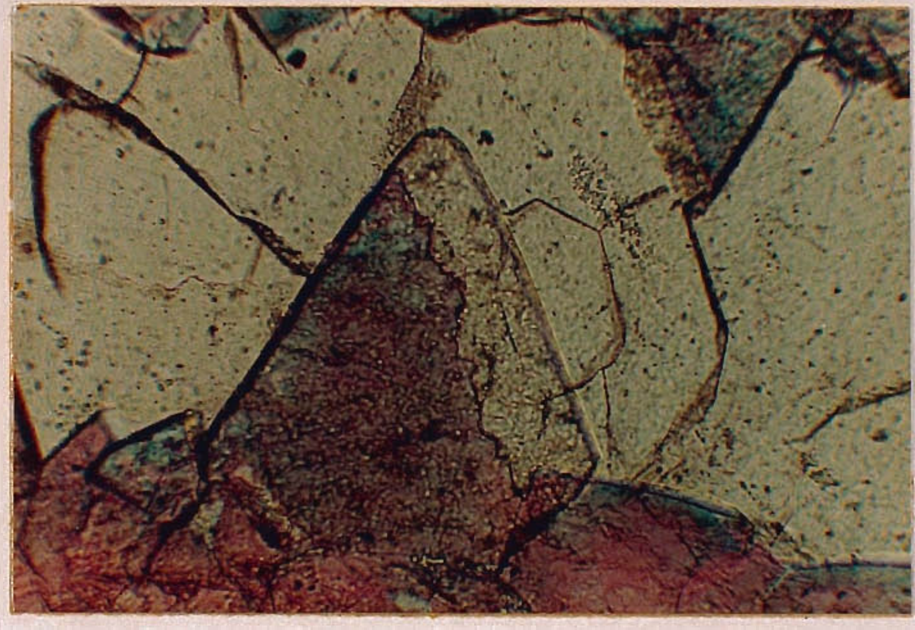

Plate 62. Part of the cement seen in Plate 61 (centre left) showing partial replacement of a well developed crystal of ferroan calcite by quartz.
(stained thin section, p.p.l., x 150)
Underset Limestone, Grisedale (SD 760938).

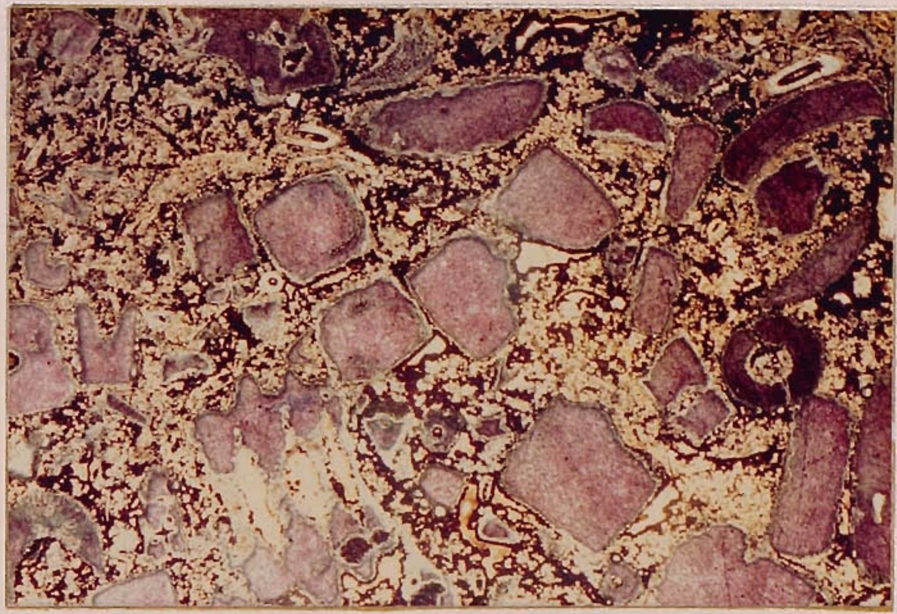

Plate 63. Crinoid debris in a chert nodule showing peripheral replacement by chalcedony.
(stained thin section, p.p.l., x 7)
Underset Limestone, Barton Quarry (NZ 216083), near Melsonby.

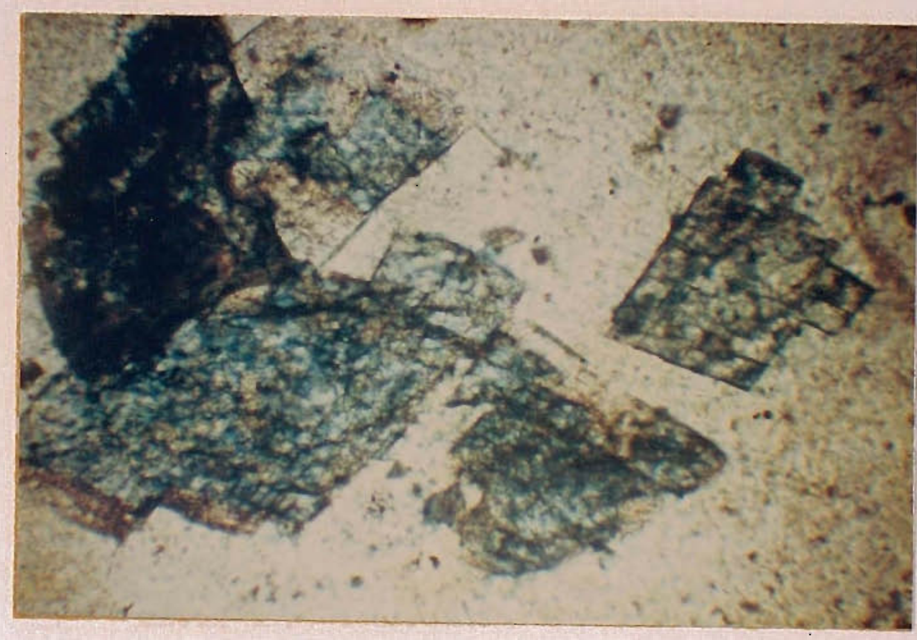

Plate 64. Ferroan dolomite rhombs in a chertified crinoidal biomicrite showing corrosion of their periphery and along their cleavage and partial silicification.
(stained thin section, p.p.l., x 150)
Middle Limestone, Trollers Gill (SE 072625), near Appletreewick.

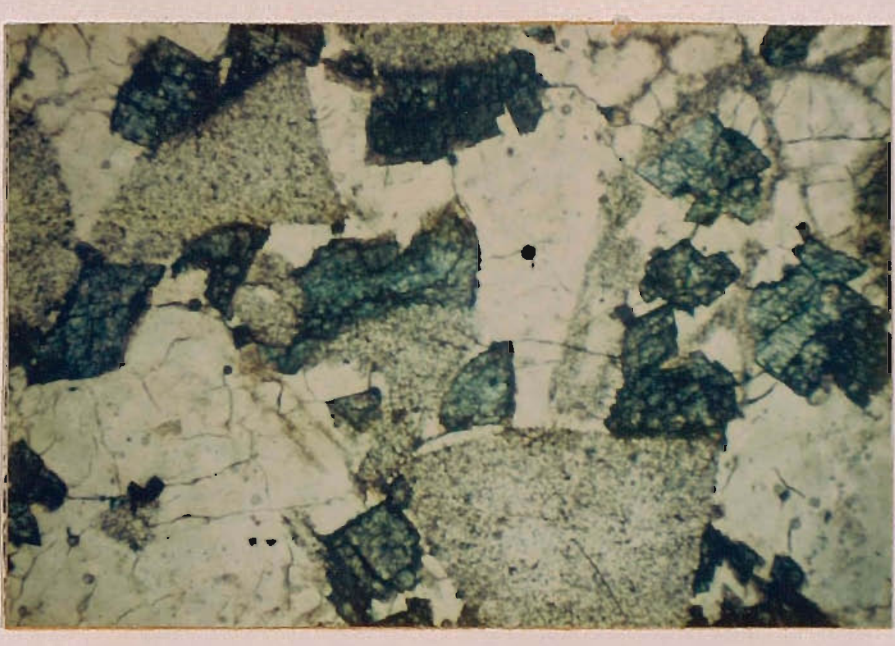

Plate 65. Ferroan dolomite rhombs preferentially replacing the matrix in a packed crinoid-ossicle biomicrite which has since been silicified. The dusty areas are silicified crinoid debris. (stained thin section, p.p.l., x 40)
Crow Limestone, East Gill (SD 837967), Cotterdale.

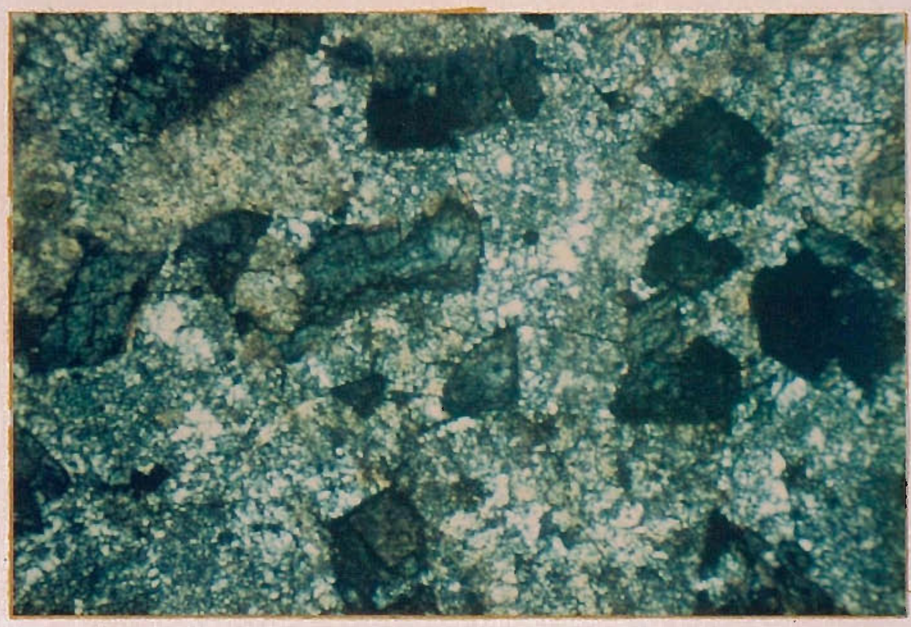

Plate 66. View as in Plate 65 showing replacement of all but the ferroan dolomite by cryptocrystalline to microcrystalline quartz and chalcedony.
(stained thin section, x.p.l., x 40)
Crow Limestone, East Gill (SD 837967), Cotterdale.

Plate 67.

Laminated spicular chert.
(stained thin section, p.p.l., x 40)
Crow Limestone,
Sod Dyke Nick
(SD 973954)
Swaledale.

Plate 68.

Laminated spicular chert as in Plate 67.
(stained thin section, x.p.l., x 40).
Crow Limestone,
Sod Dyke Nick
(SD 973954)
Swaledale.

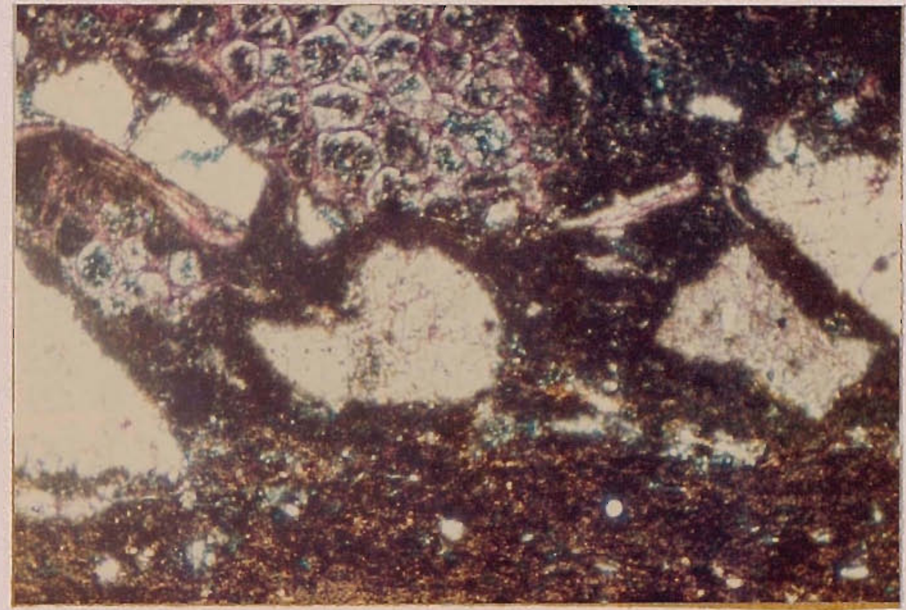

Plate 69. Calcareous chert with bioclastic debris including crinoid, brachiopod and bryozoan fragments.
(stained thin section, p.p.l., x 40)
Crow Limestone, Sandbeck East Bridge Quarry (SE 171998), south of Richmond.

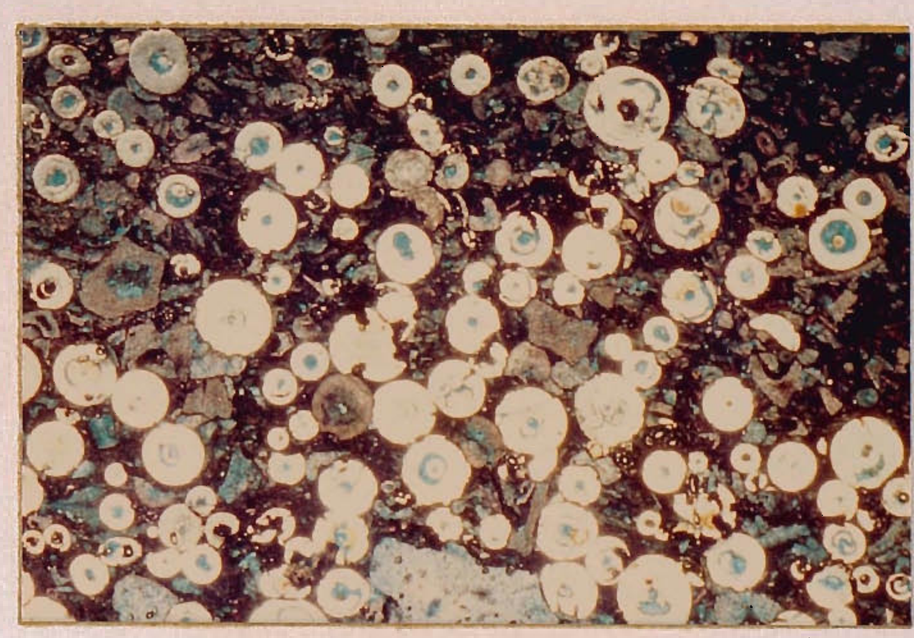

Plate 70. Hyalostelia spicules, partly replaced by ferroan calcite, in a chertified packed biomicrite.
(stained thin section, p.p.l., x 7)
Crow Limestone, Benty Gutter (NY 936030), Gunnerside.

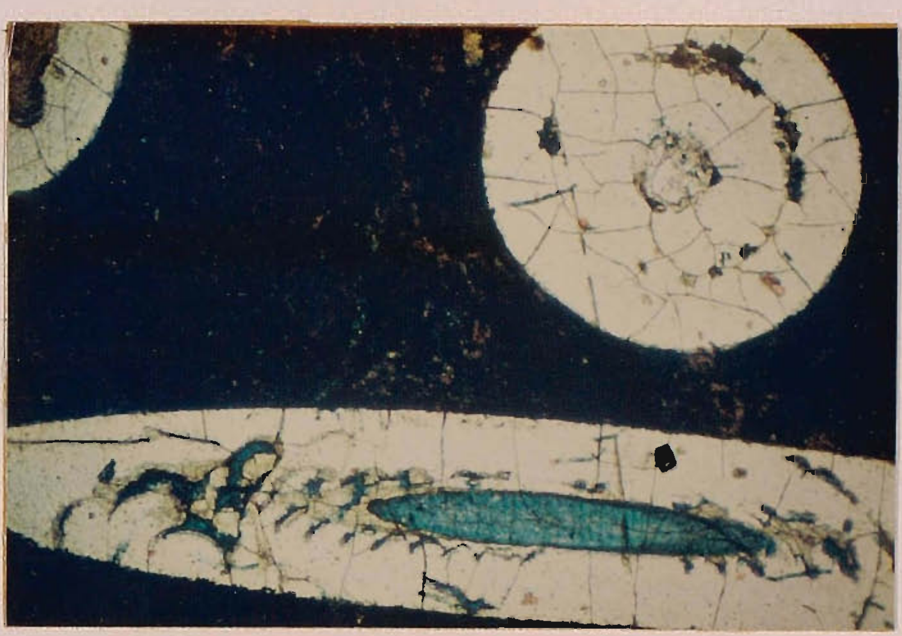

Plate 71. Chalcedonic Hyalostelia spicules partly replaced by ferroan calcite, dolomite and ferroan dolomite. The central canal is infilled with chalcedony in the spicule top right and ferroan calcite in the spicule in the lower part of the photomicrograph.
(stained thin section, p.p.l., x 40)
Crow Limestone, Benty Gutter (NY 936030), Gunnerside.

Plate 72. View as in Plate 71. showing the chalcedonic nature of the Hyalostelia spicules.
(stained thin section, x.p.l., x 40)
Crow Limestone, Benty Gutter (NY 936030), Gunnerside.

Plate 73. Chert with part of silicified brachiopod in which the structure of the shell has been preserved.
(stained thin section, x.p.l., x 40)
Crow Limestone, Sod Dyke Nick (SD 973954), Swaledale.

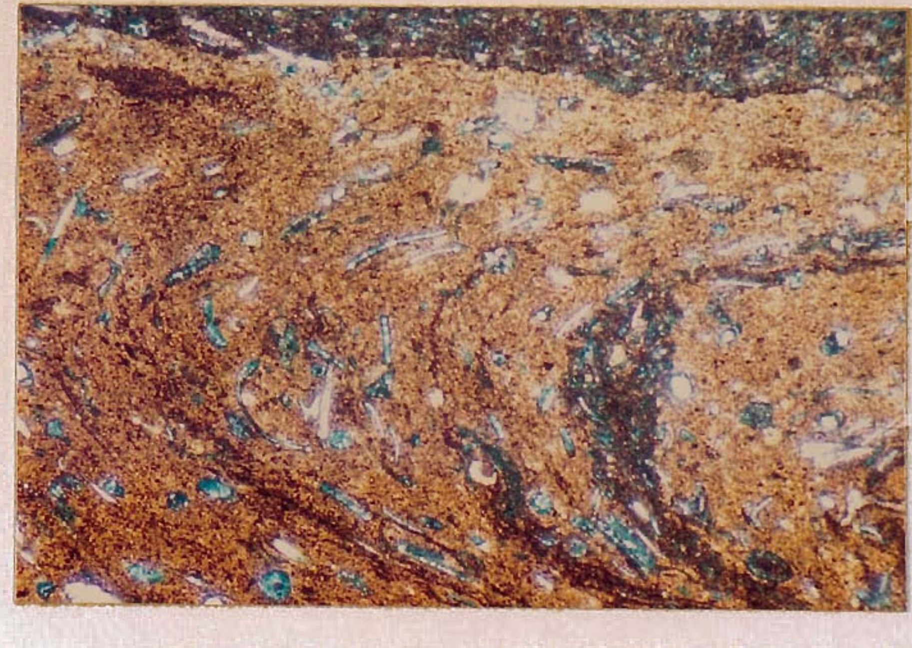

Plate 74. Part of Zoophycos burrow in a bioclastic calcareous chert showing orientation of spicular debris in the burrow parallel to the spreite.
(stained thin section, p.p.l., x 40).
Underset Limestone, Rake Gate (NZ 079057), northwest of Marske.

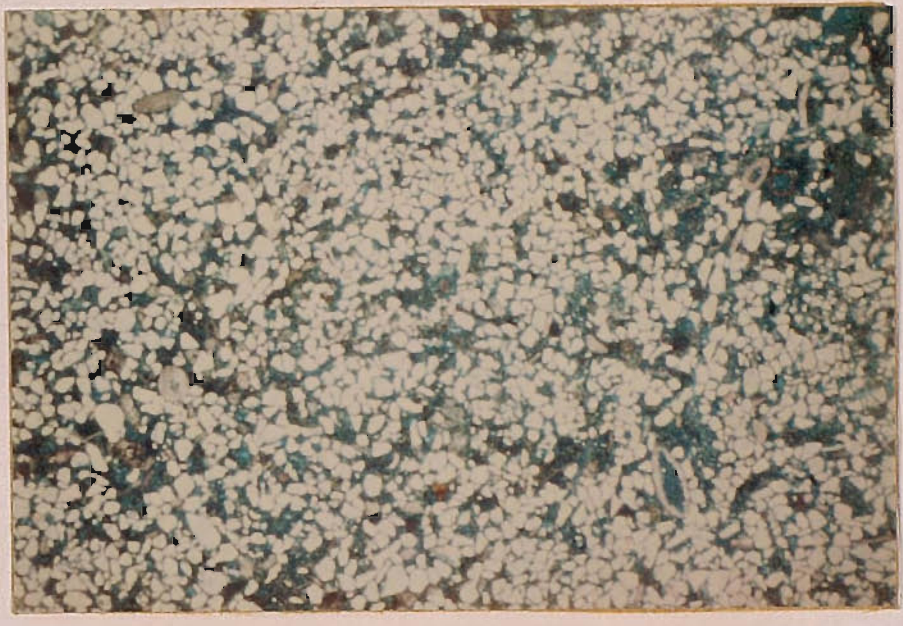

Plate 75. Fine grained quartz sandstone with calcareous bioclastic debris and a ferroan calcite cement.
(stained thin section, p.p.l., x 13)
Lower Parting, Smout Gill (SD 779908), Garsdale.

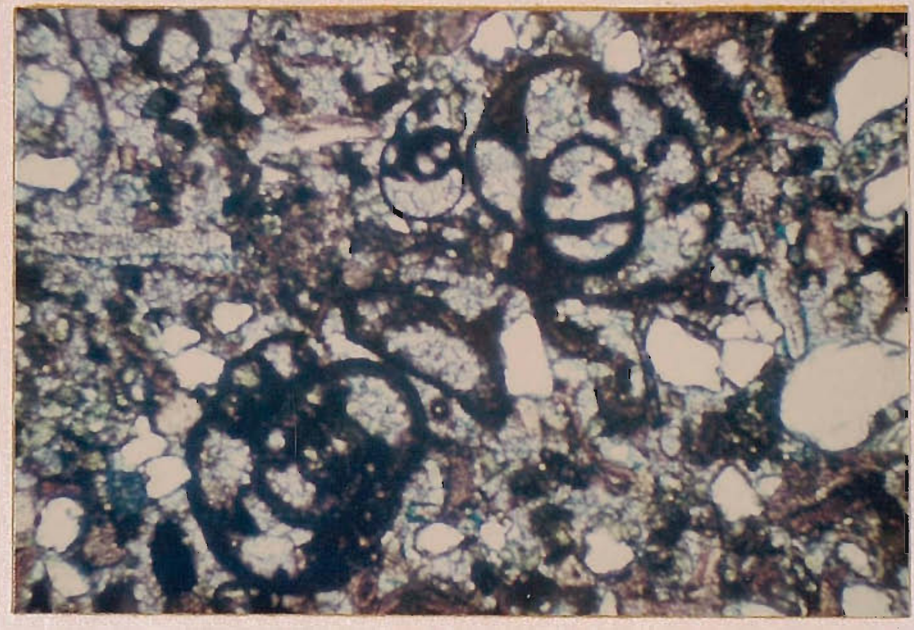

Plate 76. Sandy biosparite with ferroan calcite cement.
(stained thin section, p.p.l., x40)
Lower Parting, River Clough (SD 782922), Garsdale.

Plate 77. Glauconite sandstone showing micro-cross-lamination.
(stained thin section, p.p.l., x 3)
Crow Limestone, Caveside Gill (NY 869026), Whitsundale.

Plate 78. Compaction of laminae in a glauconite sandstone around a phosphate nodule.
(stained thin section, p.p.l., x 3.5)
Crow Limestone, Wetshaw Gill (NY 881041), West Stonesdale.

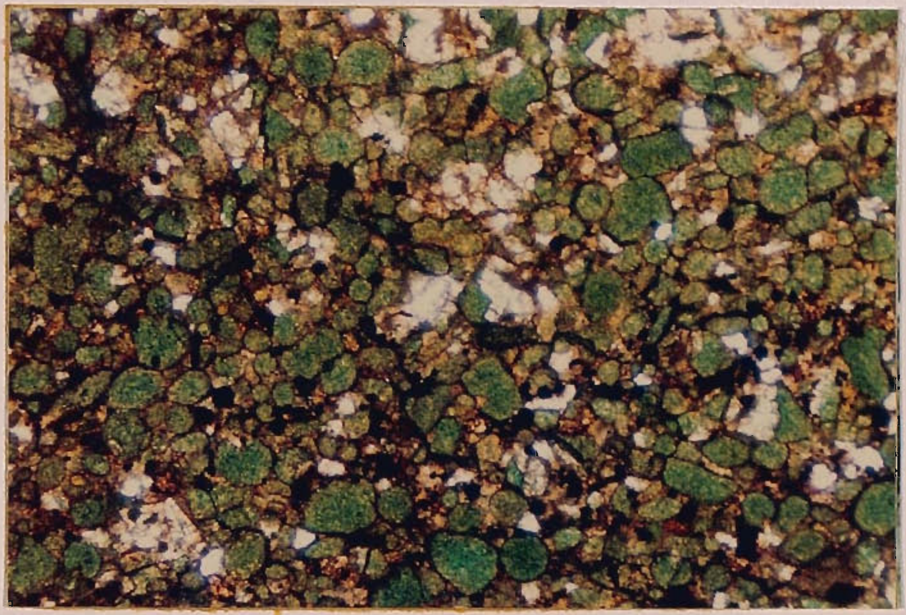

Plate 79. Glauconite sandstone with scattered quartz sand and a chert matrix.
(unstained thin section, p.p.l., x 40)
Crow Limestone, Hoods Bottom Beck (NY 863038) Whitsundale.

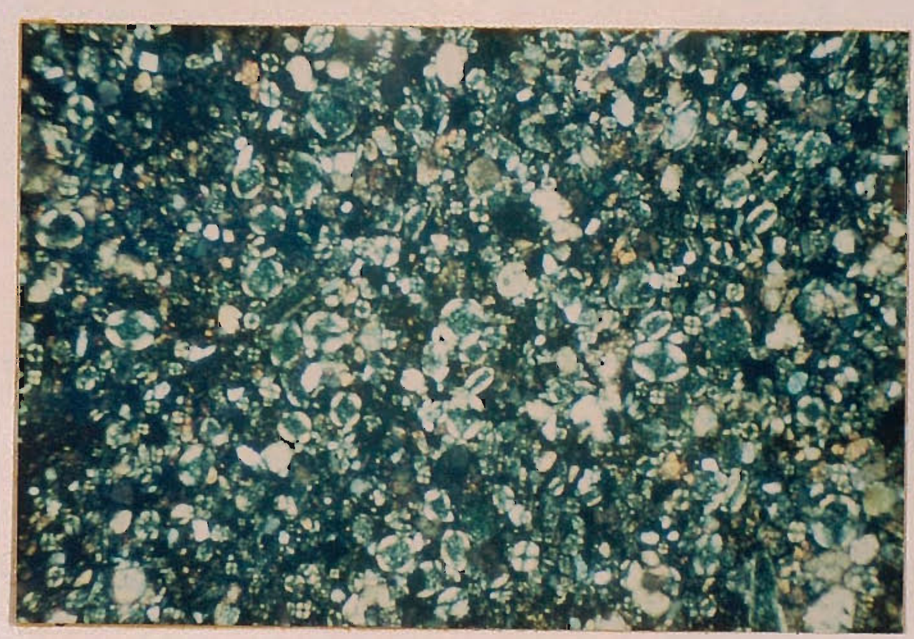

Plate 80. Glauconite sandstone with many of the glauconite grains showing an 'oolitic' structure.
(unstained thin section, x.p.l., x 40)
Crow Limestone, Birkdale Beck (NY 852012), Birkdale.

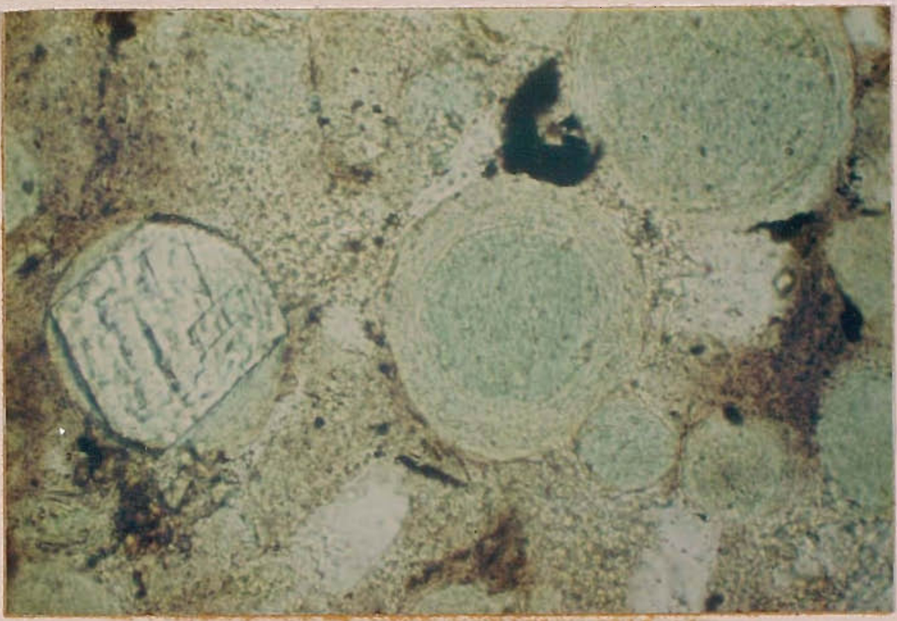

Plate 81. Glauconite with a central nucleus of randomly oriented microcrystalline glauconite platelets and an outer part of concentrically oriented glauconite platelets with their c-axes perpendicular to the surface of the grain. The glauconite grain on the left is replaced by ferroan dolomite.
(unstained thin section, p.p.l., x 375)
Crow Limestone, Birkdale Beck (NY 852012), Birkdale.

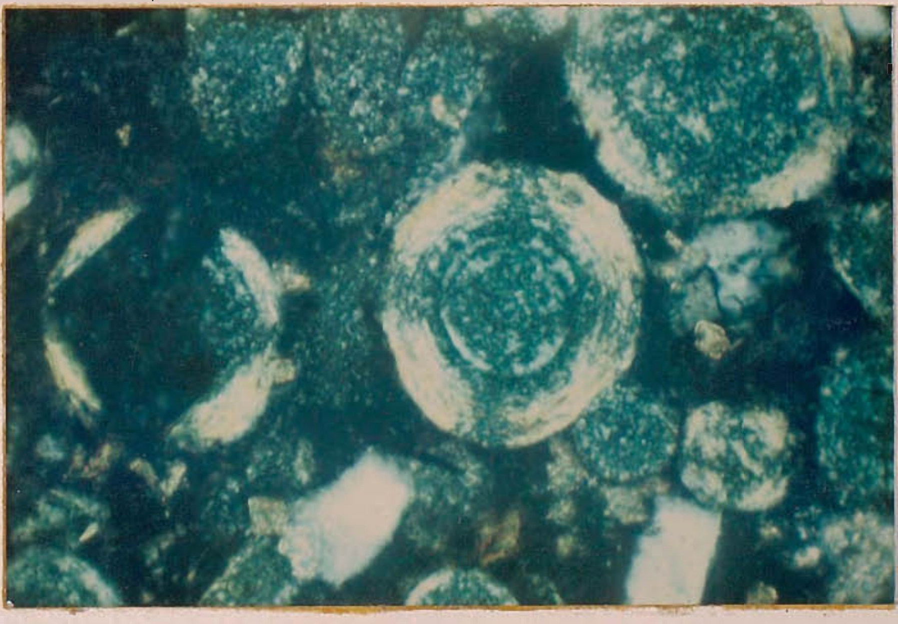

Plate 82. View as in Plate 81. The 'oolitic' structure of the glauconite is well shown by extinction crosses.
(unstained thin section, x.p.l., x 375)
Crow Limestone, Birkdale Beck (NY 852012), Birkdale.

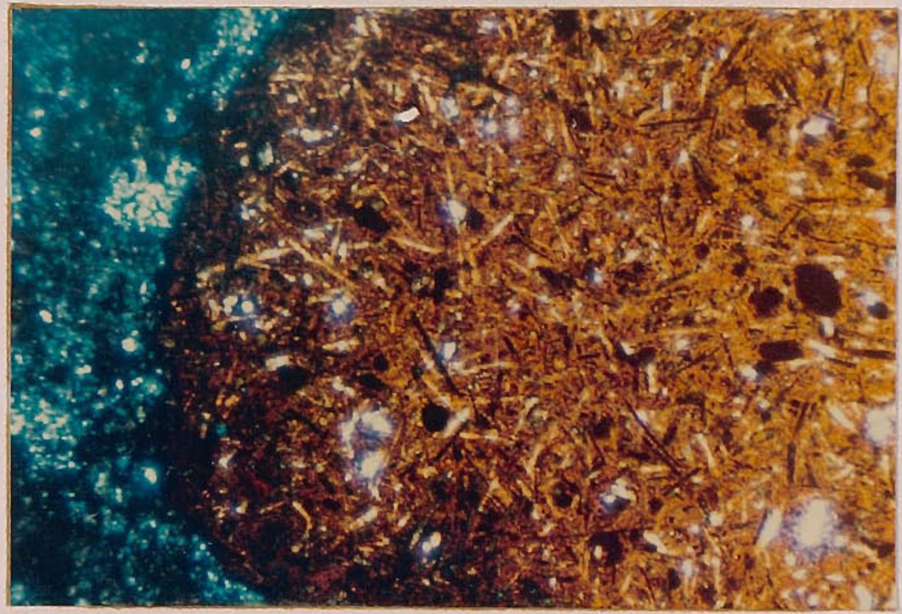

Plate 83. Phosphate nodule with abundant spicular debris and scattered quartz sand. The nodule is surrounded by ferroan dolomite. (stained thin section, p.p.l., x 40)
Crow Limestone, Bleaberry Beck (NY 843071), Brownber.

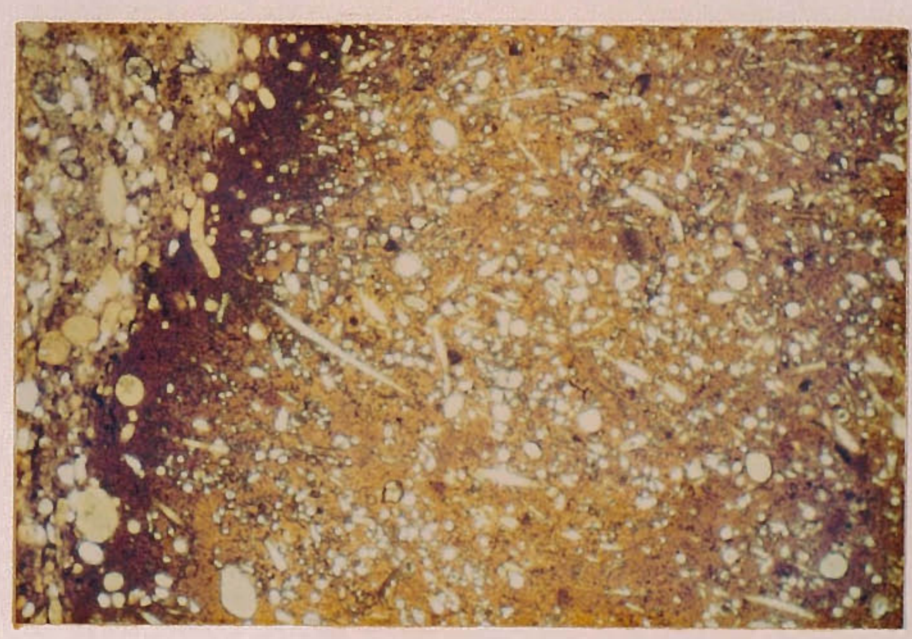

Plate 84. Phosphate nodule with abundant spicular debris and grains of glauconite and quartz. The dark periphery of the nodule is characteristic.
(unstained thin section, p.p.l., x 40)
Crow Limestone, Birkdale Beck (NY 852012), Birkdale.

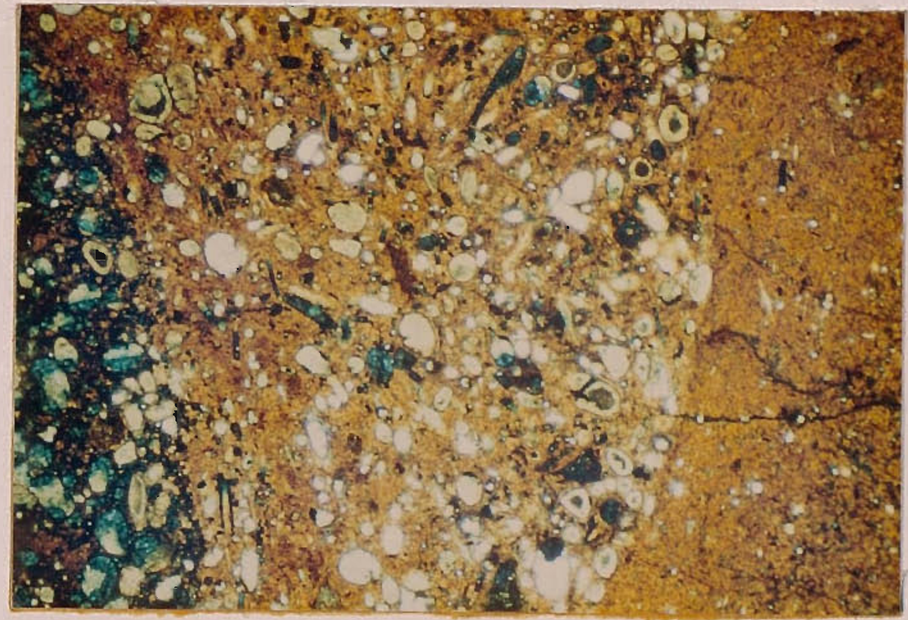

Plate 85. Phosphate nodule showing an outer later generation of phosphate which has incorporated much of the surrounding sediment including grains of glauconite, quartz sand and sponge spicules. (stained thin section, p.p.l., x 40)
Crow Limestone, Hoods Bottom Beck (NY 863038), Whitsundale.

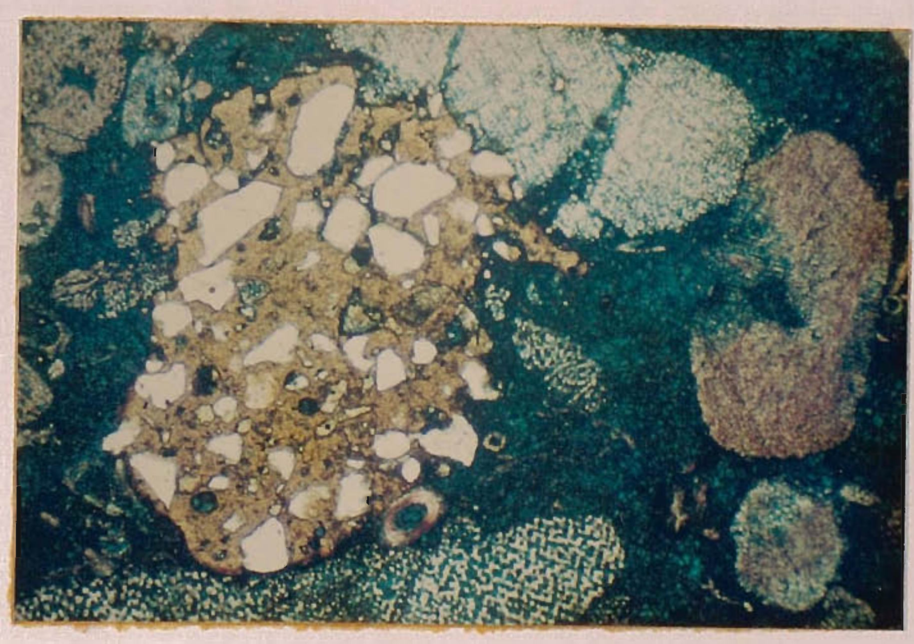

Plate 86. Phosphate lithoclast containing quartz sand, glauconite and sponge spicules in a packed crinoid-stem biomicrite which has been largely replaced by ferroan calcite.
(stained thin section, p.p.l., x 40)
Crow Limestone, Ceaseat Beck (SD 762918), Garsdale.

OUTCROP MAP OF THE MIDDLE, UNDERSET AND CROW LIMESTONES OF THE YOREDALE GROUP IN NORTH YORKSHIRE