UNIVERSITY OF SOUTHAMPTON

SEDIMENTOLOGY OF THE MID-VISÉAN LIMESTONES OF THE SOUTHERN PART OF THE ASKRIGG BLOCK, NORTH YORKSHIRE.

A thesis submitted in the University of Southampton
for the degree of Doctor of Philosophy

by

Gillian Scott

September, 1984

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ABSTRACT

FACULTY OF SCIENCE

GEOLOGY

Doctor of Philosophy

SEDIMENTOLOGY OF THE MID-VISÉAN LIMESTONES OF THE SOUTHERN PART OF THE ASKRIGG BLOCK, NORTH YORKSHIRE.

by Gillian Scott

The earliest Carboniferous deposits, resting with profound unconformity on Lower Palaeozoic rocks, have been mapped across their entire outcrop area on the Askrigg Block. The sediments, comprising approximately half of the thickness of the Dinantian Great Scar Group, have been subdivided into four formations listed in ascending stratigraphical order:- the Thornton Force Formation and its lateral equivalent the Douk Gill Formation, the Raven Ray Formation and finally, the Horton Limestone.

Each of these formations has been described in great detail, noting the variations in thickness and the various rock-types contained therein. This data has been used to identify sixteen rock-types which occur in at least one and usually in all of the studied formations.

The depositional environment of each of these rock-types has been interpreted by means of palaeoenvironmental analysis of the fossil groups and sedimentary structures present and from the distribution of each of the rock-types. The diagenetic history of the carbonates has been studied by means of staining techniques.

The earliest deposits of the Thornton Force Formation were formed in a marginal marine environment. Although beach-nearshore sediments accumulated in an active environment, inundation of the Askrigg Block appears to have been a gradual and gentle process, allowing local preservation of soils and debris flow deposits in more protected pockets and hollows. The ridges of Lower Palaeozoic rock supplied detritus throughout deposition of nearshore shallow subtidal calcarenites of the formation.

The Douk Gill Formation, restricted in outcrop to a local topographic hollow in Ribblesdale, is probably a lateral equivalent of the Thornton Force Formation. A ridge of Lower Palaeozoic rocks provided a protective barrier, allowing clastic and later carbonate sediments to accumulate in the sheltered environment. Infilling of the lagoon resulted in the formation of tidal flats, and culminated in subaerial exposure and the development of a thin coal.

During deposition of the Raven Ray Formation a shelf-edge shoal must have formed, separating the Pennine Basin from the normal marine shelf lagoon of lime mud deposition. Small shoals occasionally developed in the extensive lagoon environment. Shoreline deposits formed around those Lower Palaeozoic ridges which persisted as islands.

The Horton Limestone represents an episode of deposition predominantly of cross-laminated calcarenites formed within surge depth. Eventually, shelf-edge shoals created a barrier which separated the Pennine Basin from a restricted marine, shallow lagoon of lime mud deposition. Gradual infilling of the lagoon led to the creation of a tidal flat environment. Tidal channels were common in this environment. Periodically the barrier shoals were breached and the lagoon-tidal flat environment overwhelmed by carbonate sand.

The principal mechanisms controlling sedimentation have been discussed. During the initial stages of inundation, the topography of the pre-Carboniferous rocks exerted a significant but dwindling influence on the rock-types deposited and on their distribution. Burial of the land surface eliminated this effect and the rates of sedimentation and subsidence became the most significant mechanisms controlling the type and distribution of Dinantian sediments.

ACKNOWLEDGEMENTS

This research was undertaken during the tenure of a University of Southampton Scholarship, which is gratefully acknowledged.

I am indebted to Dr.D.Moore for his supervision and guidance during the course of this research, and for his critical reading of this thesis. Professor F. Hodson and Professor R. W. Nesbitt made available the facilities of the Department of Geology, Southampton University.

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I also wish to thank Robertson Research International Limited for their constant financial support during the preparation of this thesis,and for making available the facilities of the drawing office and photographic department. Tony Stephens gave valuable advice and assistance with preparation of diagrams. Mrs. Yvonne Parkhurst and Robert Sockett kindly typed this thesis.

I thank the managers of quarries in the study area for permitting me access and I am grateful to the many farmers in North Yorkshire who allowed me unrestricted access on to their land.

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CHAPTER ONE

INTRODUCTION

1.1 The Dinantian Subsystem of Great Britain.

The Mid Viséan sediments of the Dinantian Subsystem are exposed extensively in Great Britain, forming distinctive scenery. The distribution of the Mid Viséan rocks (Fig.1.1) and their palaeogeographic settings are well known although there are problems of correlation between the different regions. There are two broad facies groups; shallow water shelf and basin. The area of present day England and Wales consisted of a number of small land masses surrounded by extensive shelf areas and restricted basins.

The biostratigraphy of the Great Scar Group of Yorkshire has been exhaustively studied; the lithostratigraphy, however, has been neglected. There has been considerable confusion of biostratigraphy and lithostratigraphy in Northern England (Garwood, 1913; Garwood & Goodyear, 1924). The Productus corrugato-hemisphericus Zone (Garwood, 1913) with its fauna, has no designated type section and the zonal name is rarely used in Derbyshire. Moreover, Garwood (1913) divided the zone partly on a lithological basis into three rock-groups which he called subzones. The lack of clarity in the way in which Garwood (1913) thought of zones can be demonstrated; the Gastropod Beds, a subzone, which are "characterised by a rich assemblage of gastropods" but are without a "species that can be cited as an index."

It is the aim of this thesis to examine the depositional and diagenetic textures and determine the palaeoenvironments of the Mid Viséan sediments, to correlate the different rock-types, and to produce a sequence of models of the changing palaeoenvironment.

The study was limited geographically to the exposures of Mid Viséan sediments on the southwestern part of the Askrigg Block, where they

FIGURE 1.1 Generalised palaeogeographic map of Great Britain during Dinantian times, showing the distribution of major structural units (after D. Moore and R.B. Davies, unpublished).

overlie folded and faulted Lower Palaeozoic slates and graywackes and are overlain, apparently conformably, by the Kingsdale Limestone, the top formation of the Great Scar Group. The areal distribution of Carboniferous rocks of Northern England is shown in Figure 1.2.

The Dinantian Subsystem was first correlated by Vaughan's (1905,1906) coral-brachiopod zones, first established in the Avon Gorge. Garwood (1913) erected a separate zonal scheme for Northern England, also based on coral-brachiopod faunas; problems arose in correlating this scheme with Vaughan's. Various revisions resulted finally in one scheme of Dixey & Sibly (1918), which gained general acceptance (Fig.1.3.). All these zonal schemes are based on faunas which are restricted to shallow water carbonate sediments. They do not apply to the dominantly fluvio-deltaic equivalents of Scotland, nor to the basinal environment in England.

Recently the Carboniferous sediments have been correlated in terms of "cycles" by Ramsbottom (1973,1974,1977) who developed a concept of cycles of transgression and regression, recognised by the repetition of a facies sequence in which each unit had a characteristic fauna. Ramsbottom (1973,1974,1977) identified four major cycles and two groups of minor cycles (each given the status of a composite major cycle) in the Dinantian Subsystem of Britain. He postulated that the primary control of these cycles was eustatic rise and fall of sea level, that consequently, the cycle boundaries represented absolute time planes and that they could, therefore, be used for correlation. Ramsbottom (1973 p.569) claimed that his major cycles provided "an improved means of stratigraphical division of the Dinantian [Subsystem]". In collaboration with others of the Dinantian Working Group of the Geological Society's Stratigraphic Committee (George & others, 1976) he established six stages which he equated precisely with his major cycles (Fig.1.3.) though this was denied by George (1978,p.232 on). None of these newly proposed stages has been divided into zones, even though zones are the fundamental unit in biostratigraphy.

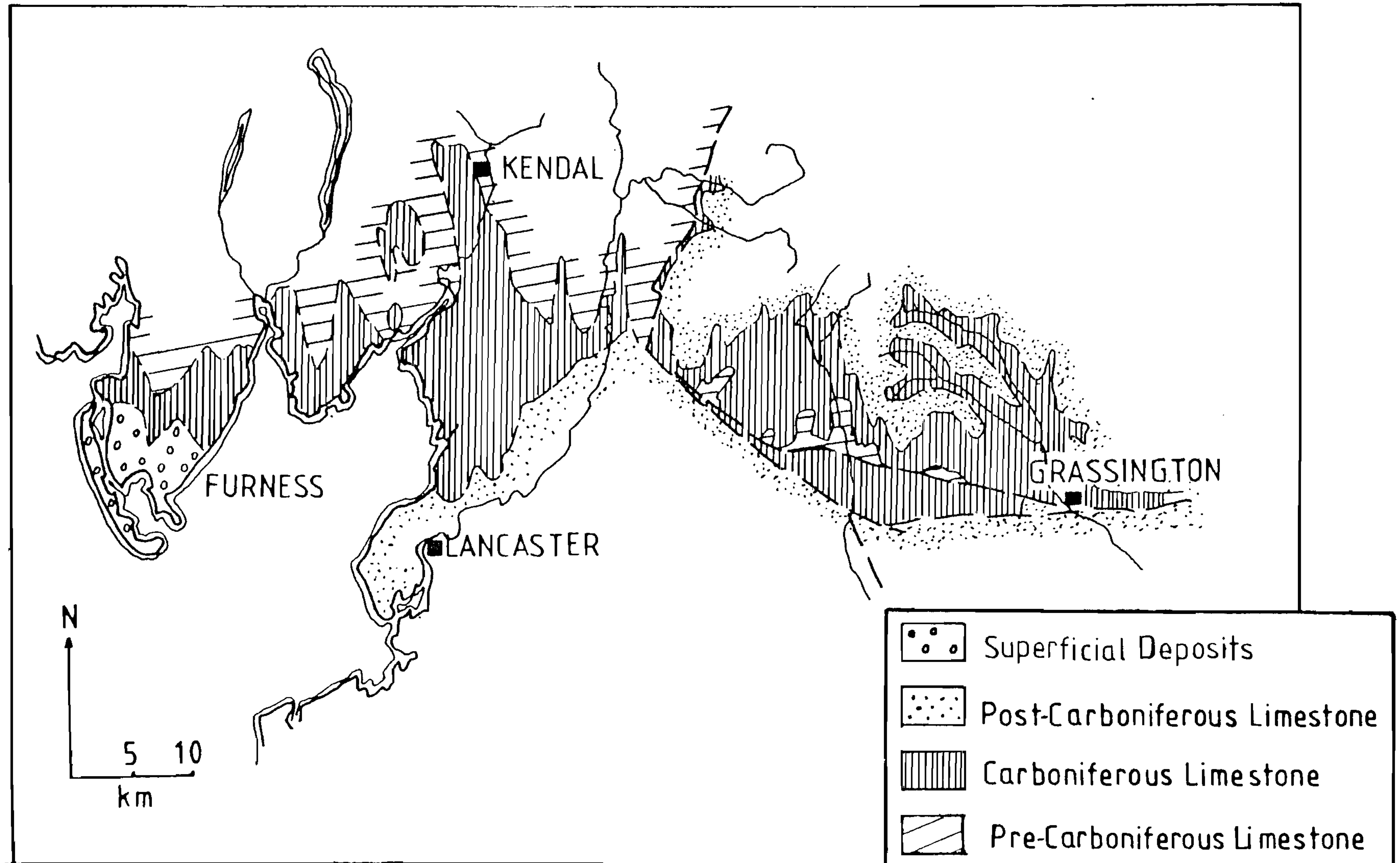


FIGURE 1.2 The areal distribution of Carboniferous Limestone (Dinantian) in northern England.

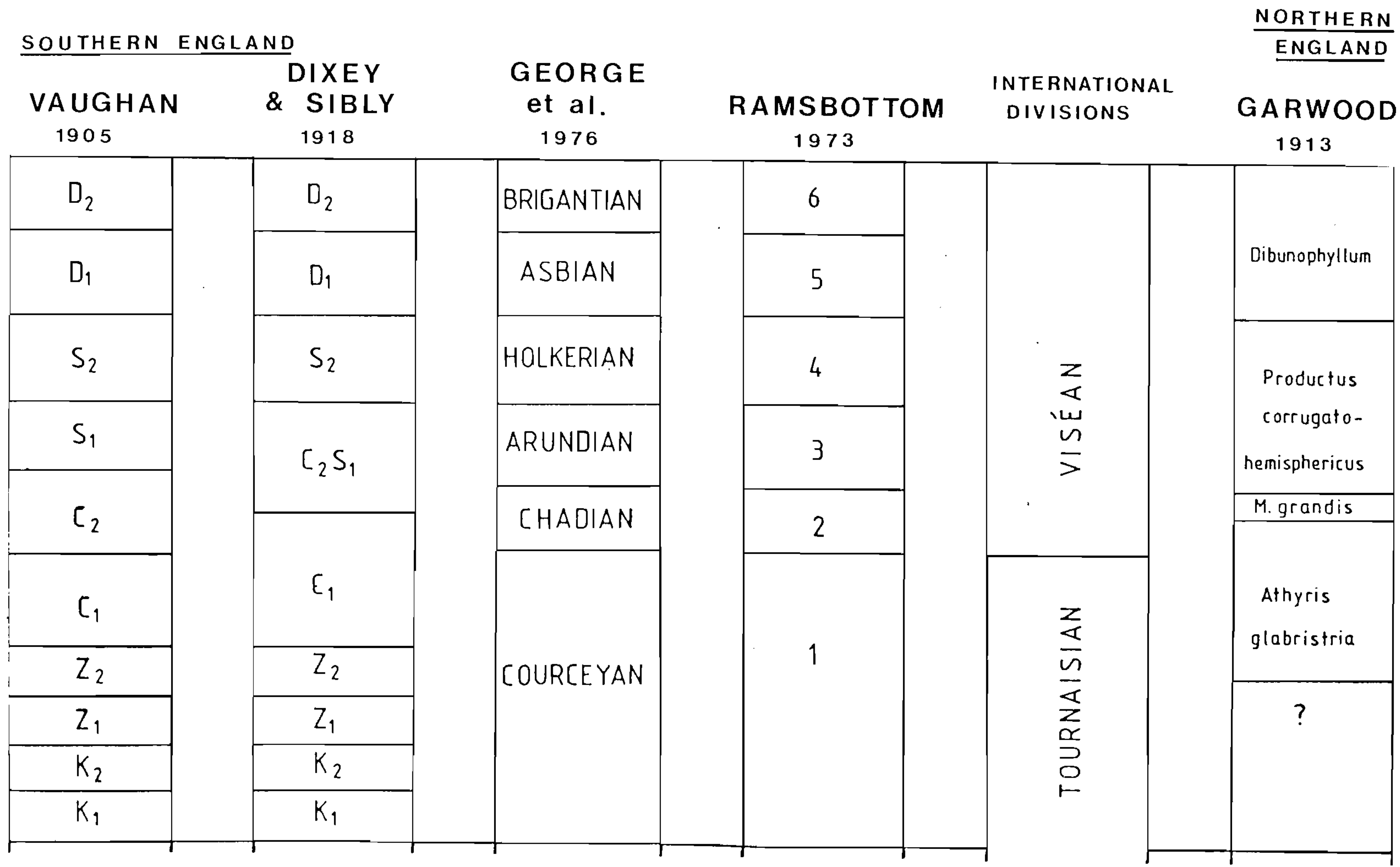


FIGURE 1.3 Major zonal schemes (Vaughan, 1905; Dixey & Sibly, 1918; Garwood, 1913) proposed for the Dinantian rocks of the British Isles and their relationships to the regional stages of George & others (1976) and the major divisions of the Dinantian Subsystem of Belgium.

1.2 Terminology and Techniques

Fieldwork constitutes a substantial part of this research project. Bed-by-bed measurements were taken where the formations were completely exposed. In less well-exposed ground an Abney level was used to measure thickness.

There is no difficulty in recognising the base of the succession, since the Dinantian rocks rest with profound unconformity on Lower Palaeozoic slates and graywackes. Exposure at the unconformity is often good because of the frequent springs at this level. Vertical, sometimes overhanging, cliffs occur above the springs, but higher in the sequence the beds become very uniform and well jointed and outcrop tends to be poorer. This is particularly so where the overlying Kingsdale Limestone is preserved. The top of the studied sequence is well defined in the more northerly outcrops where it is marked by a calcilutite more than one metre thick. This fails southwards and in its absence the top is undefinable.

Considerable variations occur at the base of the sequence where three lithologically distinct units have been mapped. They are designated as formations. Although two of them correspond closely to formations already named in the Furness District (Red Hill Oolite and Dalton Beds of Rose & Dunham, 1979) there are differences in age, rock-type and thickness and new formation names have been constructed incorporating the type-locality. The Thornton Force Formation, cross-laminated, well sorted calcarenites with variable amounts of lithoclasts from the slates and graywackes, is overlain by the Raven Ray Formation, interbedded black mudstones and foetid, black calcarenites. The third formation, a partial equivalent of the others, is restricted to a small area around Horton-in-Ribblesdale, where it has only four outcrops. It is named, after the thickest and most variable outcrop, as the Douk Gill Formation. The rest of the sequence, by far the greater part, is much more uniform: cross-laminated, well sorted calcarenites similar to those of the Thornton Force Formation though lacking the lithoclasts except in Crummack Dale. This is named the Horton Limestone retaining the name as first proposed by Ramsbottom (1974, p. 58), not as he later used it (Fewtrell, Ramsbottom & Strank, 1981). All currently available exposures of the Thornton Force Formation, Raven Ray Formation and Douk Gill Formation have been examined and described; the Horton Limestone has been examined only in the better exposures where top and/or base are visible. Samples of all rock-types except the boulder rudites have been collected for laboratory investigation, but bed-by-bed sampling has not been undertaken.

Large-area thin sections on 50mm x 75mm slides were made, all orientated perpendicular to bedding. Those of limestone were stained with an acid solution of Alizarin red-S and potassium ferricyanide to differentiate the various carbonate minerals and thus interpret the diagenetic history of the rock (Dickson, 1966).

XRD analysis for clay minerals was carried out on the shale specimens collected,on both bulk sample and less than 5 μm fraction.

1.2.1 Nomenclature of Carbonate Rocks

The classifications used in this report are described below.

1.2.1.1 Stratal Terminology

Bedding and Lamination.

The classification used for bedding and lamination (Fig.1.4.) is that proposed by Campbell (1967), wherein a bed is defined as an individual unit of sedimentation bounded by upper and lower bedding surfaces which are time-planes. A group of contiguous, identical beds is call a bed-set. Beds may be internally subdivided into laminae, each lamina being internally homogeneous. Laminae lying oblique to bedding are cross-laminae which can be classified according to the scheme of Allen (1963).

metres	bedding & parting	lamination	millimetres
	v.thick		
1			
	thick		
0.3			
	medium	v.thick	
0.1			100
	thin	thick	
0.03			30
	v.thin	medium	
			10
		thin	
			3
		v.thin	

FIGURE 1.4 Classification of bedding, parting and lamination after Campbell (1967).

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		

FIGURE 1.5 Particle Size Scale (after Pettijohn, 1957).

1.2.1.2 Classification of Carbonate Rocks

Many classifications of carbonate rocks have been proposed (Ham & Pray, 1962; Bissel & Chillingar, 1967) but as yet no single classification has been adopted universally. In rocks which show such enormous depositional variability as do the carbonates and in view of their sensitivity to diagenesis any comprehensive classification is likely to be so complex as to be unusable, whereas any usable classification is bound to be oversimple when applied in detail.

The classification used in this study follows the precept of Folk (1959); a field classification based on the Wentworth-Udden Grade Scale (Pettijohn, 1957) and a petrographic classification (Fig.1.6.) adapted from Folk (1962) and Dunham (1962).

1.2.1.2a Field Classification

The majority of limestones encountered in this study have a framework of allochems, dominantly bioclasts and intraclasts. In the field they are broadly classified into calcilutites, calcisiltites, calcarenites and calcirudites (Grabau, 1904; 1913). Grain-supported carbonates (Dunham, 1962) were distinguished from matrix-supported carbonates where possible. Calcarenite and calcirudite are applied only to those carbonates in which allochems of the appropriate size clearly form the framework. Carbonates with sparse allochems of arenite or rudite size are classified as calcilutites with an adjective expressing the abundance of allochems visible e.g. sparse, scattered or abundant. Unless otherwise stated the allochems are of arenite size.

Rock colours are described in accordance with the A.S.T.M. Rock Colour Chart. The rocks are described as pale grey, medium grey and dark grey only. Differences in illumination and sample-wetness make meaningful distinction of intermediate colours impossible.

<table>
<tr><td colspan="4">Group Name</td><td>SPARITES</td><td colspan="5">MICRITES</td><td rowspan="4">Bioherm rocks</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></tr>
<tr><td colspan="4" rowspan="2">Allochems</td><td colspan="3" rowspan="2">Grain-Supported</td><td colspan="3">Lime Mud-Supported</td></tr>
<tr><td>> 10%</td><td>1% - 10%</td><td>1%</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></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></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 rowspan="2">bioclastic micrite</td></tr>
<tr><td>Bioclasts: pellets 3:1 - 1:3</td><td>biopelsparite</td><td>packed biopelmicrite</td><td>sparse biopelmicrite</td></tr>
<tr><td>Bioclasts: pellets <1 : 3</td><td>pelsparite</td><td>packed pelmicrite</td><td>sparse pelmicrite</td><td>pelletiferous micrite</td></tr>
</table>

FIGURE 1.6 Classification of carbonate rocks adapted from Folk (1962) and Dunham (1962).

1.2.1.2b Petrographic Classification

As no single classification can include all the features observed in carbonate rocks it is necessary to construct or select a classification which subdivides carbonate rocks into well-defined groups. Genetic and highly specialised classifications should not be used; sedimentological interpretation must be based only on data which is objectively collected and objectively reported.

The classification used in this study is based on that proposed by Folk (1959;1962) because it is descriptive, practical and reasonably comprehensive. The classification has been adjusted by including some of the parameters defined by Dunham (1962). This combined Folk (1959;1962)-Dunham (1962) classification has previously been used successfully by Cousins (1976) and Davies (1980).

Folk (1959) recognised two fundamental constituents in carbonate rocks, "orthochems" and "allochems". "Orthochems" are essentially normal chemical/biochemical precipitates formed within the basin of deposition or within the rock itself, thus including both primary microcrystalline calcite (micrite) and secondary sparry calcite cement (sparite). "Allochems" ("allo" meaning-out of the ordinary) are transported carbonate clasts which are not ordinary chemical precipitates.

Folk (1962) modified his approach and described limestones as being composed of three basic components, discrete carbonate aggregates (allochems), microcrystalline calcite and sparry calcite cement. "Orthochem" as a fundamental constituent was abandoned. Micrite is still regarded principally as a chemical/biochemical precipitate, formation by abrasion of allochems being relegated to a minor role. Folk (1959;1962) recognised four types of allochem, intraclasts, oolites, fossils and pellets. Fossils (Folk,1959;1962) are defined as fragmentary biogenic remains.

Rock names are formed by combination of roots and names given to the basic components, the first referring to the allochems, the second to the interstitial material (Fig.1.6.).

Several critisms of Folk's (1959;1962) classification can be made. Fossil is not the correct term to describe fragmentary biogenic remains, the term bioclast is preferred in this thesis. Oolite, as the name of a carbonate grain is easily confused with the rock name. Oolith is used to describe spherical or ellipsoid bodies which have concentric-structured envelopes. Folk made no distinction between grain-supported and matrix-supported carbonates. The distinction between grain-supported and matrix-supported carbonates (Dunham, 1962) is more significant than division based on arbitary allochem percentage (Folk, 1962). The classification (Fig.1.6.) has been modified to demonstrate this. A grain-supported bioclast sand can contain 90% void space. Ten percent bioclasts is the boundary between fossiliferous micrite and sparse biomicrite of Folk (1962).

The classes defined in the modified Folk classification (Fig.1.7.) 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 ten percent allochems to mudstones.

Ooliths and bioclasts are readily recognisable, and in many limestones it is possible to distinguish pellets from intraclasts because of the differences in their internal texture, shape and size. However, in some rocks the distinction between intraclasts and pellets both composed of microcrystalline calcite is impossible, a problem recognised by Folk (1962). He suggested that all pellet-like clasts less than 0.2mm in diameter should be termed pellets, and all clasts of greater size, intraclasts. This arbitary division is unsatisfactory; in poorly sorted sediment containing silt-sized and sand-sized grains of micrite, all grains are probably derived from the same environment, and are all intraclasts. The probability of re-eroding faecal pellets deposited in their original pellet-mud environment to produce a pellet

Fig. 1.7 Definition of some of the terms used in the modified Folk classification.

Allochem:	An inclusive term for transported carbonate grains or particles produced by chemical/biochemical precipitation of carbonate within the basin of deposition; includes intraclasts, ooliths, bioclasts, pellets and pelletoids.
Intraclast:	fragment of more or less consolidated calcareous sedimentary material produced by erosion within the basin of deposition and redeposited nearby; limestone pebbles derived from an emergent land surface are not included therein, they are lithoclasts.
Grapestone:	grape-like clusters of silt-sized carbonate grains. Classed with intraclasts even though grapestone are formed by incipient cementation and not by abrasion.
Oolith:	a spherical or ellipsoid body, 0.25mm-2mm in diameter, which may or may not have a nucleus and a concentric-structured envelope. A rock composed predominantly of ooliths is an oolite.
Superficial oolith:	a type of oolith in which the thickness of the accretionary coating is less than the radius of the nucleus (Leighton & Pendexter, 1962).
Bioclast:	calcium carbonate grain of skeletal origin. Bioclast is equivalent to "fossil" in Folk's original work. Fossil is used to describe unbroken shells only.
Pellet:	excreta, mainly of invertebrates, of ovoid or rod-shaped form; showing remarkable uniformity of size and shape, ranging from 0.03mm-0.2mm, devoid of any internal structure.
Pelletoid:	carbonate body of uncertain origin. Pelletoid (pellet-like) preferred to the term peloid (which means pel-like). The term allows reference to grains composed of micrite or microspar without the need to imply any particular mode of origin.
Lithoclast:	rock fragment. Pieces of lithified material derived by erosion of rocks outside the environment of deposition and transported in.
Sparite:	chemically precipitated pore-filling cement. 10μm or more diameter. Distinguished from micrite by its clarity in thin section and coarser crystal size.
Micrite:	microcrystalline calcite ooze, formed of grains 1-4μm in diameter, translucent in thin section. This is also the name given to limestone consisting of microcrystalline calcite and less than 1% allochems.
Poorly washed sparite:	limestone which has sparry calcite cement but which also has one-third to two-thirds of all interstices filled with carbonate mud (i.e. poorly sorted rock). Probably formed as the result of partial winnowing of lime mud from the sediment.
Microspar:	5-15μm sized crystals of calcite, produced by recrystallization of micrite (up to 30μm in size).
Pseudospar:	neomorphic calcite fabric consisting of relatively large calcite crystals (average size greater than 30μm).

sand, rather than winnowing of silt-grade intraclasts from a poorly sorted deposit, is extremely small. Angular grains, regardless of their size, are much more likely to be intraclasts. In this account the term pelletoid is used to describe all micrite clasts less than 0.2mm in diameter of uncertain origin.

The main weaknesses of the Folk classification are the lack of emphasis on silt-sized particles (he believed them to be almost entirely diagenetic), and the grouping of accretionary aggregates such as grapestone (Illing, 1954) with erosional intraclasts. However, providing that the limitations are recognised, the modified classification proposed here (after Folk, 1962; Dunham,1962) provides a practical way of classifying the carbonate rocks encountered in this study.

1.2.1.3. Terminology for Carbonate Cements

Folk (1965) constructed a simple classification to standardize and produce a more satisfactory description of carbonate cements. The classification is based on four parameters which can be observed for authigenic calcite in thin section. These parameters are, the mode of formation of the calcite, its shape, its crystal size and it foundation (Fig.1.8.).

Mode of Formation: four possibilities; - passive precipitation, displacive precipitation, neomorphism and replacement which is confined to non-carbonate minerals. Displacive precipitation has not been reported by any other worker and is probably nonexistant.

Crystal Shapes: subdivided into three by axial ratio (Fig.1.8.).

Crystal Size: divided into seven classes (Figs. 1.8., 1.9.)

Foundation: describes the relationship of the authigenic calcite to the nucleant surface. There are three foundations, overgrowths in which the authigenic calcite is in optical continuity with the nucleus, crusts in which the calcite is physically orientated by the nucleant surface and spherulitic growth where there is no obvious nucleus. Examples of

Fig. 1.8 Summary of the code for authigenic calcite. After Folk, 1965.

1. Mode of Formation.

P : Passive precipitation.
P : Normal pore filling,
Ps: Solution - fill

D : Displacive precipitation.

N : Neomorphism.
N : as a general term, or where exact process unknown,
N_i: Inversion from known aragonite,
N_r: Recrystallization from known calcite,
N_d: Degrading neomorphism (also N_{id} - N_{rd}),
N_s: original fabic strained significantly,
N_c: coalescive neomorphism (as opposed to porphyroid).
R : Replacement.

II. Shape.

E : equant, axial ratio 1½:1
B : Bladed, axial ratio 1½:1 - 6:1
F : Fibrous, axial ratio 6:1

III. Crystal Size.

Class 1,2,3,4,5,6,7,

IV. Foundation.

O : Overgrowth, in optical continuity with the nucleus.
O: Ordinary,
O_m: Monocrystal overgrowth,
O_w: Overgrowth widens our from nucleus.
C : Crust, physically orientated by nucleant surface.
C: Ordinary
C_w: Widens outwards from nucleus.
S : Spherulitic with no obvious nucleus (fibrous or bladed calcite only).

No symbol : randomly orientated, no obvious control by foundation.

Size, mm	Name	Symbol
4.00mm	Extremely coarsely crystalline ECxn	7
1.00mm	Very coarsely crystalline VCxn	6
0.25mm	Coarsely crystalline Cxn	5
0.062mm	Medium crystalline Mxn	4
0.016mm	Finely crystalline Fxn	3
0.004mm	Very finely crystalline VFxn	2
0.001mm	Aphanocrystalline Axn	1
If the crystal size is transitional or widely varying, one can use such symbols as P.E_{34} etc.		

FIGURE 1.9 Table of crystal sizes. After Folk, 1965.

Formative Mechanism	Foundation	Grain Shape	Term	Symbol
Directly Precipitated (P)	Syntaxial Overgrowth (O)	Equant: on mono-crystalline nucleus	x-Monocrystalline[1] Overgrowth	P.E.*O_m
		Equant on poly-crystalline nucleus	x-Equant Overgrowth	P.E.*O
		Bladed -on poly-crystalline nucleus	x-Bladed Overgrowth	P.B.* O
		Fibrous, on poly-crustalline nucleus	x-Fibrous Overgrowth	P.F.* O
	Crust -(C) orientated physically on surface	Equant	x-Equant Crust	P.E.*C_w
		Bladed	x-Bladed Crust	P.B.*C_w
		Fibrous	x-Fibrous Crust	P.F.*C_w
	Randomly-orientated	Equant	x-Mosaic	P.E.*
		Bladed	Very rare or non-existent."Bladed Mosaic" may perhaps exist;"Fibrous Mosaic" probably non-existent.	
		Fibrous		

* Add number for crystal size, e.g.P.$E._4O_m$, P.F_2C.

x Add crystal size term. e.g. Finely Bladed evergrowth (or finely crystalline Bladed overgrowth); Medium Fibrous crust (Medium crystalline Fibrous crust).

[1] monocrystals may be Bladed or rarely Fibrous; use "Bladed Monocrystalline overgrowth" if desired, P.BO_m, etc.

FIGURE 1.10 A code for directly precipitated calcite. After Folk, 1965.

Formative Mechanism		Foundation	Grain Shape	Term	Symbol
Neomorphism (N) includes Recrystallization (N_r) and/ or Inversion (N_i)	Probably always Aggrading	Syntaxial Overgrowth-optically orientated by nucleus (O).	Equant, on monocrystalline nucleus	Neomorphic x-Monocrystalline Overgrowth	N.E.*O_m
			Equant, on polycrystalline nucleus	Neomorphic x-Equant Overgrowth	N.E.*O
			Bladed, on polycrystalline nucleus	Neomorphic x-Bladed Overgrowth	N.B.*O
			Fibrous, on polycrystalline nucleus	Neomorphic x-Fibrous Overgrowth	N.F.*O
		Crust-Orientated physically but not optically by the nucleus (C)	Equant	Neomorphic x-Equant Crust	N.E.* C
			Bladed	Neomorphic x-Bladed Crust	N.B.*C
			Fibrous	Neomorphic x-Fibrous Crust	N.F.*C
		No obvious nucleus	Equant	4-31 μm x-microspar	$N.E._{2-3}$
				> 31 μm x-pseudo-spar	$N.E._{3-7}$
			Bladed	4-31 μm x-bladed microspar	$N.B._{2-3}$
				> 31 μm x-bladed pseudospar	$N.B._{3-7}$
			Fibrous, random orientation	Neomorphic x-Fibrous Random Calcite	N.F.*
				Neomorphic x-Fibrous Sperulitic calcite	N.F.*S
	Degrading	Usually in a skeleton	Equant	Degrading Neomorphic x-Calcite	N_dE.*
			Bladed	Degrading Neomorphic x-Bladed Calcite	N_dB*
			Fibrous	Degrading Neomorphic x-Fibrous Calcite	N_dF*

* Add number for crystal size, e.g. $N.F_5C$, $N.E_2O$.

x Add crystal size term, e.g. Neomorphic coarsely (crystalline) Bladed Overgrowth

FIGURE 1.11 A code for neomorphic calcite. After Folk, 1965.

the different varieties of authigenic calcite observed, together with the symbols used, are given in Figures 1.10 and 1.11.

This classification is descriptive, explanatory and easily understood. It is used in this form in the thesis. However, it contains one major weakness. Folk (1965) believed that the bulk of all microspar was the result of diagenetic alteration and that it was virtually never a primary deposit.

1.2.2. Non-Carbonate Fragmental or Clastic Deposits

Clastic rocks can be divided into three groups based on their grain size, a division recognisable in the field. Sediments of grain size coarser than 4mm consist of rock fragments (lithoclasts), each in turn being built up of numerous mineral grains. Medium texture sediments, between 60μm and 4mm, are commonly composed of monomineralic particles. The finest grained clastic rocks, the clays and muds, consist predominantly of minute platy crystals formed as the insoluble decomposition product of chemically weathered rocks.

A division into these three types forms a natural basis of classification of clastic rocks since it emphasises important differences in petrological, chemical and physical properties of these materials. The three groups are described in grain-size textural terms as rudites, arenites and lutites (Grabau, 1904; 1913). These terms do not have a genetic implication. The classification, nomenclature, grain size, shape and composition, transport mechanism and bed forms of clastic rocks are shown in Figure 1.12.

Rudites are classified in terms of the size of the dominant lithoclast, for which such terms as boulder, cobble and pebble are used. As the spaces between the lithoclasts are usually filled with finer sediment, then the particle size distribution within the rock is often bimodal or polymodal.

Arenites can be defined as siliceous sediments composed mainly of quartz clasts in the size range 60μm-4mm. Most attempts to devise a

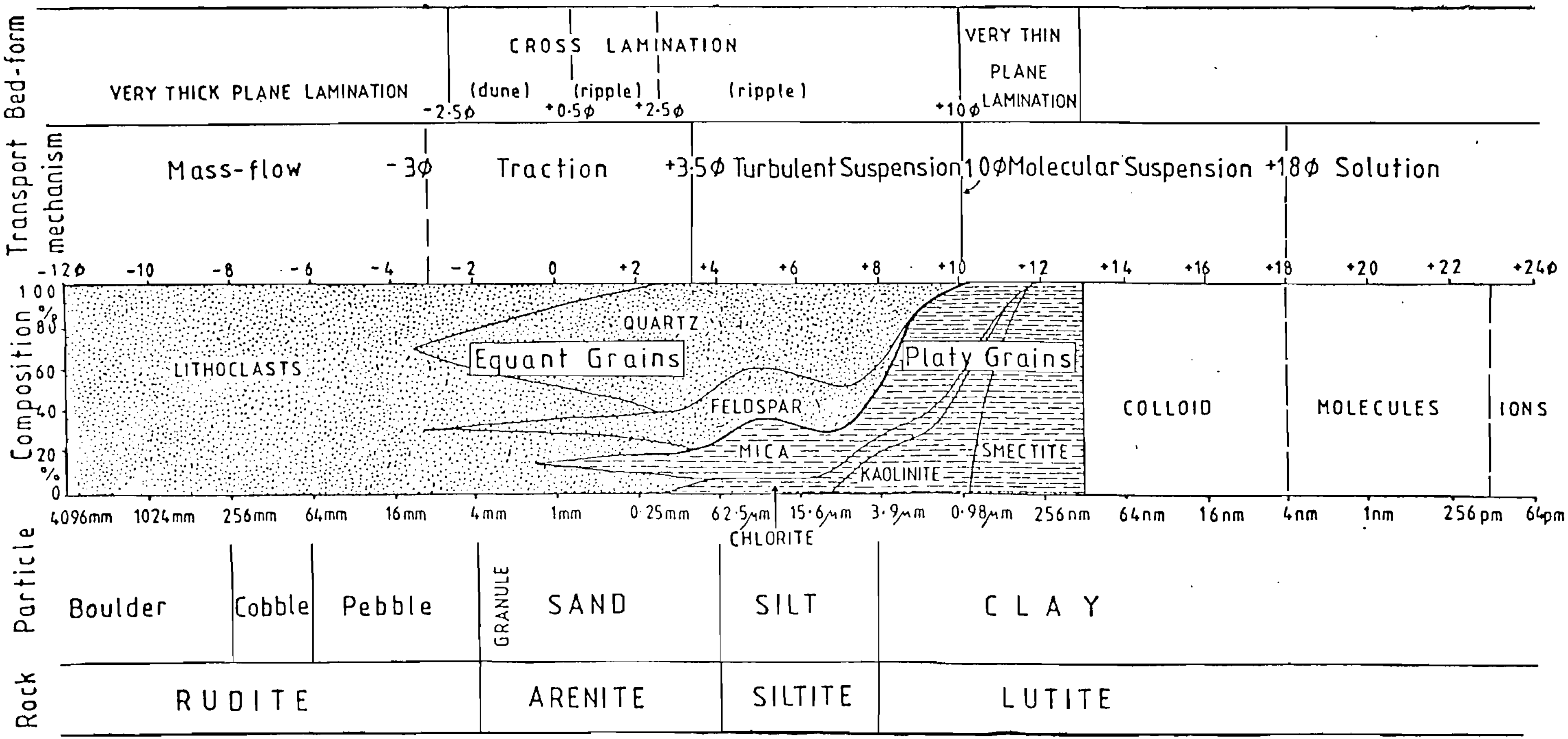
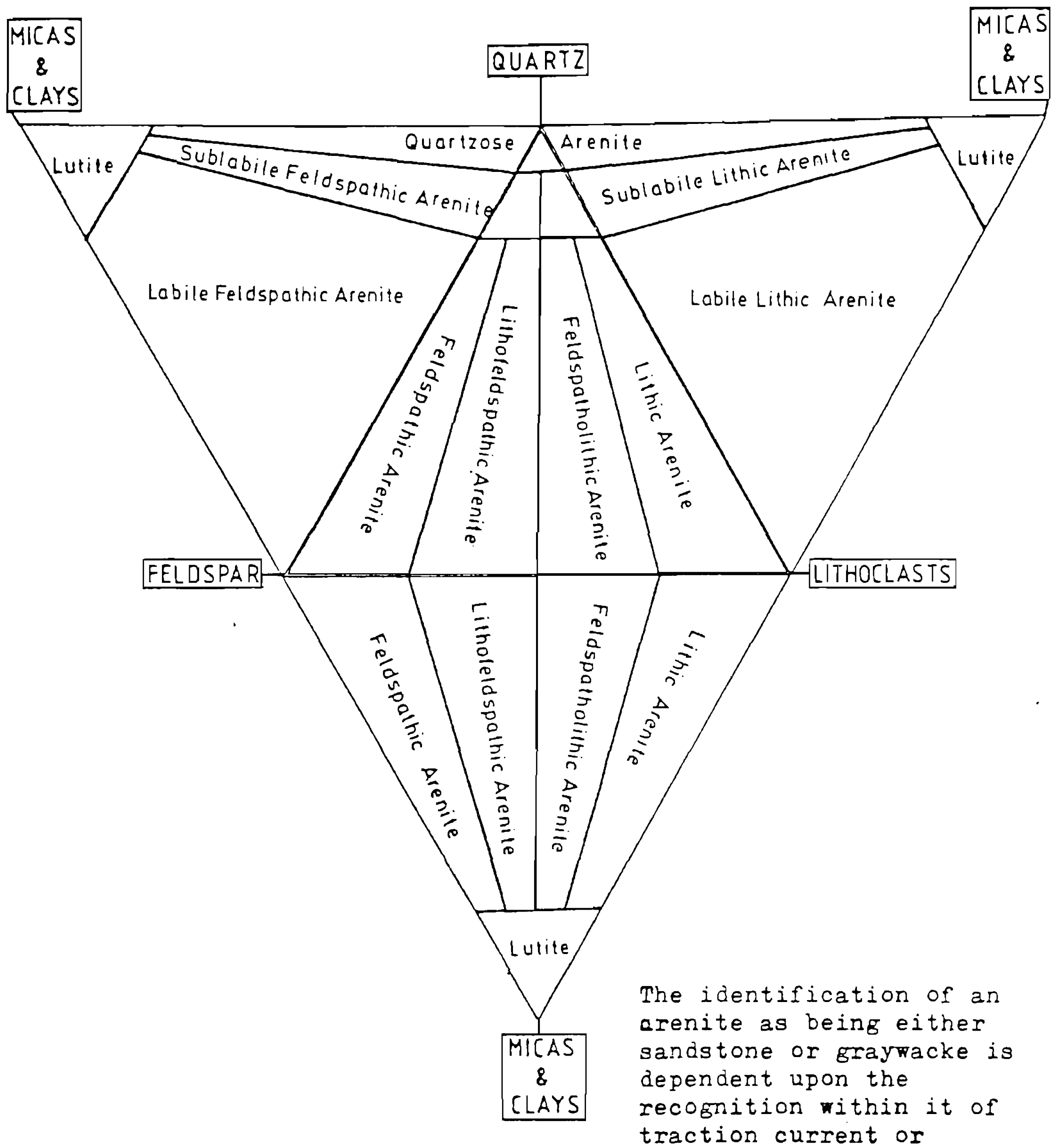


FIGURE 1.12 Diagram comparing rock-names, particle-names, particle size and composition, transport mechanisms, and bedforms of clastic rocks.



The identification of an arenite as being either sandstone or graywacke is dependent upon the recognition within it of traction current or turbidity current structures respectively.

FIGURE 1.13 A classification of arenites. After Crook, 1960.

comprehensive and systematic classification of arenites, based on the mineral composition of the "light" mineral fraction, have not been very successful. In most cases the procedure has been to select three mineral species or grains as poles of an equilateral triangle, which has been internally subdivided on an arbitary basis. A large number of arenite classifications have been published since the original end-member triangle devised by Krynine in 1948 (classifications reviewed in Klein, 1963; and Okada, 1971). The classification used in this thesis is that proposed by Crook (1960) which is both practical and applicable (Fig.1.13.). Most arenites plot within the inner triangle: a split binary system which compares the quantities of destructible and indestructible components comprising each arenite.

Lutites can be divided into two types; those which consist predominantly of clay minerals (particle size less than 4μm) and those which contain a large proportion of silt-size particles (4μm-60μm). These siltites are composed of tiny fragments of quartz, feldspar and mica (Fig.1.12.). It is just possible to identify silt-sized components by optical means; for identification of finer grained components X.R.D. analysis must be used.

1.2.3. Terminology For Coal Petrography

Petrographic terminology for the description of coals is very complex. The 1935 "Stopes-Heerleen" nomenclature (Jongmans & others, 1938) is used in this thesis. It recognises that coals are granular, the grains being called macerals by analogy with minerals in inorganic rocks. Coals are composed

of three groups of macerals, vitrinite (woody tissue and lignoproteins), liptinite or exinite (cuticles, spores and resins), and inertinite (sclerotin and burnt woody material). Microlithotypes (Seyler, 1954) are maceral associations analogous to laminae. Their names are determined by the macerals present (Fig.1.14.).

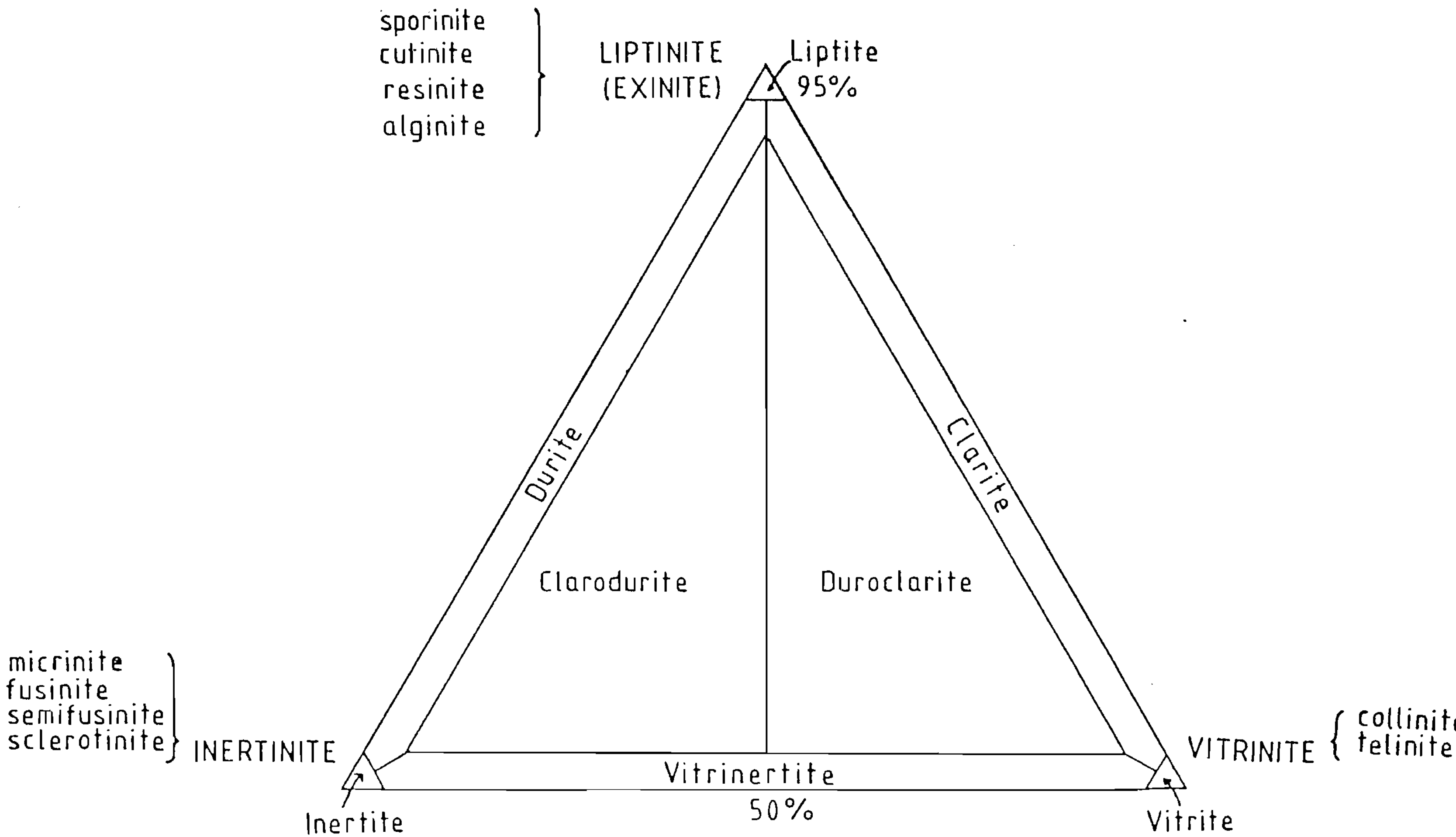


FIGURE 1.14 Classification of coals. Microlithotype terminology is determined by the percentage of each maceral (capital letters) present.

Macroscopic rock-names, analogous to beds, are determined by the quantities of macerals present. Rocks containing greater than 95% vitrinite are termed vitrains, those dominated by liptinite and inertinite durains, those of liptinite and vitrinite clarains, and those composed mostly of inertinite fusains. Coal petrographers rarely use rock-names but prefer to describe coals in terms of the percentage of each maceral present. There is little interest in developing sedimentological methods of description because of the economic bias in coal petrography.

1.2.4. Practical Techniques

1.2.4.1. Thin Section

Manufacture

The large-area thin sections used in this study were made using standard techniques. Rock slices were all cut perpendicular to bedding and mounted on 75mm x 50mm glass slides and ground down to a thickness of about 30μm. Next they were stained in an acid solution of Alizarin red-S and potassium ferricyanide; the resulting stain permits the differentiation of the various carbonate minerals (see discussion below). After thorough drying they were sprayed with a quick-drying liquid, *in lieu* of a glass coverslip. The liquid has similar optical properties to glass, does not affect the stain, and is unaffected by water and immersion oil. This eliminates the risk of shattering the thin section and detaching the stain involved in remounting the thin slices in Canada Balsam under a glass coverslip. It also saves a considerable amount of time.

Staining: the technique

This is a very simple process. Each thin section is stained in an acid solution of Alizarin red-S and potassium ferricyanide following the method outlined by Dickson (1965;1966). This method differentiates dolomite from calcite and also permits the detection of variations of ferrous iron within those minerals. The staining procedure is given in Figure.15. The slides were dried quickly (since the stain is relatively soluble in water) and handled carefully as the stain is only a surface precipitate and is dislodged easily.

Discussion

The staining technique permits the distinction of ferrous and non-ferrous dolomite and calcite. It was once thought that dolomite alone contained ferrous iron but Evamy (1963) showed this to be incorrect. Any carbonate mineral can contain small quantities of ferrous iron and will stain providing the carbonate can be made to react with acid.

Originally the intensity of the stain was thought to reflect the amount of ferrous iron present. This is not entirely true. The intensity depends on the rate of liberation of ferrous iron from the carbonate solution. Thus ferroan calcite and ferroan dolomite which stain at the same intensity indicate the presence of much more ferrous iron in the dolomite because it dissolves much more slowly in the staining solution. In all carbonate minerals reaction rates increase with increasing iron content (Dickson, 1965).

Alizarin red-S is most selective as a stain in a concentration of hydrochloric acid between one and two weight percent. At an acid concentration greater than 1.5% rapid etching of the thin section occurs and the thickness is greatly reduced. Large gas bubbles may be generated and adhere to the surface. Both factors reduce the efficiency of the staining. At acid concentrations below 1% the stain becomes so thick that it obscures fine details and may also develop desiccation cracks on drying.

It is important to note that at an acid concentration of 1.5% calcite is more deeply stained parallel to the c-axis than in any other orientation.

STAGE	PROCEDURE	TIME	CARBONATE	RESULTS
I	Etch with 1.5% HCl	10 secs	Calcite Ferroan calcite Dolomite Ferroan dolomite	Considerable etching Considerable etching Negligible etching Some etching
2	STAINING 0.2g Alizarin red S per 100ml of 1.5% HCl plus 2g potassium ferricyanide per 100ml of 1.5% HCl mixed in the ratio 3:2	45 secs	Calcite Ferroan calcite Dolomite Ferroan dolomite	Very pale pink-red (depends on optical orientation). Very pale pink-red, plus pale blue-dark blue (Turnball's Blue), the two colours superimposed give mauve-blue. No stain. Pale-deep turquoise, depending on the ferrous iron content,
3	STAINING 0.2g Alizarin red S per 100ml of 1.5% HCl	10 secs	Calcite Ferroan calcite Dolomite Ferroan dolomite	Very pale pink-red Very pale pink-red No colour No colour
RESULTING STAINS:	Calcite		Very pale pink-red (depending upon optical orientation).	
	Ferroan calcite		Mauve, purple or royal blue.	
	Dolomite		No colour.	
	Ferroan dolomite		Pale-deep turquoise, depending upon ferrous iron content.	

FIGURE 1.15 Staining procedure for the differentiation of carbonate minerals, after Dickson, 1965.

Finally, the differing solubilities of calcite and dolomite in dilute hydrochloric acid result, under normal staining techniques, in calcite originally 30μm thick being etched to approximately 15μm thick whilst dolomite remains at 30μm. This is a feature clearly observed under the microscope.

1.2.4.2 Acetate Replicas

Manufacture of carbonate replicas

The process is simple and quick. The flat surface of a rock is polished with carborundum grits and powder, cleaned, etched with 1.5% hydrochloric acid for one minute, then washed and dried. The prepared surface is then coated with acetone, a piece of acetate sheet is smoothed carefully onto the surface and the specimen is left to dry. Next the peel is removed carefully and washed in 5% hydrochloric acid to remove any adhering carbonate grains. Finally the peel is washed in distilled water, dried and mounted.

Stained carbonate replicas

The rock is polished and etched as before then stained for two minutes in an acid solution of Alizarin red-S and potassium ferricyanide (0.2g Alizarin red-S per 100ml of 0.5% hydrochloric acid and 2g potassium ferricyanide per 100ml of 0.5% hydrochloric acid mixed in the ratio 3:2). Such a low acid concentration, considerably less than that used when staining thin sections, produces very intense stain. Next the surface is washed carefully to remove any excess precipitate, dried, coated with acetone and acetate peels are made as described above.

CHAPTER TWO

THE GREAT SCAR GROUP

2.1. Introduction

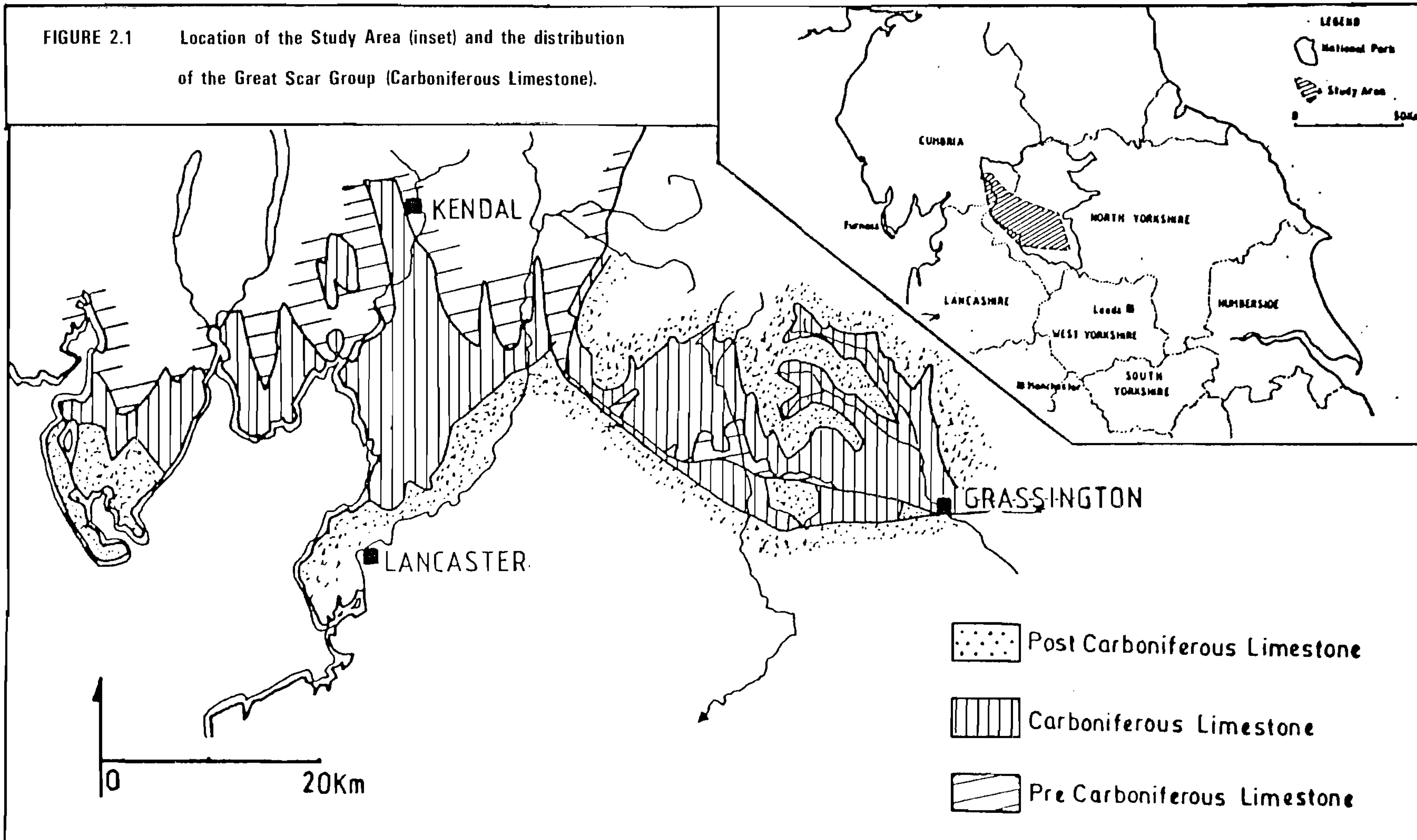
The Great Scar Group has been mapped and described over an extensive area (Phillips, 1836; Dakyns & others, 1890; Marr, 1881 and 1887; Garwood & Goodyear, 1924; Wager, 1931; etc). Biostratigraphical and structural studies have dominated. Regional variations within the Group and its constituent formations have not been recognised nor investigated with the exception of Garwood & Goodyear (1924) and Schwarzacher (1958). The formations of this investigation, the Thornton Force Formation, Douk Gill Formation, Raven Ray Formation and Horton Limestone, comprise the lower 100m of the Great Scar Group. They are overlain by the 100m-thick Kingsdale Limestone which completes the Group. These formations consist of well-defined lithological units, persistent over large areas. Limestone of varying grain size is the dominant rock in all these formations. Clastic lenses occur sporadically at the base of the Group. They are closely associated with topographic irregularities in the unconformity, filling hollows and lensing out from ridges. They show considerable lithological variation.

2.2. Location of the Study Area

Exposure of the Great Scar Group is confined to the southwestern part of the Askrigg Block (Fig. 2.2a). All but a few localities visited are in the Yorkshire Dales National Park, in the counties of North Yorkshire and Cumbria (Fig.2.1.).

The western and southern boundaries of the study area concide with the north-trending Dent Fault and the east-trending Craven Faults which bound the Askrigg Block. The base of the Group is defined clearly by the profound unconformity which separates it from the underlying folded and faulted Lower Palaeozoic rocks which crop out as a series of inliers

FIGURE 2.1 Location of the Study Area (inset) and the distribution of the Great Scar Group (Carboniferous Limestone).



along the north side of the Craven Faults. The top of the studied sequence is marked by the outcrop of the overlying Asbian Kingsdale Limestone, the top formation of the Great Scar Group, which limits the study area to the north and east.

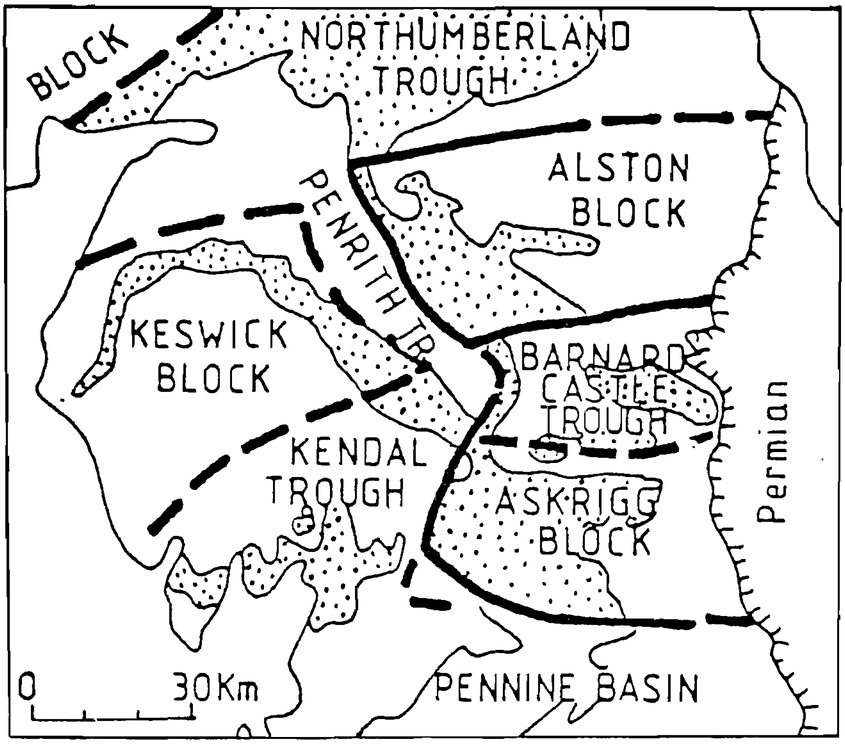
2.3 Structure of the Askrigg Block

The Askrigg Block was named by Hudson (1938) as an analogue to the area to the north which had been named the Alston Block by Trotter & Hollingworth (1928).

The western and southern edges of the Block are the Dent Fault and Mid Craven Fault respectively (Fig.2.2 b). The Dent Fault separates the Block from the Kendal Trough (Moore, ms) and the Mid Craven Fault separates the Block from the Pennine Basin. The northern edge of the Block is the Stockdale Fault, with the Barnard Castle Trough (Moore, ms) to its north. The eastern edge is obscured by Permian and Mesozoic rocks. The "Darlington Fault" (Fowler, 1944) has been shown not to exist by recent re-surveying and revisions by the Institute of Geological Sciences (Richmond Sheet 41,1970).

Geophysical investigations have revealed much about the basement structure. Initial research by Whetton & others (1956) on the negative gravity anomaly recorded beneath the Askrigg Block indicated that there was an acid core of igneous and metamorphic rocks. The anomaly was studied in more detail by Bott (1961,1967) and Myers & Wardell (1967). Finally, convincing geophysical evidence was provided favouring a granite which Bott (1961) had named the Wensleydale Granite. In 1973 the Institute of Geological Sciences borehole at Raydale confirmed Bott's hypothesis; it penetrated granite at a depth of 500m beneath surface (Dunham, 1974).

The Lower Palaeozoic rocks are unconformably overlain by the Great Scar Group and rhythmic sediments of the Yoredale and Millstone Grit Groups which dip gently at one to two degrees to the northeast. Faults, mostly of small displacement, are frequent within the Craven Fault Belt

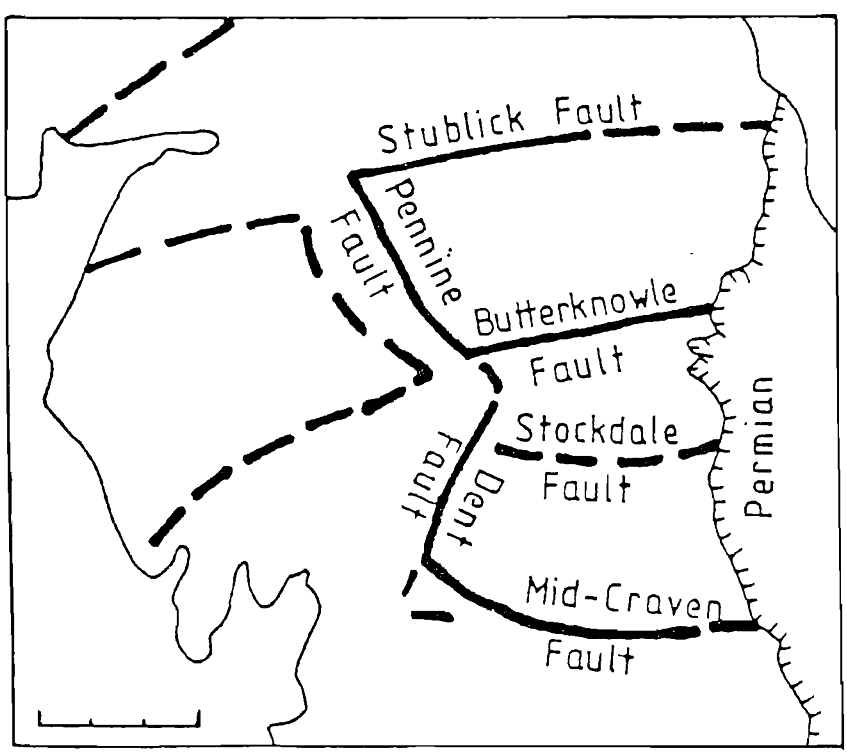


2.2a

FIGURES 2.2a,2.2b

Maps of northern England showing the main structural elements (after D. Moore, unpublished).
Figure 2.2a shows the outcrop of Dinantian rocks (stippled).

2.2b



and extend for about five kilometres north of it (Fig.2.3), linking to the Dent Fault in the west. Some of these faults are mineralised, particularly around Grassington. To the north and east faults are sparser and mostly aligned north-south.

2.4. Physiographic Evolution of the Study Area

Warping of the peneplained surface of the Askrigg Block, probably in Miocene times (De Boer, 1974), initiated the modern drainage pattern. River and glacier erosion was controlled strongly by the sub-horizontal structure of the rocks and their contrasting lithologies, and was dependent upon the original and later warping of the peneplain.

The western section of the Askrigg Block forms a plateau at 550m, rising to 620m where it crosses the Dent Fault. It is a dissected peneplain with isolated monadnocks indicating that it was formed from a higher surface. Peneplanation was initiated by mild erosional attack on the summit surface. Later movements led to the dissection of the peneplain into the existing major groups of fells and ridges, and then caused rejuvenation during which the river profiles were steepened. In the southern part of the Askrigg Block the dale floors are cut into by narrow gorges at their lower ends, the result of further rejuvenation. Nick-points occur in all major streams where they cross the North Craven Fault (Sweeting, 1950).

In a broad sense the drainage pattern of the Askrigg Block is radial; there is no case of down-dip drainage. The controlling factors are the joints and possibly the buried ridges of pre-Carboniferous impervious rock (De Boer, 1974). Some adjustment of drainage to structure is indicated in the lower part of stream courses.

"U-shaped" valleys, eg. Kingsdale, developed during the glacial period. Evidence from within the cave systems suggests that the pre-glacial fluvial valleys were no more than half their present depth (Waltham, 1974). Modification of the valley profile by post-glacial streams is minor and the blocking of older pre-glacial courses by till

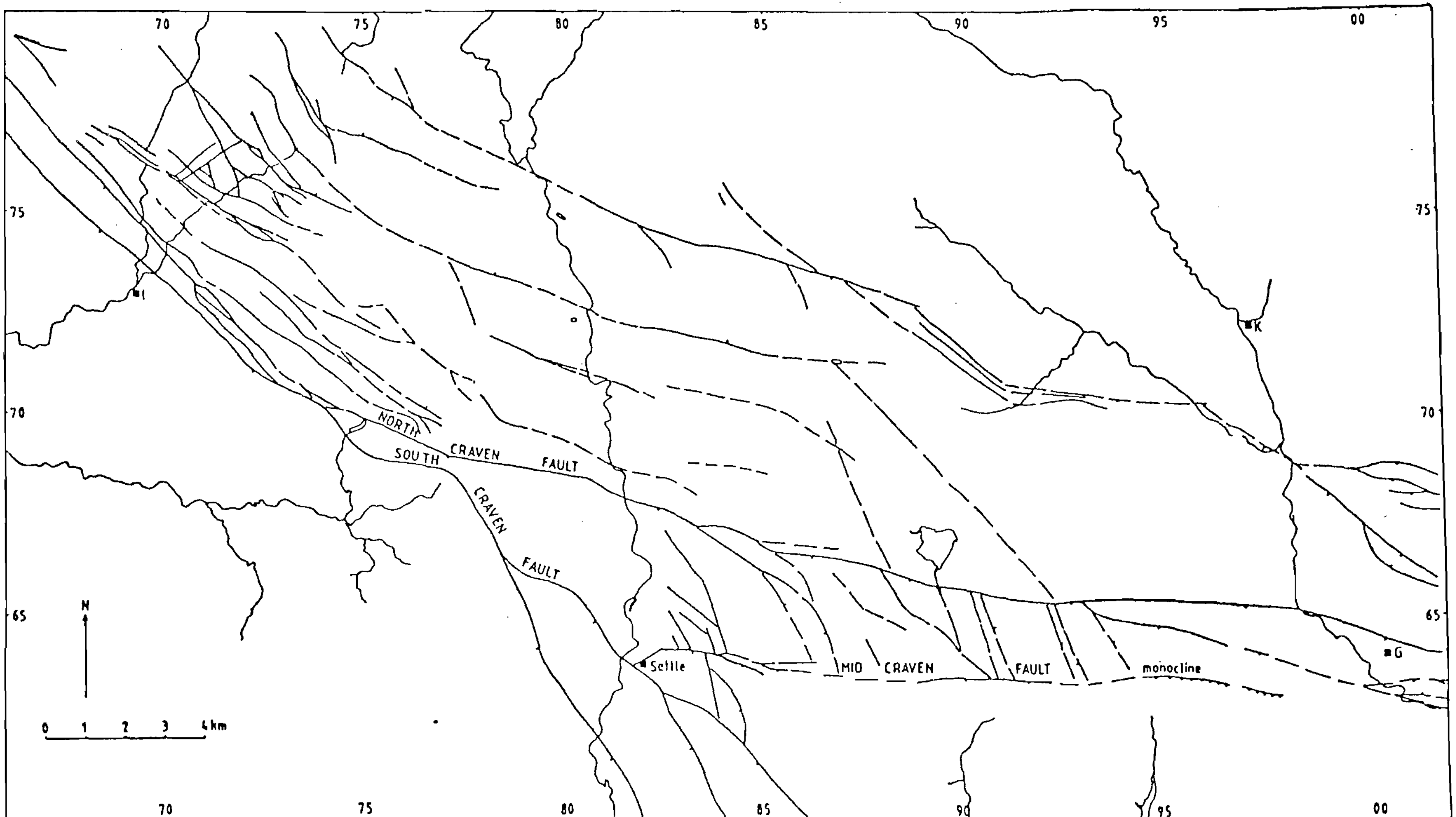


FIGURE 2.3 Map to show the fault-pattern along the southwestern margin of the Askrigg Block.

ridges and drumlins has given rise to stream diversions. Caves are developed at many levels in the Great Scar Group, there are numerous examples of perched water tables (Waltham, 1974). There are two cave systems; phreatic caves which are out of phase with the present relief, and vadose caves which formed in an environment above the local resurgence level. Most caves are of the latter type and extend down to the valley floor. Some caves are very old having formed during interglacial periods; the Kingsdale Master Cave probably is about 400,000 years BP and the vadose mainstream passage of White Scar Cave at the unconformity gives a date of 225,000 years BP (Atkinson & others, 1978).

2.5 Review of Previous Research

Only a brief summary of previous research is here included as a number of earlier reviews exist (Hudson, 1933; Rayner, 1953; Ramsbottom, 1974).

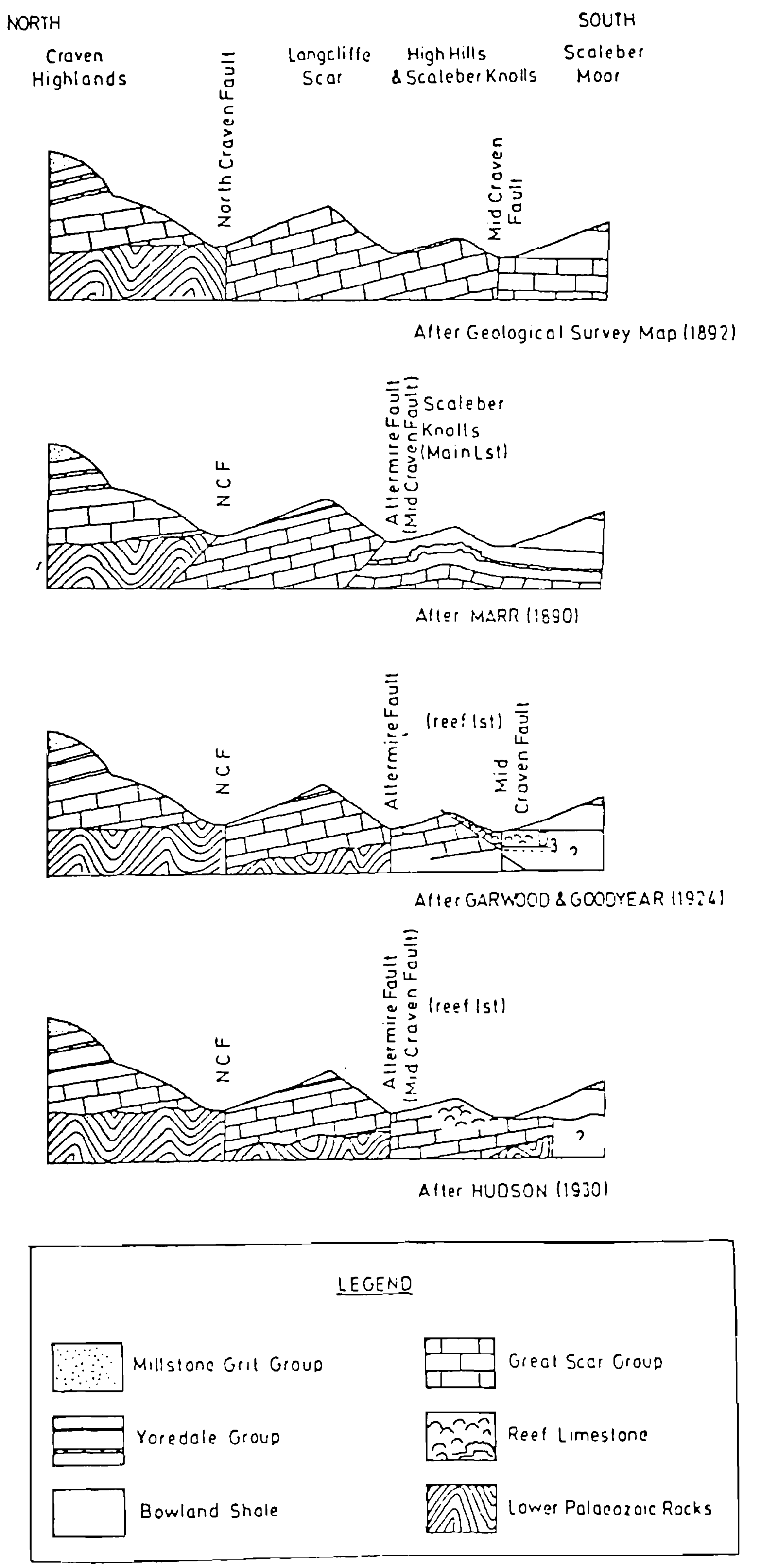
The name "Great Scar Limestone" was first introduced by Phillips (1829,p18) but replaced in his more famous work (1836) by "Mountain Limestone". Sedgwick (1835) called this sequence the "Carboniferous Limestone" and Marr (1881,1887) who first specified its restriction to the area known as the Askrigg Block, called it the "Scar Limestone". Garwood & Goodyear (1924) resurrected the name "Great Scar Limestone", and were the first to describe a sequence of distinctive limestone types within it. Schwarzacher (1958) identified a cyclic sequence at the top of the Great Scar Limestone, attaining a thickness of 100m, and subsequently Ramsbottom (1974) named this cyclic unit the Kingsdale Limestone, and the underlying part of the Great Scar Limestone as the Horton Formation. He retained Garwood & Goodyear's (1924) informal names for the very base of the sequence. Having been divided into formations, the original unit has now achieved Group status and is here defined as the Great Scar Group.

The Great Scar Group comprises mostly limestone; thin clastic beds occur sporadically at the base, where it rests with profound unconformity on folded Ordovician and Silurian rocks. It has been mapped and described over much of its outcrop area, yet, with the exception of Garwood & Goodyear (1924) regional variations of the individual units have remained unobserved and need investigation.

The earliest works determined the generalised lithological succession. The most important were those of Sedgwick (1835) and particularly Phillips (1836) who gave detailed successions of the Mountain Limestone, Yoredale Series and Millstone Grit. He recognised the distinction between the northern "Mountain Limestone District" (the Askrigg Block in modern terminology) and the area to the south (now called the Pennine Basin) where he described the Bowland Shales.

So thorough was the work of Phillips that no further advance was made until the detailed mapping of the area by the Geological Survey between 1870 and 1890. The main results of this survey did not involve the Great Scar Limestone, except in the records of exposure of clastic lenses overlying the unconformity, and the recognition of macro-relief (ridges) in Chapel-le-Dale and Crummack Dale. In a separate publication, one of the Survey geologists, Tiddeman (1889), proposed that the boundary between the Great Scar Limestone facies and the southern facies coincided with the North and Mid Craven Faults, and that movement had taken place along them during deposition of Lower Carboniferous sediments. A corollary to his thesis was the identification as reef limestones of the low ovoid hills occurring in a belt between the two areas. Their shape was attributed to an original depositional form. Tiddeman proposed that the Mid Craven Fault was a normal fault downthrowing south and positioned south of High Hills (Fig.2.4). This was contested by Marr (1899), an academic geologist, who regarded the Mid Craven Fault as an overthrust to the south positioned at the foot of Langcliffe Scar. Subsequently Garwood & Goodyear (1924) accepted the existence of two faults (Fig.2.4), the Attermire Fault in Marr's position and the Mid Craven Fault in Tiddeman's position, both being normal faults downthrowing south. The current interpretation was initiated by Hudson (1930) who recognised only one fault in the position of the Attermire Fault which he called the Mid Craven Fault.

FIGURE 2·4 **The various interpretations as to the age of the Scaleber Knoll limestones and the position of the Mid Craven Fault.**



At the beginning of the twentieth century determined attempts were made to produce a biostratigraphic subdivision of the Carboniferous System. Success was achieved for the Lower Carboniferous with the publication of the coral-brachiopod zones of Vaughan (1906) in the Bristol Gorge, and Garwood (1913) in northwest England west of the Dent Fault and close to the Askrigg Block (Fig.2.5). Poor definition of Garwood's subdivisions, through omitting to specify type-localities and mixing faunal boundaries with lithological boundaries, rendered his scheme less useful than Vaughan's.

Wilmore (1910) and Vaughan (1916) were able, subsequently, to recognise an almost complete Lower Carboniferous succession (Z-D in terms of the Bristol Gorge) in the Craven Lowlands, whereas Johns (1906,1908) and Garwood (1907) identified the "basement beds" in the Ingleborough area of the Askrigg Block as being of C_2-S age in Bristol Gorge terms. They jointly provided an explanation for the differences in thickness of the Lower Carboniferous sequences in the Craven Lowlands and the Askrigg Block. The Craven Lowlands were part of a basin in which sedimentation had taken place since early in Carboniferous times, whereas the Askrigg Block only began to accumulate sediment in Mid Avonian times.

Garwood & Goodyear (1924) published a detailed account of the stratigraphy and structure of the Great Scar Limestone and some of the overlying sediments, extending the zonal scheme of Westmorland (Fig.2.5) to the Settle area. They supported the hypothesis of Marr (1921), that the district north of the Craven Faults had acted as a rigid block (now called the Askrigg Block) and that it was free from all important disturbances. They were able to recognise a four-fold division of the Great Scar Limestone over a large area (Fig.2.5), each division being an extensive lithological unit containing a specific, diagnostic fauna. The four lithological units are described in ascending stratigraphical order as the *Michelinia grandis* Beds (Thornton Force Formation), Gastropod Beds (Raven Ray Formation), *Nematophyllum minus* Beds (Horton Limestone) and Lower *Dibunophyllum* Beds (Kingsdale Limestone). Garwood & Goodyear (1924) traced these units across the outcrop from Ingleton to

Beds with Lithostrotion = VISÉAN	Dibunophyllum Zone (D)	- Upper Subzone (D_2) - Lower Subzone (D_1)
	Productus corrugato-hemisphericus Zone (S)	- Upper Subzone, Nematophyllum minus (S_2) - Middle Subzone, Cyrtina carbonaria (S_2) - Lower Subzone, Gastropod Beds (S_1)
Beds without Lithostrotion = TOURNAISIAN	Michelinia grandis Zone (C)	- Upper Subzone, Chonetes carinata (C_2) - Lower Subzone, Camarophoria isorhynchia (C_1)
	Athyris glabristria Zone (Z)	- Upper Subzone (Z_2) - Lower Subzone (Z_1)

FIGURE 2·5 Dinantian zones of northern England, after Garwood (1913).

Wharfedale but had difficulties in correlation in the immediate vicinity of Horton-in-Ribblesdale. Their Cyrtina carbonaria Subzone was apparently reduced to a thin shale and limited to three outcrops lying on an east-west line through Horton-in-Ribblesdale. Everywhere else it seemed to be absent.

At the top of their Nematophyllum minus Subzone they mapped a bed of white calcilutite (the Porcellanous Bed) which they correlated with the Bryozoa Band of Westmorland previously interpreted (Garwood, 1913) as the S-D zone boundary. This was convenient because east of the Fault the S and D zones are otherwise difficult to distinguish in poorly fossiliferous limestones. Their mapping resulted in the identification of numerous faults, particularly between the North and Mid Craven Faults, though they misinterpreted the position of the latter.

Detailed mapping of Garwood & Goodyear's faunal zones enabled Wager (1931) to delineate the structure of the Great Scar Limestone in greater detail, and to interpret the character of faulting and jointing. During the same period Miller & Turner (1931) and Hudson (1933) were using biostratigraphic zones to correlate and interpret deposits found along the western and southern margins of the Askrigg Block, east of the Dent Fault and between the Craven Faults. Hudson (1931) defined the Attermire Fault as the continuation of the Mid Craven Fault, thus agreeing with the much earlier work of Marr (1899).

Anderson (1928) published a detailed account of the Carboniferous strata of the Skyreholme Anticline which lies south of the North Craven Fault. Using Garwood & Goodyear's faunal zones he correlated the exposed faunal bands with the Great Scar Limestone north of the North Craven Fault. He demonstrated that the exposed strata of the Skyreholme Anticline are closely related to the northern Great Scar Limestone facies although reefs are fully developed only three miles to the west and the area is structurally part of the Pennine Basin. He observed permanent springs at the base of the S zone limestones and suggested that they owed their existence to a ridge of basement rock. Finally, Anderson proposed that the North Craven Fault is post-Carboniferous in age since the Great Scar Limestone facies crops out on either side.

East of Skyreholme, the Greenhow Anticline was neglected and virtually unknown until Dunham & Stubblefield (1945) published a detailed description. Then in 1953, Dunham & others published their account of the stratigraphy and structure of the Ingleborough area. Although very descriptive, their report provided very little new material except for the correlation of the Lower Palaeozoic rocks. Their conclusions relating to the outcrop and lithology of the Carboniferous rocks closely paralleled those of Garwood & Goodyear (1924).

Geological interests diversified during the next decade. The hypothesis of the Askrigg Block acting as a rigid block was proposed once more (Dunham,1959), and Johnson (1967) postulated basement control of sedimentation. At the same time other workers (George, 1958; Turner, 1959) were beginning to interpret sediments in terms of their depositional environments and were producing palaeogeographic models for the Dinantian Subsystem.

Schwarzacher (1958) first proposed "cyclic" stratification of the Great Scar Limestone in the Settle area. He believed that the limestones between the calcilutite (Porcellanous Bed) and the base of the Yoredale Group could be divided into nine cycles, and that the major bedding planes separating the cycles could be traced over the entire outcrop area of the Great Scar Limestone. He proposed that master bedding planes were produced by periodic decrease in lime production and increased current activity resulting from climactic fluctuations. Schwarzacher appeared not to favour the producing of master bedding planes as a result of tectonic or eustatic activity.

In the mid - 1960's, but not published until much later, Jefferson (1980) tried to apply the hypothesis of cyclic sedimentation to the Holkerian (S_2) limestones north of Settle, between the North and Mid Craven Faults. He could discover no evidence of cyclicity in outcrop but was able to demonstrate a pattern of bioclast concentrations after detailed petrographic study. It proved impossible to use the bioclast concentrations observed in thin section as a means of correlation if neither the distinctive top nor base of the Horton Limestone was exposed.

Waltham (1971) published a detailed sedimentological study of the D_1 (Asbian) limestones of the Great Scar Group as exposed in the numerous potholes in the area, and discussed the nature of the shale units therein. Apparently shale beds do not occur at constant positions within each of the nine minor cycles of the limestones (Schwarzacher, 1958). Waltham had two important conclusions. Firstly, the shales developed during periods of emergence and their great lateral extent suggests that this palaeoenvironment was not a local feature. He did not indicate whether it was tectonic or eustatic adjustments which controlled their formation. Secondly, he showed that Schwarzacher's (1958) cycles were too simplistic. The pothole outcrops revealed a much greater lithological complexity than was visible at surface. The authors of the Dalesman compendium Northern Caves (5 volumes, Second Editions

I Wharfedale & Nidderdale 1979, BROOK,D,COE,R.G,DAVIES, G.M. & LONG,M.H.144pp.

II Penyghent & Malham 1982, BROOK,A. & D., DAVIES, G.M. & LONG, M.H. 128pp

III Ingleborough 1981, BROOK, A. & D., DAVIES, G.M. & LONG, M.H. 144pp.

IVA Scales Moor & Kingsdale 1983, BROOK, D., DAVIES, G.M. & LONG, M.H. 82pp.

IVB Leck & Casterton Fells 1983, BROOK, D., DAVIES, G.M., LONG, M. H. & SUTCLIFFE, J.R. 83pp.

V The Northern Dales 1977, BROOKE, D., DAVIES, G.M. LONG, M.H. & RYDER, P.F. 160pp.)

give incidental references to shale beds and cherts in the Kingsdale Limestone and one reference, Dale Head Pot (SD840718), to the Moughton

Calcilutite Member - "a distinctive white limestone about 6 inches (150mm) thick" (p.47, Vol. II). This must be close to the southern edge of the Moughton Calcilutite Member. They also give depths of all recorded potholes, most of which start at or near the top of the 100m thick Kingsdale Limestone, so revealing which potholes penetrate into the Horton Limestone, and how few penetrate the full thickness of the Great Scar Group.

Wager's (1931) investigation of joint orientations was amplified by Moseley & Ahmed (1967) and Doughty (1968). The latter observed and described the joint pattern and density over much of the outcrop of the Great Scar Limestone. He was able to demonstrate that there are three types of joints, conjugate, tension and low-angle. The most important, the conjugate joints, are regularly spaced in each bed except where joints extend across bedding planes. He discovered little variation in joint density in the S zone limestones whereas nine rhythms (Schwarzacher, 1958) could be recognised in the D_1 subzone limestones where the succession is complete. The rhythmic nature results from fluctuations in bed joint density which, in turn, are the result of the beds' grain size. The highest joint densities were recorded in coarse grained limestones, the lowest in calcite mudstones.

Doughty (1974) used this technique to map the outcrop of the nine minor cycles of the D_1 limestones, and the distribution of <u>Davidsonina septosa</u> within them, north of Settle between the Craven Faults. He proposed that it was inadequate mapping and misinterpretation by Garwood & Goodyear (1924), who had assumed only one level of <u>Davidsonina septosa</u>, which had lead them to suggest the pattern of complex faulting in the area. Finally he proposed that his new and simpler interpretation of the structure of the area conformed more closely with the original mapping of the Geological Survey (1892). This was challenged at the time (McCABE, in discussion to Doughty, 1974).

In the late 1960's and 1970's positive attempts were made to revise Dinantian correlations after the zonal schemes proved unsatisfactory. The greater understanding of depositional processes and faunal provinciality resulted in the recognition of large hiatuses in Vaughan's Bristol Gorge section. At the same times new faunas (conodonts and foraminifera) were being considered as new means of zonation and correlation.

It was to discuss these problems and to produce a viable Dinantian correlation that the Dinantian Working Group was set up in the late 1960's. Ramsbottom, a member of the Dinantian Working Group, independently published and in his 1973 paper "A Synthesis of Dinantian Stratigraphy" he partially pre-empted the Working Group. He accepted uncritically the Schwarzacher cycles and claimed to recognize them throughout the British Dinantian rocks. He further claimed that they were cycles of transgression and regression, controlled by eustatic changes in sea level and that the whole of the Dinantian Subsystem of Great Britain could be correlated by them. Ramsbottom (1974) expounded his hypothesis, discussing the Dinantian stratigraphy of Yorkshire in detail. He constructed the formation names Kingsdale Limestone and Horton Limestone, named after their type-localities. The Kingsdale Limestone equates with the D_1 limestones, and the Horton Limestone with the S_2 limestones of Garwood & Goodyear (1924). All beds below the level of Horton Quarry floor Ramsbottom ascribed to the Gastropod Beds and Michelinia grandis Beds of Garwood & Goodyear (Fig.2.6). In the most recent publication (Fewtrell, Ramsbottom & Strank, 1981) the latter names have been abandoned and the base of the Horton Limestone has been extended to the base of the Great Scar Group.

In his publications Ramsbottom (1973,1974) proposed a correlation of the Great Scar Group with his Dinantian cycles. He suggested that the Michelinia grandis Beds and the Gastropod Beds were deposited during the latter part of cycle three, the Horton Limestone (Ramsbottom, 1974) during cycle four, and the Kingsdale Limestone was deposited as a series of minor cycles comprising major cycle five. Deposition of the Yoredale Group commenced during the sixth composite cycle.

In 1976 the Dinantian Working Group of the Geological Society's Stratigraphic Committee (George & others) published their results. They

GARWOOD & GOODYEAR 1924 Zonal Names	RAMSBOTTOM 1974 Formations & Cycles	STAGES GEORGE & others 1976	RAMSBOTTOM & STRANK 1981 Formation Names	SCOTT 1982 Formation Names
Dibunophyllum (lower subzone D_1)	Kingsdale Limestone 5	ASBIAN	Kingsdale Limestone	KINGSDALE LIMESTONE
Productus (S_2) corrugato-hemisphericus Zone (S_1)	Horton Limestone 4	HOLKERIAN	Horton Limestone	HORTON LIMESTONE
	Gastropod Beds 3	ARUNDIAN		RAVEN RAY FORMATION
Michelinia grandis Zone	M.grandis Beds			DOUK GILL FORMATION/ THORNTON FORCE FORMATION

FIGURE 2·6 Correlation of zonal names (Garwood & Goodyear, 1924), stages (George & others, 1976), and the changing formation names in the study area.

proposed that the Dinantian Subsystem should be divided into six stages, each stage being equivalent to one major cycle or group of minor cycles. The Great Scar Group was deposited during Arundian, Holkerian and Asbian times (Fig.2.6.).

The subdivision of the Dinantian Subsystem into six stages has been accepted by most later authors, althought a few modifications have proved necessary (George, 1978). It is possible that the six stages are simply a series of biostratigraphical zones containing a fauna which may prove to be facies-controlled (Chlupac & others, 1981). At present the stratigraphic terminology for subdivisions of the Dinantian Subsystem are undecided; the six stages are used in this thesis.

In the late 1970's the officers of the Institute of Geological Sciences (I.G.S. Ann. Repts 1976-1979 inclusive) remapped the Settle area (Sheet 60). They have reinterpretted the succession in the southern part of the Askrigg Block, defining this as beyond the southern margin of the Porcellanous Bed. Their new succession (Mundy & Arthurton, 1980, p32-34) at Malham is:-

Wensleydale Formation	(formerly Yoredale Group)
Malham Formation	upper member 85m of scar-forming pale limestones ______marked bedding plane__________ lower member 75m of massive pale grey limestones forming the Cove.
Kilnsey Formation	dark grey limestones seen at Mill Scar below Malham Cove and at Halsteads (SD848638, west of Stockdale Farm, Scaleber).

Later they refined this (Mundy & Lord, 1981, Proc. Yorks. Geol.Soc., 44, p211-213) and correlated it with the new subdivisons of the Dinantian Subsystem.

Brigantian Stage	Wensleydale Formation
Asbian Stage	Malham Ftn (Gordale Limestone [Member] & reef equivalents)
Holkerian Stage	(Cove Limestone [Member])
Arundian Stage	Kilnsey Formation

They re-interpreted Hudson's (1930) succession at Scaleber, showing that the apparently conformable passage upward from bedded Scaleber Quarry Limestone of Asbian age into reef limestone was incorrect. Rotated geopetal structures in these upper limestones showed that they were a boulder bed of reef debris; moreover the boulder bed yielded B_2 and P_{1a} goniatites of end-Asbian age (Ann. Rept. for 1978, 1979 p22).

Other I.G.S. officers, principally I.C. BURGESS and A.A.WILSON, erected a separate stratigraphic sequence for the Raydale and Beckermonds Scar boreholes. They based this sequence on the isolated outcrop at the Clough, Garsdale but have not yet published any account of the Clough section, which seems to consist of

Danny Bridge Limestone
Garsdale Limestone
Fawes Wood Limestone
Ashfell Sandstone
Tom Croft Limestone
Penny Farm Gill Dolomite
Sedbergh Formation

Cautley Mudstone of late Ordovician age.

In the Raydale borehole, the Sedbergh Formation rests unconformably on the Wensleydale Granite 395 metres below the top of the Garsdale Limestone, whereas at Berkermonds Scar the Tom Croft Limestone lies unconformably on Ingleton Group only 163 metres below the top of the Garsdale Limestone. Wilson (in Wilson and Cornwell, 1982, p62,Fig.2) specifically correlates the top of the Garsdale Limestone with the Porcellanous Bed of the Horton Limestone.

CHAPTER THREE

SEDIMENTOLOGY-AN INTRODUCTORY SYNTHESIS

3.1 Introduction

The limestones of the Great Scar Group divide into two distinctive units, the Horton and Kingsdale Limestones of Ramsbottom (in Fewtrell & others, 1981); they record the contrasting episodes of carbonate deposition. The first episode is the burial of a rugged island and its conversion into a carbonate sand platform with lagoons in its lee. Internally almost a-tectonic, this episode was terminated by uplift clearly associated with tilting of the area southwest of the North Craven Fault. The subsequent episode is the development of a reef-fronted carbonate platform whereon deposition was frequently interrupted by emergence. In detail, each of these episodes is so complex that the present research has been restricted to the first episode alone, that is to the Horton Limestone as defined by Ramsbottom (op.cit).

In this chapter there is a brief description of the topography of unconformity between the Great Scar Group and underlying Lower Palaeozoic rocks followed by details of the separation of the Horton Limestone of Ramsbottom into four clearly defined formations, including a redefined Horton Limestone. The final part of this chapter is devoted to description of the well defined lithological units, often persistent over large areas, which comprise these formations.

3.2. Nature of the Unconformity between the Great Scar Group and the Lower Palaeozoic Rocks.

The unconformity between the Lower Palaeozoic rocks and the Great Scar Group was first described by Playfair (1802). He observed nearly horizonal limestones overlying vertical, cleaved graywackes at White Scar Cave (SD712745) and horizontal limestones, the lower beds full of graywacke lithoclasts, overlying vertical slates at Thornton Force (SD695753). Phillips (1829) described, briefly, the extensive relief in Crummack Dale. The first detailed account occurs in the Ingleborough Sheet Memoir (Dakyns & others, 1890); "it is evident that these >limestone< beds were deposited upon an uneven floor of the Silurian Rocks, for the line dividing the two formations runs sharply up or down twenty or thirty feet in places, whilst the bedding of the limestone remains horizontal "(p23). Marked examples of overlap of Carboniferous deposits in Crummack Dale along Moughton Scar, above Capple Bank and Hunterstye, were also described by them. Kendall (1911) observed that the Carboniferous sediments had been laid down on a rigid platform of older rocks. He described the unconformity as an undulating surface with ridges 100-150 feet above the level of the intervening hollows. At the same time he observed that the ridges generally follow the strike of harder members of the Ordovician and Silurian strata. The softer rocks were more easily eroded to form hollows.

The Lower Palaeozoic succession was first described by Phillips (1829,1835). Soon after the area became the focus of many geological studies of the Lower Paleozoic rocks, synthesised in the report of Dunham & others (1953). More recent studies by O'nions & others (1973), McCabe (1972) and McCabe & Waugh (1972) have resulted in some re-interpretation of the stratigraphy and structure of the Lower Palaeozoic rocks. The successsion listed below is after Ingham & Richards (1974) and Moseley (1984).

System	Series	Rock-name	Rock-type
Carboniferous	Visean	Great Scar Group	mainly limestones
UNCONFORMITY			
	Ludlow	Studfold Fn	graywackes
		Horton Fn	siltstones
Silurian	Wenlock	Arcow Fn	carbonate
		Austwick Fn	graywackes
	Llandovery	Stockdale Shale	shales

Ordovician	Ashgill	Coniston Group	calcareous shales & limestones
UNCONFORMITY*			
Ordovician	Arenig	Ingleton Group	slates & graywackes

* Postulated by King & Wilcockson (1934) and confirmed by O'Nions & others (1973).

The distribution of the various units is shown in Figure 3.1.

Pre-Carboniferous faulting of the Lower Palaeozoic rocks can be demonstrated below Thornton Force and at Horton-in-Ribblesdale. In both places tightly folded chloritic Ingleton Group rocks are thrown against unmetamorphosed rocks of the Coniston Group. The change in strike of the Cautley Mudstone against the North Craven Fault can be demonstrated to have occurred prior to intrusion of lamprophyre dikes in Kingsdale. This indicates to a sharp downwarp of late Silurian-early Devonian age along the line of that Fualt. The relationship between the Lower Palaeozoic and Carboniferous strata is locally complicated by post-Carboniferous tectonism which has resulted in considerable small-scale faulting and folding. Large-scale warping of the entire Askrigg Block has given rise to dips of approximately 2^{o} (20m per km) and, in contrast, smaller-scale warping and faulting has produced dips of 11^{o} on Scales Moor (Waltham, 1974) and along faults such as Tatham Wife Hole Fault with a northeast throw of 12 metres (Foley, 1979). Whilst it is possible to locate and map such faults and warps with ease in the Kingsdale Limestone, it is extremely difficult to observe such features in the limestones below. Since the throws on these faults are of comparable magnitude to the local relief on the unconformity, it is essential to have sufficiently good outcrop to prove depositional topography. The topography of the unconformity is demonstrated in Figure 3.2; it can be studied in relationship to the stratigraphy of Lower Palaeozoic rocks when Figures 3.1 and 3.2 are compared. Relief on the unconformity is mostly the product of differential Devonian-early

Carboniferous weathering and erosion of Lower Palaeozoic shales and graywackes. Post-Carboniferous warping and faulting, with only local exceptions, have had little effect on the 225 metres of relief which is visible at outcrop.

In Kingsdale and Chapel-le-Dale the unconformity is developed mainly on tightly folded, cleaved slates and graywackes of the Ingleton Group. The Coniston Group crops out immediately adjacent to the North Craven Fault (Fig.3.1) however, the unconformity is not exposed. There are approximately ten metres of relief in Kingsdale and a maximum of 35 metres (225-260m O.D.) in Chapel-le-Dale. The relief along either side of Chapel-le-Dale is gentle, approximately fifteen metres; the ridges are developed on graywackes and the hollows in slates. In the vicinty of God's Bridge (SD733763) the unconformity is exposed at a much lower level (225-235m). Pronounced faults in the Carboniferous Limestone separate this area from the rest of the unconformity in Chapel-le-Dale, and probably affect the Lower Palaeozoic strata also. Further evidence of the topography of the unconformity has been gathered by detailed surveying of caves in Chapel-le-Dale. Skirwith Cave (SD708738) is formed parallel to the edge of the limestone at the valley side (Halliwell, 1979) and the Dale Barn Spring - Dry Gill Cave system (SD712745) probably defines the western limit of the graywacke ridge near Twisleton Dale House. There is evidence for another hollow beneath White Scars, likewise defining the termination of a graywacke ridge. The entrance to White Scar Cave (SD712745) is at the unconformity but the cave passage descends into the hillside through limestone. Finally, evidence from Meregill Skit, immediately north of God's Bridge, suggests that the unconformity must descend steeply behind its outcrop just below God's Bridge, only 200 metres away (Brook, 1974). Meregill Skit, although it occurs at the same altitude as God's Bridge, has a permanently flooded passage 20-25m deep excavated in limestone. Probably the passage is kept flooded by water ponded behind the ridge of basement rocks (Halliwell, 1979). The throws on the faults recorded immediately north of God's Bridge are significant. This area of depressed basement behind God's Bridge is apparently a horst (Foley, 1979).

The authors of the Dalesman compendium Northern Caves (5 volumes, second editions) give the depths of all recorded potholes, most of which start at or near the top of the Kingsdale Limestone. Few potholes penetrate the Horton Limestone and even fewer penetrate the full thickness of the Great Scar Group to the unconformity. Water levels in the sumps are at resurgence levels - usually at the unconformity. Any significant depth in a sump means a depression in the unconformity surface, caused either by initial topography or by post-Carboniferous tectonism or both. Good examples are provided by caves in the Ingleton area. In Kingsdale the major resurgence is Keld Head at 253m O.D. and in the Horton Limestone. Both the East and West Kingsdale cave systems sump deeply, East Kingsdale to 26m depth and West Kingsdale to at least 20m below the Keld Head level. Over in the east on Penyghent, Penyghent Pot sumps at about the resurgence level in Brant Gill Head (261m O.D.) and has been dived to 37 metres below this. Brant Gill Head is at the same level as the Douk Gill flood resurgence and therefore also occurs just a few metres above the unconformity. On Fountains Fell Gingling Hole, also resurging at Brant Gill Head, sumps at a depth of 169m below the Girvanella Bed and has been dived for nine metres and Fornah Gill Cavern, not far upstream from the unconformity by Fornah Gill Barn, at 375m O.D., descends dry to 23m from 386m O.D. and then has a 10 metre sump.

On the southern flanks of Ingleborough there are a number of poor exposures of the unconformity showing Carboniferous limestones resting abruptly on the Coniston Group. In Jenkin Beck SD713729) the unconformity is unusually high, 255m O.D., compared with outcrops to the east, but this exposure lies immediately adjacent to a complicated section of the North Craven Fault. In the main stream in Clapdale (SD75107015), the unconformity occurs below the 210m contour, whilst at Cat Hole (SD74887000) it occurs at 225m O.D. The entrance to Ingleborough Cave is located above the unconformity but many of the lower passages are flooded suggesting that the unconformity may not be far below. The unconformity is not exposed in the intervening area between Clapdale and Jenkin Beck. However, limestones of the Raven Ray Formation crop out at the quarry floor (230m O.D.) in Newby Cote Quarry (SD733707) and there could be some 20 metres of limestone between it and the unconformity.

The much more extensive outcrops in Crummack Dale show a far greater complexity (Fig.3.2). The lowest point is Nappa Scar (SD769697) where the unconformity rises from 230m to 245m; lithoclast-rich limestones rest abruptly on steeply dipping Coniston Group. Northwards the unconformity is obscured by a thin veneer of till but must continue to rise steeply. The next exposure (SD767704) where the limestones lie on Silurian graywackes, shows another abrupt rise from 300m to 310m. At SD774712, the unconformity reaches its greatest elevation on the western side of the dale, 365-370m.To the northeast the level of the unconformity falls rapidly to 350m at SD76787127, to 335m at SD76877133 and then to 300m near Crummack Farm where it disappears below till. Continuing northeastwards there is no exposure until Austwick Beck Head (SD77647186) where the Coniston Group reappears beneath Carboniferous sediments at about 280m. Beyond here, the unconformity is obscured by till reappearing at SD77767216 where there is a small exposure of graywacke under limestone at about 290m.

Eastwards, along the head of Crummack Dale, the unconformity rises gently over Capple Bank, a ridge of steeply dipping Silurian graywackes, to a maximum elevation of 325m at SD78327194. Eastwards the unconformity falls rapidly to 310m at Moughton Whetstone Hole (SD78457194). To the south, along the eastern side of Crummack Dale, there is another ridge of Silurian graywacke over which the unconformity rises sharply. At its maximum elevation of 365-370m near SD782711, the unconformity is poorly exposed. Southwards it drops rapidly and is better exposed ("flags" have been quarried immediately below Studrigg Scars). Phillips (1829) observed that the high limestone scars "are in several places undulated, so that the slate is exhibited at very different heights on opposite sides of the valley". The unconformity is at 320m at SD78167097, and at 300m at SD78107067. This elevation is then maintained around the end of Moughton Scars, until the unconformity gradually becomes obscured by till.

Above the village of Wharfe the unconformity is exposed again at SD786699, where limestones rest abruptly on steeply dipping Silurian graywackes at about 320m. The unconformity remains at this height along the southern slope of Moughton. At Moughton Nab (SD77566959) the unconformity has risen slightly to 330m.

North of Moughton Nab, the unconformity is intermittently exposed along the western side of Ribblesdale. There are excellent exposures above Dry Rigg Quarry (SD799699), Combs Quarry (SD800701) and Arcow Wood Quarry (SD801704), first observed by Phillips (1829). At Combs Quarry (SD800701), below Foredale Limestone Quarry, the unconformity is perfectly exposed at 325m O.D. and is almost horizontal with occasional ribs of graywacke projecting above the common level. North of this locality the exposure is patchy. From SD80077037 to SD80057070 the unconformity is horizontal at 335m O.D. dropping to 315m at SD80027127, and 300m at SD79967145. At Gillet Brae (SD80037193) the unconformity is well exposed at approximately 280m. Northwards it is no longer exposed on this side of Ribblesdale. Prior to the opening of Horton Lime Quarry in 1886, there was an exposure at about SD801722, described by Garwood (1922), who recorded micro-relief (§20cm) on the unconformity. The exposure is now obscured by quarry waste.

On the east side of Ribblesdale the unconformity is exposed in only two places; at Douk Gill (SD81577245) at 250m O.D., and at Dub Cote Gill (SD81867174) at 265m. Between these two localities there is a possible but poor exposure at Brackenbottom (SD81717212).

In Silverdale, the next valley to the east, there are a few outcrops of the unconformity. Pebble rudites rest abruptly on Silurian graywackes at SD83246905, but wedge out as the unconformity rises steeply northwards from 345m to 375m at SD83486942, beyond which it is obscured by till. Where next exposed, at Silverdale Barn (SD83886966), it has dropped to about 340m O.D., but rises again eastwards to 375m at the resurgence of Roughlands or Fornah Gill (SD84536943).

Southwards along the southern flank of Fountain Fell, the unconformity is not exposed but its position can be approximated by scrappy graywacke and limestone outcrops. It seems to maintain the elevation of Roughlands Gill (375m O.D.). At SD852670 the outcrop swings eastward and is lost below till. It next reappears in the glacial overflow channel on the north side of Black Hill (SD86556653), where poorly exposed pebbly limestones abruptly overlie cleaved graywackes at 425m O.D. There is no exposure for 4.5km across the flats of Malham Tarn. The final exposure is in Gordale Beck at SD911658. The unconformity is very poorly exposed, being much masked by till. It lies at approximately 360m O.D.

The unconformity does not reach the surface in the valley of Wharfedale or Littondale, although the floor level is well below the 360-425m elevation of the unconformity on Malham Moor. The 300m contour crosses Darnbrook Beck at the confluence with Cowside Beck and Littondale floor is on limestone at Litton (250m O.D.), dropping to 220m at Arncliffe and 190m at the confluence with the Wharfe. At Kettlewell Bridge, the valley floor is a few metres below 205m O.D., whereas at Mill Scar Lash the floor is just below 180m O.D. However, the unconformity may not occur far below, and it may occur below alluvium in the river bed immediately downstream of Mill Scar Lash. This was first suggested by Dakyns (1893) to explain the occurrence of Lower Palaeozoic slate and graywacke boulders in the neighbourhood of Threshfield.

At almost all localities micro-relief of up to 5.0m can be demonstrated. Some examples can be observed in Plates 1,2 and 4. Such micro-relief was first described by Johns (1906), and later by Garwood (1913) and Garwood and Goodyear (1924). They also observed that the most richly lithoclast limestones occurred in hollows in the unconformity, whereas lithoclast-free limestones lay over the eminences. The Viviparus Bed of Garwood (1922) occurred in a very localised pocket eroded into the graywackes. Micro-relief is the result of differential weathering and erosion on a bed-by-bed scale.

Only the mappable macro-relief of the unconformity has so far been described. It is the result of differential erosion of arenites and lutites which has been enhanced by extensive early Carboniferous weathering. On a larger scale, that of the Askrigg Block, there is evidence of great thickening of the Arundian sequence away from the outcrop of the unconformity. This sequence is about 60 metres thick in the Kettlewell and Beckermonds Scar boreholes and increases to 400, metres in Raydale. The unconformity occurs at 149m O.D., 78m O.D. and

-227m O.D respectively in the three wells. At the same time as the increase in thickness there are changes in lithology. The borehole limestones are generally finer grained, darker and occasional interbedded with shales and contrast sharply with the thickly bedded dominantly pale grey limestones of the southern margin of the Askrigg Block. The Ashfell Sandstone of Garsdale and the Beckermonds Scar and Raydale boreholes is not represented in the normal sequence exposed in the study area. However, the thin sandstone beds cropping out in Newby Cote Quarry, close to the North Craven Fault and probably not far above the unconformity, may correlate with this horizon.

3.3 Subdivision of the Great Scar Group

The Great Scar Group comprises mostly limestones; thin clastic beds occur sporadically at the base, where it rests with profound unconformity on folded Ordovician and Silurian rocks. It has been mapped and described over much of its outcrop area, yet, with the exception of Garwood & Goodyear (1924), regional variations of the individual units have remained unobserved. They were able to recognise a four-fold division of the Great Scar Group, each division being an extensive lithological unit. These four lithological units, listed in ascending stratigraphical order, *Michelinia grandis* Beds, Gastropod Beds, *Nematophyllum minus* Beds and Lower *Dibunophyllum* Beds, correspond to the Thornton Force Formation, Raven Ray Formation, Horton Limestone and Kingsdale Limestone of this report. Garwood & Goodyear (1924) were able to trace these units across the outcrop from Ingleton to Wharfedale but had difficulties in correlation in the immediate vicinity of Horton-in-Ribblesdale.

Schwarzacher (1958) identified a cyclic sequence at the top of the Great Scar Group and, subsequently, Ramsbottom (1974) named this cyclic unit the Kingsdale Limestone, and the underlying part of the Great Scar Group as the Horton Limestone. He retained Garwood & Goodyear's (1924) informal names for the base of the sequence. However, in a more recent publication, Ramsbottom (in Fewtrell & others, 1981) abandoned the latter names and extended the Horton Limestone to the base of the Great

Scar Group. This subdivision of the Great Scar Group is not satisfactory. The Horton Limestone as defined by Ramsbottom is composed of several distinct lithological units, separated by erosion surfaces, which can be mapped across their entire outcrop area. These units have been given formation status in this report.

The Thornton Force Formation which is the lowermost formation of the Great Scar Group, rests with profound unconformity on Lower Palaeozoic rocks and is overlain, with apparent disconformity, by the Raven Ray Formation. It crops out only in the most deeply incised valleys near the North Craven Fault where streams erode to or below the unconformity. Usually masked by superficial deposits, exposures tend to be sparse.

The formation is incompletely exposed along the southern margin of the Askrigg Block, but is at least 20 metres thick at Stainforth Force where its base is not exposed. Complete exposures occur to the north of the North Craven Fault and display a general thinning from 21.95m to zero in a northerly direction. Superimposed on this simple trend is a complex variation in thickness intimately related to the topography of the underlying Lower Palaeozoic rocks. Generally, the shales, slates and siltstones are less resistant than the graywackes and, consequently, tend to form hollows. These hollows are frequently filled with pebble, cobble or even boulder rudites, with sporadic shales, and are overlain by variably lithoclastic, cross-laminated calcarenites. Calcareous sandstones overlie rudites only in Chapel-le-Dale.

The formation is identified in the field by its characteristic hard-weathering, clean-washed, pale grey calcarenites, which are often cross-laminated, by abundance of lithoclasts and its prolific fauna. In good exposures it is a cliff-former. The overlying Raven Ray Formation rocks weather more easily than the Thornton Force Formation, thus creating a conspicuous terrace which helps to identify the succession at this level.

The Thornton Force Formation, named at after its type-section, a well-known waterfall near Ingleton, is very similar in age and lithology to the Red Hill Oolite of Furness, and both formations are overlain by similar deposits. However, there are significant differences in rock-type and succession thicknesses between the two areas. These are discussed in greater detail in Chapter 10.

The Douk Gill Formation, overlying Lower Palaeozoic rocks unconformably, crops out only in the immediate vicinity of Horton-in-Ribblesdale. It probably is at least a partial time-equivalent of the Thornton Force Formation, however, it has been designated a separate formation because of the greatly contrasting rock-types contained therein. Named after the thickest and most complete sequence at Douk Gill (16.88m), the formation is thickly mantled by till and alluvium and is exposed at only three other localities. It is definitely absent on Moughton Nab, in Crummack Dale as far north as Studrigg and to the east in Silverdale. The succession is dominated by sparsely fossiliferous, foetid mid to dark grey calcilutites, although a complex sequence of non-marine clastic rocks and marginal marine mixed carbonate and clastic rocks occurs at the base of the formation. A thin coal (2-12cm thick) is present at the top of the formation. It is overlain, apparently conformably, by foetid calcarenites assigned to the Raven Ray Formation.

The Raven Ray Formation generally is disconformable on the Thornton Force Formation, although locally, it oversteps to overlie Lower Paleozoic rocks unconformably. It abruptly, but conformably, overlies the Douk Gill Formation and is overlain everywhere by the Horton Limestone, apparently conformably as far east as Ribblesdale but with slight disconformity in Wharfedale.

There are few good exposures of the formation and the best are in quarries and stream sections. It is obscured by substantial ticknesses of till and outcrops tend to be sparse. It rarely forms a conspicuous terrace because of its relative thinness in comparison to the overlying deposits; it is thickest (about 24 metres) along the southern edge of the Askrigg Block where it overlies the Thornton Force Formation, thinning to the north where it oversteps onto Lower Palaeozoic rocks.

The characteristic sequence of foetid, dark grey calcarenites and calcisiltites interbedded with black mudstones is best developed to the north of the Craven Faults. Near the North Craven Fault more crinoidal, thicker bedded, non-foetid limestones, with erosive bedding contacts, are more common, and in a single exposure south of this fault quartz siltstones and sandstones occur at the top of the limestone sequence. Locally, pebble, cobble and boulder rudites are present at the base of the formation where it unconformably overlies Lower Palaeozoic rocks. Only the upper part of the formation is seen in Wharfedale where it retains its foetid character; its base is not exposed there.

As exposures of the formation are so few, the occurrence of closely jointed, white weathering limestones at the base of the overlying Horton Limestone has proved a reliable and useful guide to the succession at many localities. In many cases it has proved difficult to identify the Raven Ray Formation away from its type section of Raven Ray in Kingsdale because of the paucity of exposure and the rapid minor changes in lithology.

The <u>Horton Limeston</u> was first described by Ramsbottom (1974) as "the limestones exposed in Horton Quarry". This definition is inadequate since the quarry has been extended and now includes the lower part of the Kingsdale Limestone. The Horton Limestone is redefined here as the mid grey and pale grey limestones, including the Moughton Calcilutite Member, overlying the distinctive dark grey limestones of the Raven Ray Formation, and being overlain by the massively bedded, pale grey Kingsdale Limestone.

The Horton Limestone is generally conformable on the Raven Ray Formation except in Crummack Dale where it oversteps onto Lower Palaeozoic rocks, and in Wharfedale and Littondale where there is apparent disconformity between the two formations. The top of the formation is marked by a widespread erosion surface, and south of the North Craven Fualt there appears to have been some tilting at this period resulting in subaerial exposure; a thin coal with a restricted lateral extent occurs in a solution hollow in the top of the formation.

Generally, the formation varies in thickness between approximately 61 metres and 96 metres, except where it oversteps the Raven Ray Formation to overlie Lower Palaeozoic rocks. In Crummack Dale the sequence thins to only about 25 metres. The Moughton Calcilutite Member, a distinctive mappable unit occurs near the top of the formation in the northern part of the study area, thinning and failing to the south and east. In its absence it is difficult to distinguish the calcarenites of the Horton Limestone from those of the overlying Kingsdale Limestone.

It could be argued that the Moughton Calcilutite Member itself is a separate formation, being lithologically distinct from the rest of the Horton Limestone. However, as it is not possible to separate the calcarenites of the Horton Limestone lying above and below the calcilutite into meaningful units, this distinction has not been made. Instead the Moughton Calcilutite Member is included as part of the Horton Limestone and the top of the formation is marked by an erosion surface occurring some 6-11 metres above the calcilutite top.

Lithologically, the Horton Limestone is extremely uniform but it can be divided into two portions on the basis of colour; a lower dark and mid grey limestone overlain by pale grey to buff coloured limestones. Although the transition is usually abrupt there is no change in fauna.

The remainder of the Great Scar Group consists of the Kingsdale Limestone. This formation, approximately 100 metres thick, everywhere overlies the Horton Limestone, generally with disconformity, but with slight angular unconformity south of the North Craven Fault. It is overlain by mid and dark grey limestones, sandstones and shales of the Yoredale Group. The Kingsdale Limestone is composed of 9 or 10 rhythmic units of variable thickness which are attributed to cycles of transgression and regression (Ramsbottom, 1974). Laterally extensive but thin shales accumulated during periods of subaerial exposure. Lithologically the limestones of the Kingsdale Limestone are uniform, consisting of fine to coarse grained bioclastic and intraclastic calcarenites.

3.4 Rock-Types Present in the Thornton Force Formation, Douk Gill Formation, Raven Ray Formation and Horton Limestone

Sixteen rock-types (intraclastic calcarenites; oolitic calcarenites; bioclastic calcarenites; lithoclastic calcarenites; medium to thinly bedded, often shaly, mid to dark grey calcarenites and calcisiltites; fenestral calcilutites; featureless calcilutites; rudites with a clastic matrix; rudites with a calcarenite matrix; granule arenites; calcareous quartz arenites; argillaceous quartz arenites and litharenites; carbonate-cemented arenites; black lutites; variably coloured lutites; coal) have been defined on the basis of field and petrological characteristics. For each of these rock-types, the faunas, bioclast and/or grain contents, diagenetic history, distribution and thickness variations are described in Chapter 8. The environments of deposition are discussed and interpreted and sources are proposed for bioclasts and clastic grains.

The bulk of the studied part of the Great Scar Group consists of intraclastic calcarenites. The Thornton Force Formation and Horton Limestone are dominated by this rock-type and it is locally developed in both the Douk Gill Formation and the Raven Ray Formation. Intraclasts are of many types and probably have more than one origin. The well sorted and well rounded intraclasts are closely comparable with the modern carbonate sands described by Folk & Robles (1964) and Hoskins & Sundeen (1975) and the depositional characteristics are similar to those of the Lily Bank sand shoals in the Bahamas described by Hine (1977).

Oolitic calcarenites have a very limted distribution occurring at isolated outcrops in all four studied formations. However, the presence of this rock-type is significant as it implies that very specific conditions for oolith-generation existed within the Dinantian environment. The ooliths observed in the Great Scar Group are mainly superficial ooliths (Leighton & Pendexter, 1962) and it is probable that they were introduced from a more favourable environment farther offshore.

Bioclastic calcarenites are not common in the Great Scar Group; the rock-type is locally developed at the base of the limestone sequence where limestones succeed coarse clastic deposits or unconformably overlie Lower Palaeozoic rocks. It is best seen in the Thornton Force Formation and Raven Ray Formation of Chapel-le-Dale.

Lithoclastic calcarenites are common near the base of the Great Scar Group where limestones succeed clastic deposits or unconformably overlie Lower Palaeozoic rocks. In this rock-type, lithoclasts comprise a smaller percentage of the rock than do the allochems, however, they provide vital information about the geography and geology of the study area at the time of their deposition. The presence of small lithoclasts high above the unconformity at anyone locality is indicative of exposure and erosion elsewhere on the Askrigg Block.

Medium to thinly bedded, often shaly, mid to dark grey calcarenites and calcisiltites are common in the Great Scar Group, comprising the whole of the Raven Ray Formation, and occurring locally in the Thornton Force Formation, Douk Gill Formation and Horton Limestone. Although the rock-type represents only a small proportion of the thickness of the Great Scar Group studied it is widespread. No absolute depth limits have been proposed for this group of limestones but they are assumed to have formed in a quiet, deeper water environment than the pale grey calcarenites.

Fenestral calcilutites, although thin, have an extensive areal distribution, occurring in the Douk Gill Formation and in the Moughton Calcilutite Member. The presence of fenestrae (four different types have been recognised) provides a significant indicator to depositional conditions; it has been suggested by some authors (Shinn, 1968, 1983a and b; Groves & Read, 1978) that fenestrae can be used as reliable indicators of subaerial conditions. Such conditions developed only locally as fenestral calcilutites pass both laterally and vertically into featureless calcilutites.

Featureless calcilutites are the most common forms of calcilutite in the Douk Gill Formation and occur within all the calcilutite horizons of the Moughton Calcilutite Member. Beds are thin and laterally discontinuous. It is envisaged that these sediments were deposited in a lagoonal environment; they overlie shallow normal marine sediments and frequently are directly overlain by intertidal-supratidal fenestral calcilutites.

Rudites with a clastic matrix are present at base of the Great Scar Group where Carboniferous rocks directly overlie Lower Palaeozoic rocks. The lack of hydraulic sorting and marine fossils suggests that the majority formed as subaerial gravity flows. Usually, only solitary debris flow deposits are present demonstrating that debris flow events were infrequent. In contrast to the debris flow rudites, rudites with a clastic matrix at the base of the Horton Limestone are considered to be beach gravels.

Rudites with a calcarenite matrix are more common and vary greatly in thickness. They occur in Kingsdale, Chapel-le-Dale, Crummack Dale and Silverdale where Carboniferous rocks unconformably overlie Lower Palaeozoic rocks. The associated profuse marine biota is indicative of marine deposition. Thin layers and lenses of rudite filling small hollows in the unconformity or stranded on bedding planes consist of storm-worked debris, broken as a result of intense wave-battering. Thick beds of much coarser debris, restricted in occurrence to Crummack Dale, are regarded as being closely comparable to ancient shore-face storm deposits (Dott, 1974; Kumar & Sanders, 1976).

Granule arenites occur only at two localities at the base of the Thornton Force Formation. In the form of lens-shaped bodies, they wedge out from ridges of Lower Palaeozoic rock and pass laterally into cross-laminated, lithoclastic calcarenite. The rock-type formed in a non-barred, high energy shoreline environment and cross-stratification and scours demonstrate the prevalence of eroding currents moving pebbly sand as dune bedforms.

Calcareous quartz arenites occur only in the Thornton Force Formation of Chapel-le-Dale. Frequently the beds have erosional bases and pass upward into the overlying lithoclastic calcarenites.

Occasionally, plant remains are preserved. The sandstone was deposited in a nearshore, beach shore-face environment and reworked by wave and tidal action resulting in a well sorted winnowed sediment.

Argillaceous quartz arenites and litharenites occur only in the lower part of the Douk Gill Formation. The medium to thin beds are interbedded with calcarenites, calcisiltites, rudites and shales. A shallow, quiet water-environment either at or just below wave base or a protected lagoonal environment are considered to be suitable depositional environments.

Carbonate-cemented arenites occur in the Raven Ray Formation only at Newby Cote Quarry and in the Horton Limestone of Crummack Dale where it overlaps Lower Palaeozoic rocks. Sedimentary structures in the arenites are typical of sedimentation in an active nearshore environment where wave action reworked, winnowed and sorted the sediment.

Black lutites, varying greatly in thickness, occur in the upper part of the Douk Gill Formation, locally in the Thornton Force Formation. Calcareous lutites are considered to have formed in a lagoonal environment with non-calcareous, sparsely fossiliferous lutites being deposited closest to the shoreline where higher rates of sedimentation prevailed. A second type of black lutite occurs only in solution hollows formed in the top of the Horton Limestone at Meal Bank Quarry; the deposit contains abundant rootlets and is therefore a seatearth.

Variably coloured lutites occur sporadically in all four formations studied. All the coloured lutites are laterally impersistent and were deposited in a number of complex micro-environments.

Coal deposits occur at two greatly separated horizons, at the top of the Douk Gill Formation and at the top of the Horton Limestone. The deposits are local features having a restricted vertical and lateral extent. The restricted extent of both coals is the consequence of short-lived conditions for plant growth, peat formation and coalification.

It is the investigation of the individual rock-types and their distribution within the studied formations which has allowed the interpretation of their overall environment of deposition. The depositional history of the four studied formations is described in detail in Chapter 9 of this report.

FIGURES 3.1 AND 3.2

THE UNCONFORMITY

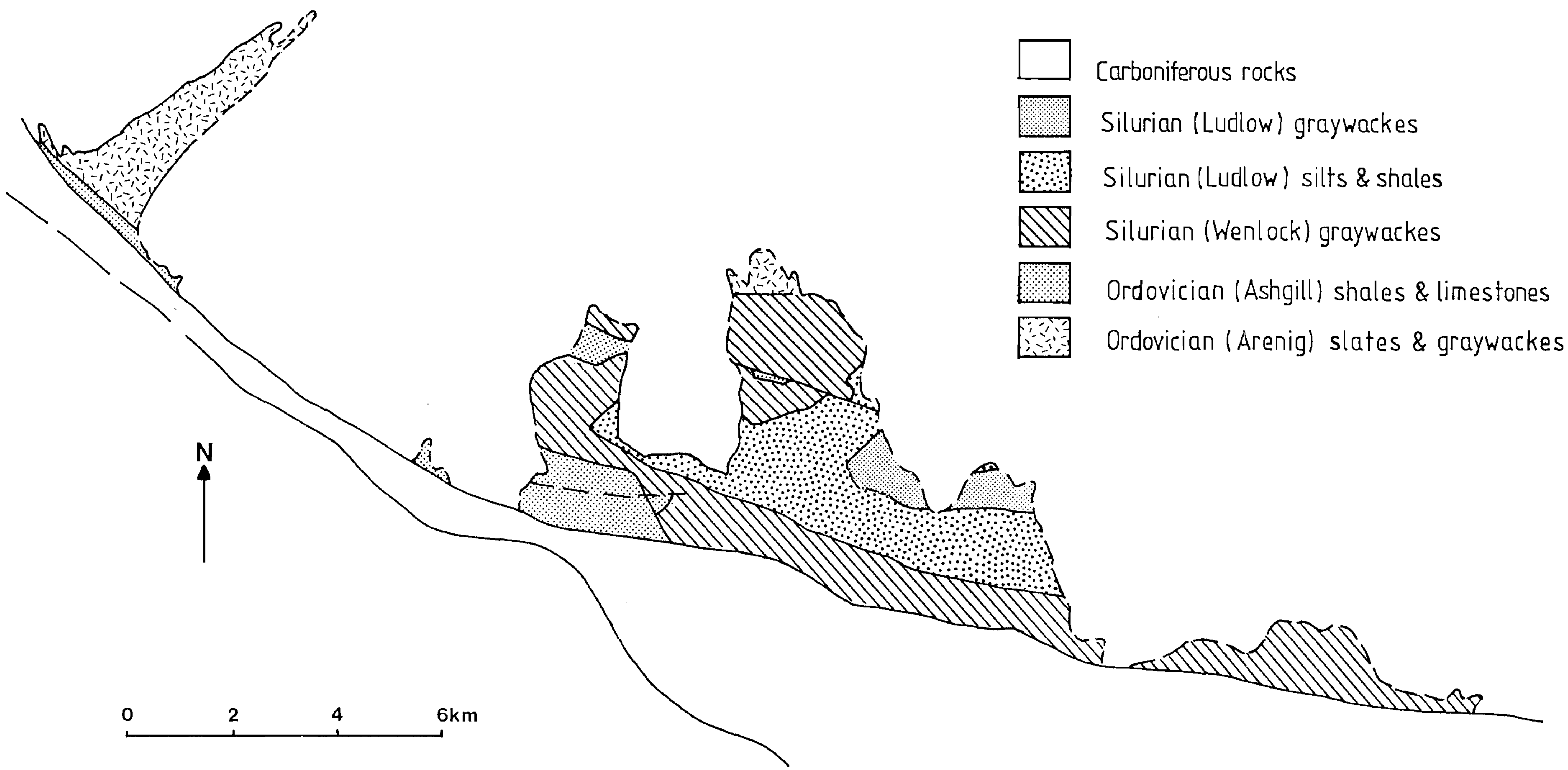


FIGURE 3.1 Structure, stratigraphy and distribution of Lower Palaeozoic rocks in the Craven Inliers.

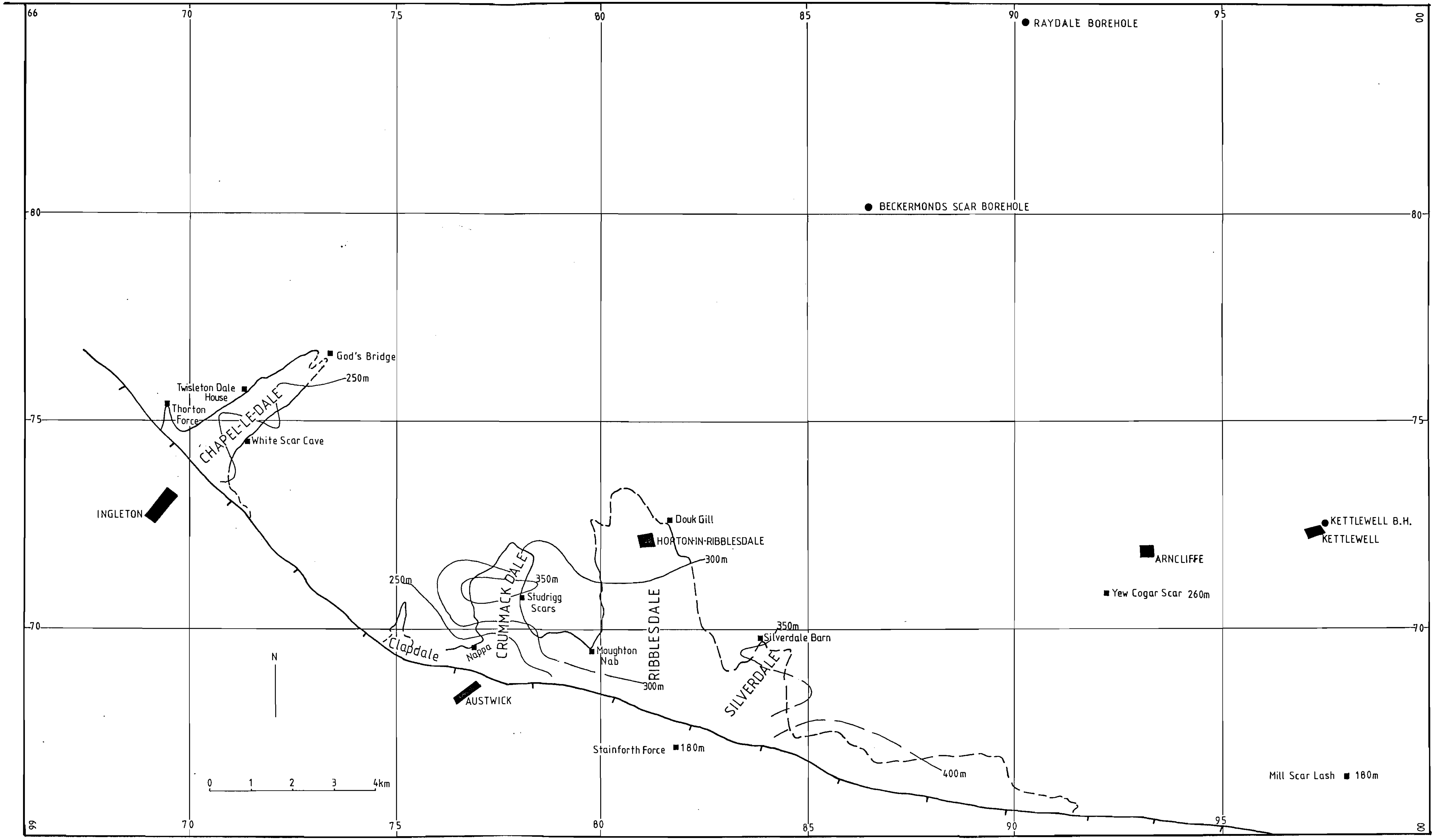


FIGURE 3·2 TOPOGRAPHY OF THE UNCONFORMITY BETWEEN THE LOWER PALAEOZOIC ROCKS AND THE DINANTIAN GREAT SCAR GROUP, WITH HYPOTHETICAL CONTOURS OF PRESENT-DAY TOPOGRAPHY

FIGURES 3.3 AND 3.8 INCLUSIVE

SUBDIVISION OF THE GREAT SCAR GROUP

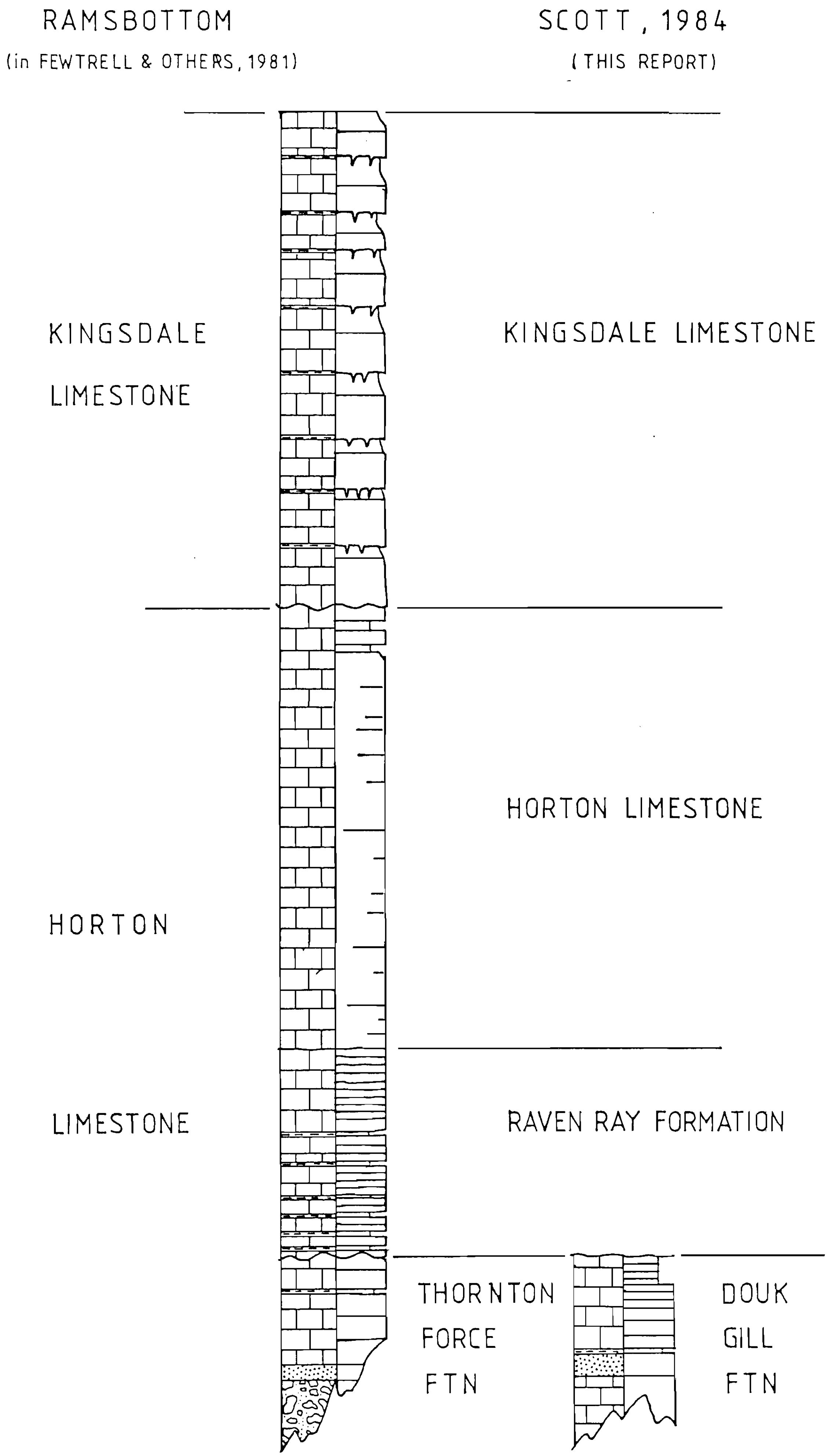


FIGURE 3·3 SIMPLE LITHOLOGICAL LOG SHOWING THE STRATIGRAPHIC SUBDIVISIONS OF THE GREAT SCAR GROUP

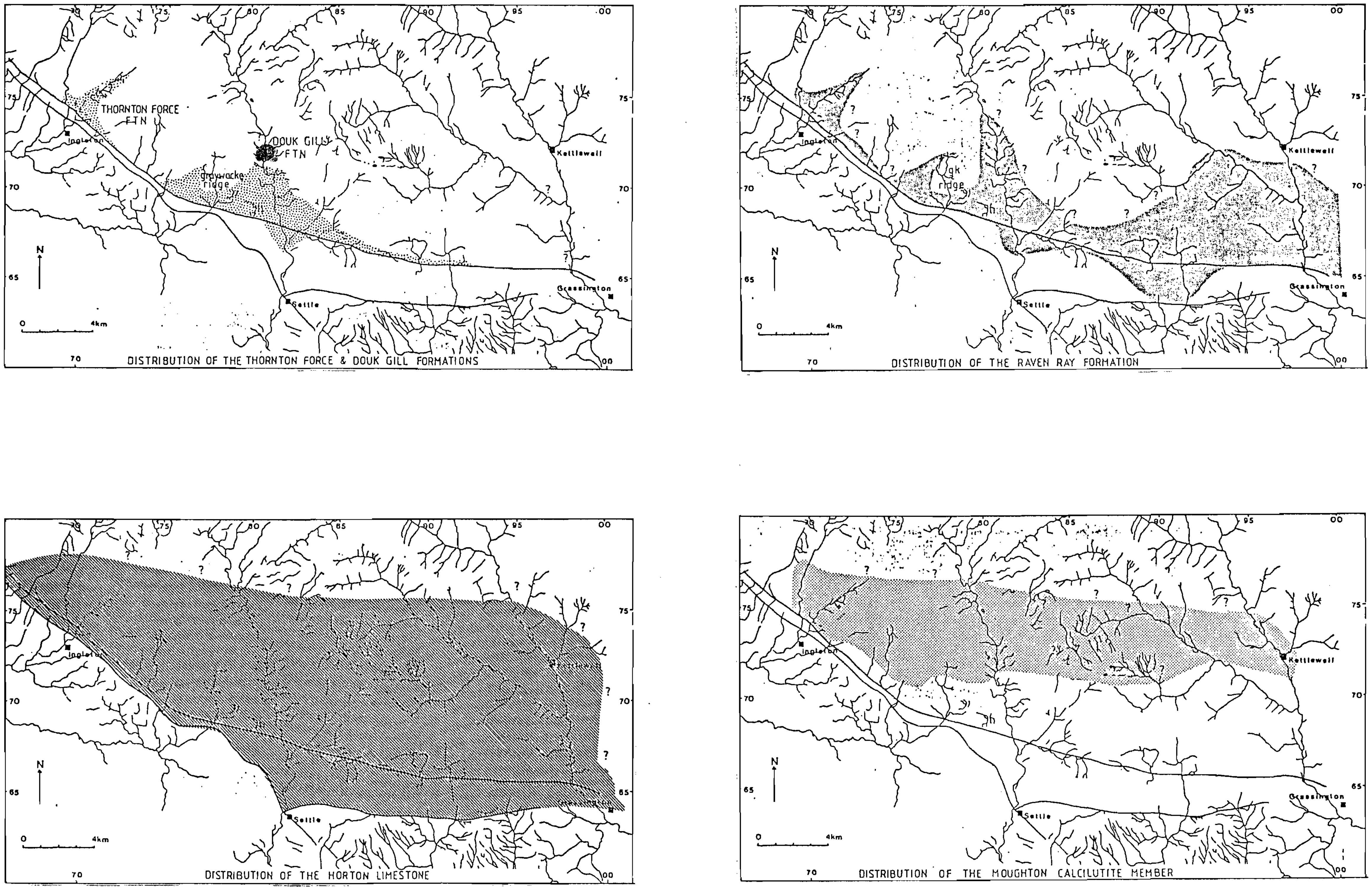


FIGURE 3·4 MAPS TO SHOW THE DISTRIBUTION OF THE THORNTON FORCE FORMATION, DOUK GILL FORMATION, RAVEN RAY FORMATION, HORTON LIMESTONE AND MOUGHTON CALCILUTITE MEMBER THROUGHOUT THE STUDY AREA.

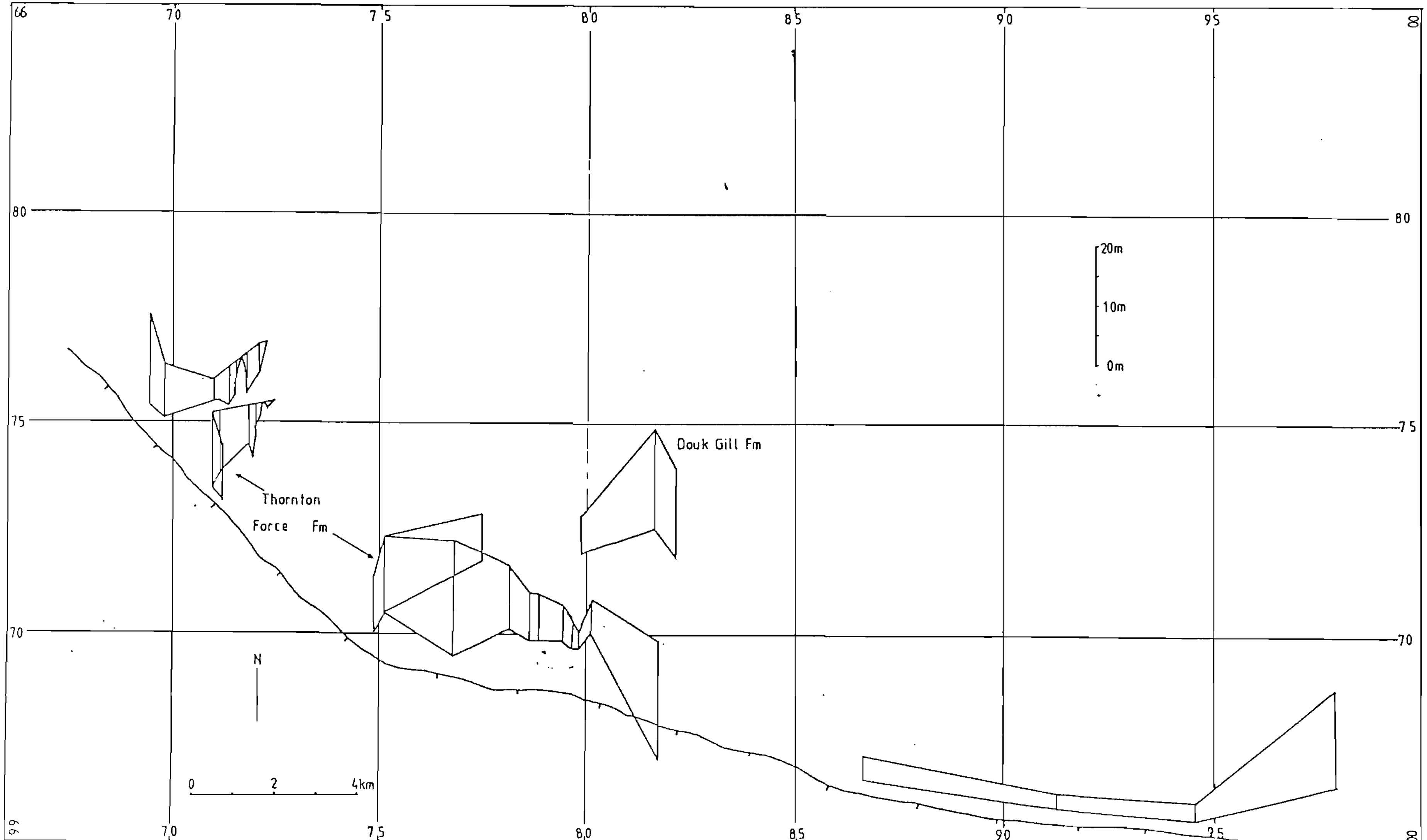


FIGURE 3·5 FENCE DIAGRAM SHOWING THE VARIATIONS IN THICKNESS OF THE THORNTON FORCE FORMATION AND DOUK GILL FORMATION

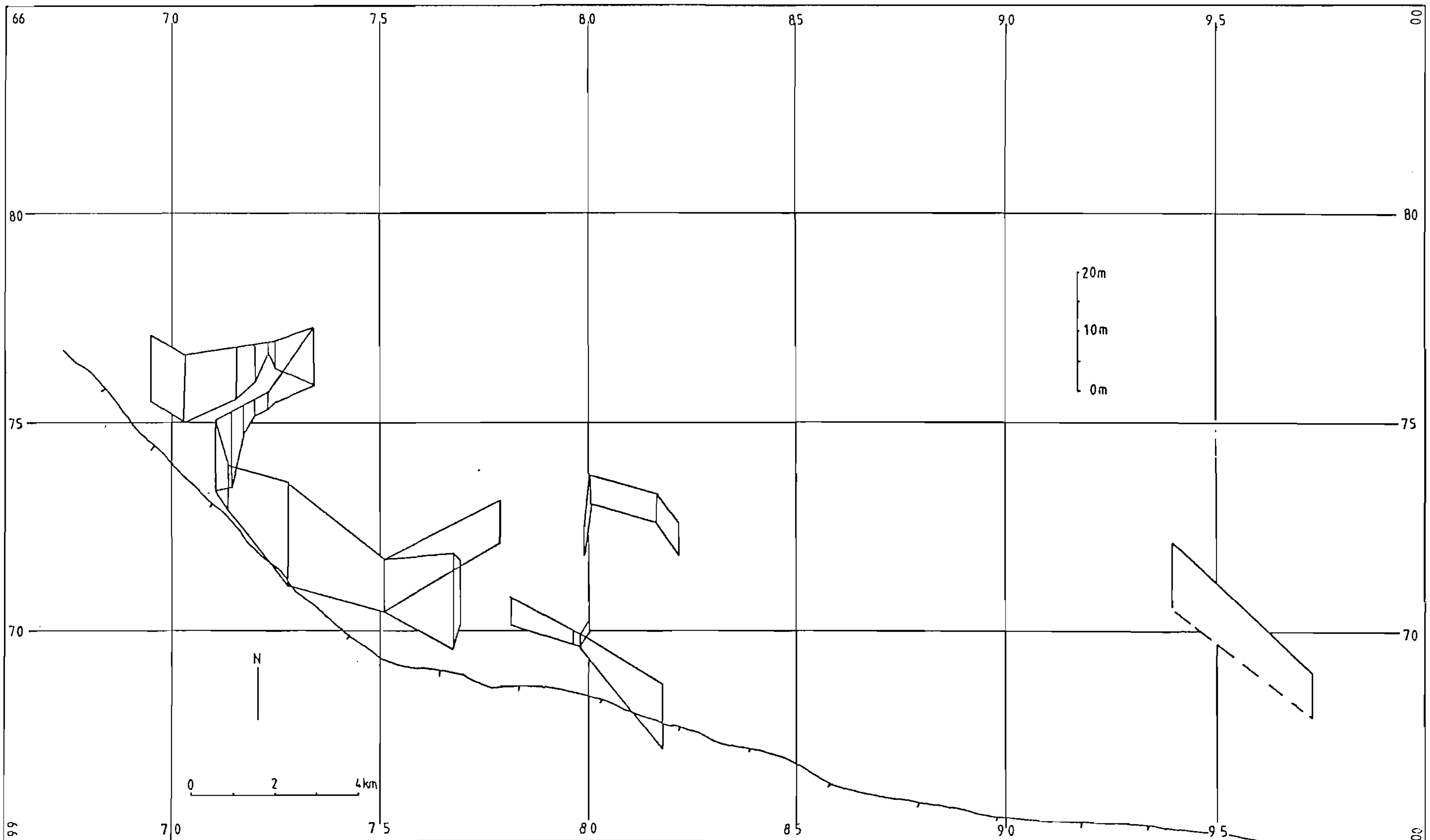


FIGURE 3·6 FENCE DIAGRAM SHOWING THE VARIATIONS IN THICKNESS OF THE RAVEN RAY FORMATION

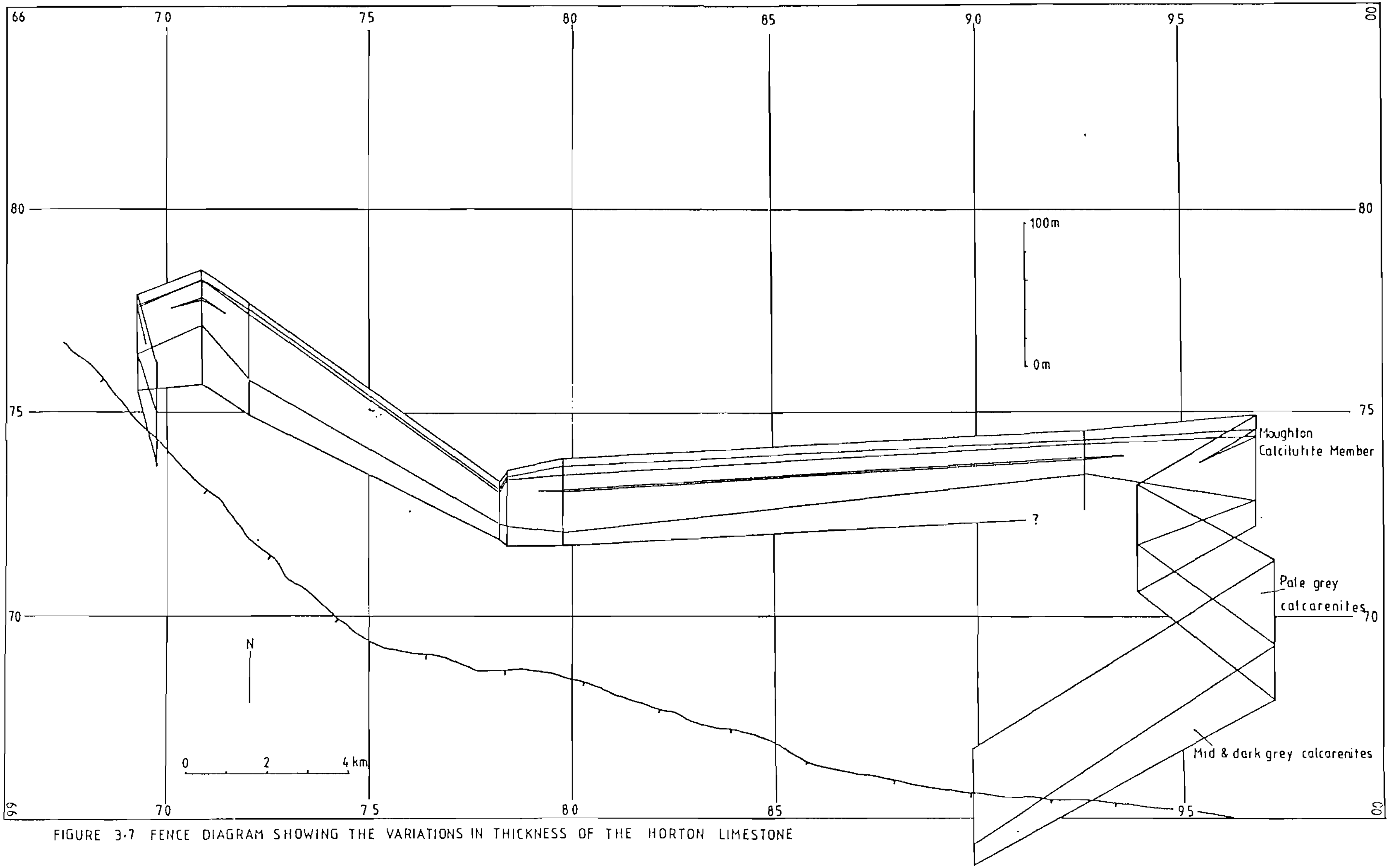


FIGURE 3·7 FENCE DIAGRAM SHOWING THE VARIATIONS IN THICKNESS OF THE HORTON LIMESTONE

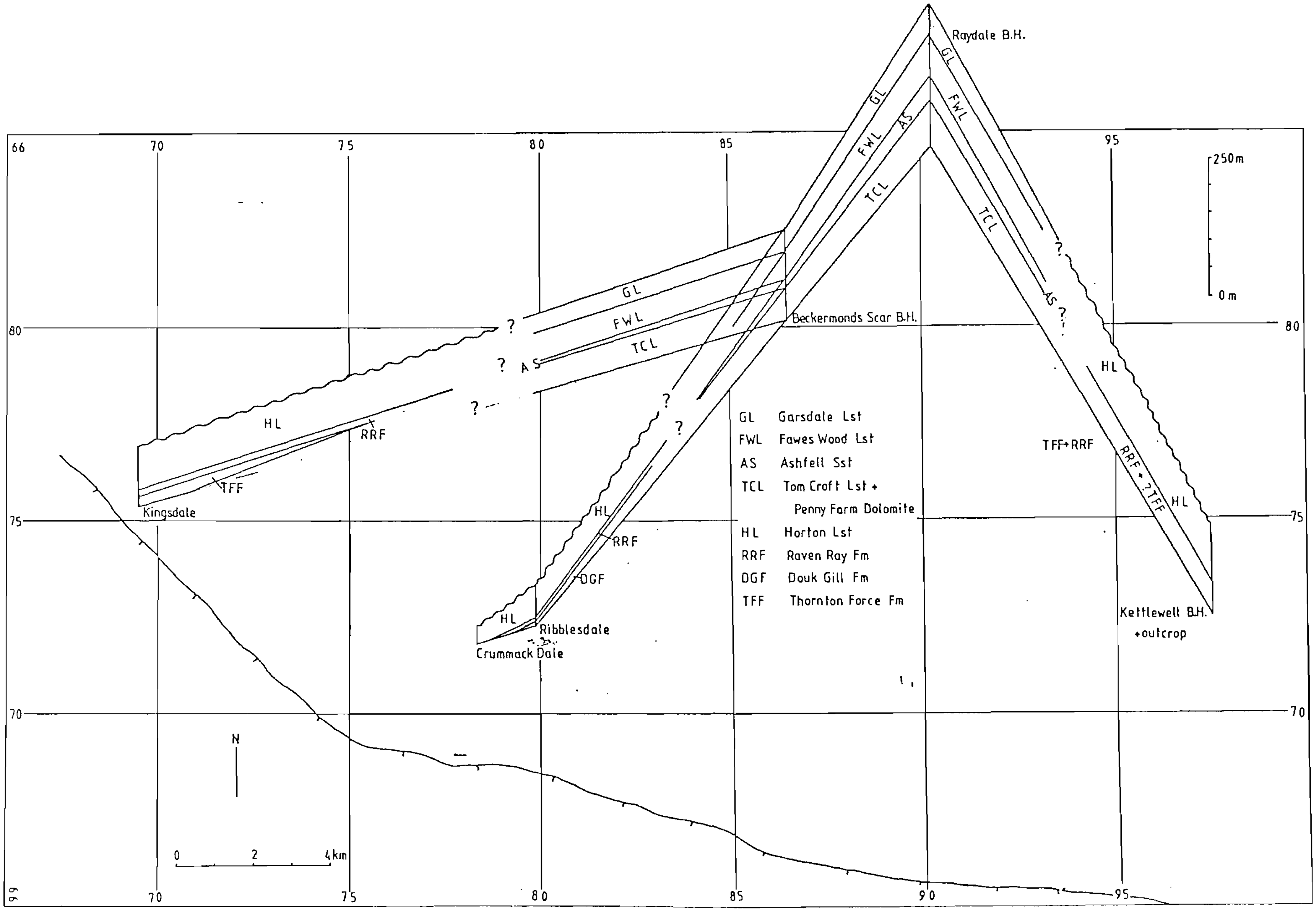


FIGURE 3·8 FENCE DIAGRAM SHOWING THE CORRELATION OF RAYDALE, BECKERMONDS SCAR & KETTLEWELL BOREHOLES WITH OUTCROPS IN THE STUDY AREA

FIGURES 3.9 AND 3.10

ROCK-TYPES PRESENT IN STUDIED FORMATIONS

FIGURES 3.9 Characteristics of rock-types in the Thornton Force Formation, Douk Gill Formation, Raven Ray Formation and Horton Limestone

FIGURES 3.10 Hypothetical cross-section showing the distribution of rock-types in the studied formations and their relationship with the relief of the unconformity

FIGURE 3.9 CHARACTERISTICS OF ROCK-TYPES IN THE THORNTON FORCE FORMATION, DOUK GILL FORMATION, RAVEN RAY FORMATION AND HORTON LIMESTONE

ROCK-TYPE	DISTRIBUTION	THICKNESS	DESCRIPTION	ENVIRONMENT
Intraclastic Calcarenites	Thornton Force Formation and Horton Limestone. Locally developed in Douk Gill and Raven Ray Formation	Few metres to tens of metres	Laterally extensive, medium-thickly bedded low angle cross-laminated, well sorted intrasparites	1) Shoreline 2) Migrating normal marine sand shoals
Oolitic Calcarenites	Limited, locally developed in all four formations	As individual beds rarely thicker than 1 metre	Bedding, characteristics similar to above. Superficial ooliths, usually oolitic intrasparites	Water <5m depth, supersaturated with $CaCO_3$. Washed in from offshore
Bioclastic Calcarenites	Locally developed in Thornton Force and Raven Ray Formations	Few metres only	Bedding characteristics similar to intraclastic calcarenites. Grain size and sorting of sediment variable	Isolated shoals
Lithoclastic Calcarenites	Common at base of Great Scar Group where limestones unconformably overlie Lower Palaeozoic rocks	Generally less than 10 metres	Bedding characteristics similar to intraclastic calcarenites. Variably sorted lithoclastic biointrasparites	1) Shoreline 2) Introduced during periodic storm event
Mid and dark grey, shaly foetid calcarenites and calcisiltites	Throughout Raven Ray Formation and locally in Thornton Force Formation and Horton Limestone	Generally less than 15 metres	Medium to thin wavy beds interbedded with black shales. Packed biomicrite and sparse biomicrites	1) Normal marine shelf lagoon 2) Protected shallow subtidal areas
Fenestral calcilutites	Moughton Calcilutite Member and locally in Douk Gill Formation	Generally less than 2 metres	Thin to medium beds of laterally impersistent fenestral biomicrite	Intermittently exposed tidal flats
Featureless Calcilutites	Moughton Calcilutite Member and locally in Douk Gill Formation	Generally less than 5 metres	Thin to medium beds, laterally impersistent, biomicrites, locally containing oncolites	Tidal flat-lagoonal environment
Rudites with clastic matrix	Locally present at base of Thornton Force and Douk Gill Formations and Horton Limestone	Generally less than 2 metres	Thin wedging beds, occasionally stacked. Matrix-supported pebble, cobble and boulder rudites	1) Subaerial debris flows 2) Beach gravels
Rudites with carbonate matrix	At base of Thornton Force and Raven Ray Formations and Horton Limestone	Less than 1 metre or 5 - 15 metres	Wedging beds of clast-supported pebble, cobble and boulder rudite with a matrix of calcarenite	1) Storm-tossed pebble lenses in nearshore environment 2) Shore-face storm deposits
Granule arenites	Only at two localities near base of Thornton Force Formation	Less than 9 metres	Thick wedging beds with erosive bases and planar cross-lamination	High energy shoreline
Calcareous quartz arenites	Restricted to Thornton Force Formation in Chapel-le-Dale	Less than 2 metres	One or two thick beds with erosive tops. Interlaminated intrasparite and lithoclast-rich intrasparite	Nearshore environment above wave base
Argillaceous quartz arenites & litharenites	Restricted to lower part of Douk Gill Formation	Less than 2.5 metres	Medium to thick beds of sublabile lithic arenite. Locally parallel or ripple laminated, bioturbated	Shallow protected lagoon with intermittent wave activity
Carbonate-cemented arenites	Isolated outcrops in the Raven Ray Formation and Horton Limestone	Less than 0.5 metres	Medium and thick beds of quartz sand cemented by calcite or dolomite. Cross or parallel laminated	Nearshore environment above wave base
Black lutites	Intermittently developed in all four formations	Usually 0.02-0.05m rarely greater than 0.5m	1) Thin, irregular beds interbedded with limestones 2) Thicker bed containing abundant rootlets	1) Shelf Lagoon 2) Seatearth
Variably coloured lutites	Intermittently developed in all formations except Raven Ray Formation	Usually less than 0.25m	Brown, green, grey and yellow, thinly bedded, mudstones	1) Soil profile 2) Offshore, quiet, marine shelf 3) Lagoon 4) Subaerial
Coal	Poorly developed at top of Douk Gill Formation and Horton Limestone	Less than 0.25m	Very thinly bedded clarains and durains	Protected swamp area

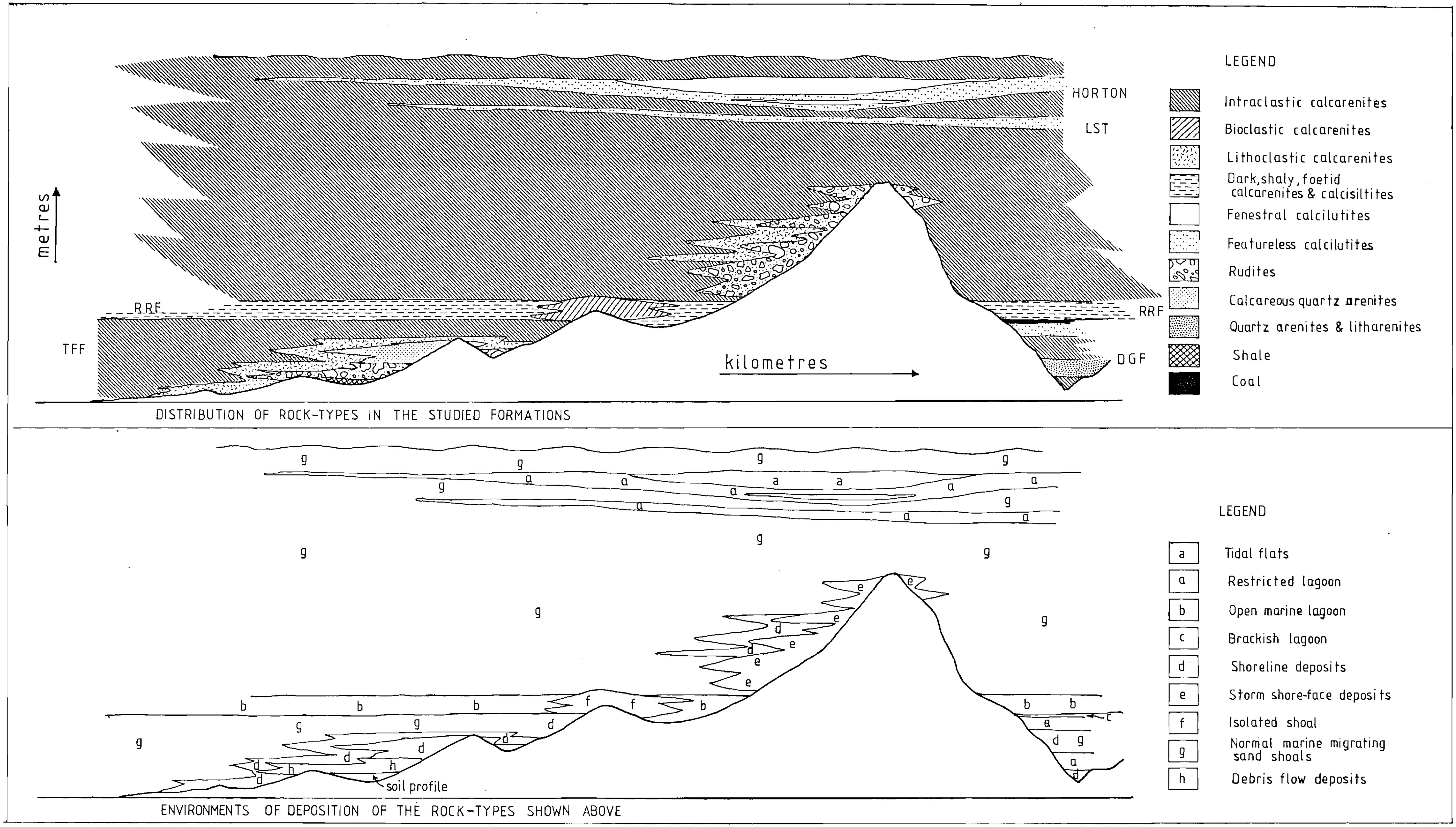


FIG 3·10 HYPOTHETICAL CROSS SECTION SHOWING THE DISTRIBUTION OF ROCK TYPES IN THE STUDIED FORMATIONS AND THEIR RELATIONSHIP WITH THE RELIEF OF THE UNCONFORMITY

CHAPTER FOUR

THE THORNTON FORCE FORMATION

In the study area, the base of the succession shows considerable local variation, owing to overlap of the Carboniferous strata on to the irregular surface of the Lower Palaeozoic rocks. In places the Michelina Zone (the Thornton Force Formation) is absent (Garwood & Goodyear, 1924).

The Thornton Force Formation is the lowermost formation of the Great Scar Group in most of the southern part of the study area; the deposits are limited to the neighbourhood of the North Craven Fault. The Formation was described first by Playfair (1802) and Phillips (1829, 1836). Both authors observed concentrations of pebble to boulder-sized lithoclasts at the base of the formation at numerous localities including Thornton Force (SD69487533). The Formation was described in greater detail by the Geological Survery (Dakyns & others, 1890). Johns (1906) observed that the "basement beds themselves consist of a conglomerate of varying coarseness, replaced here and there by pure limestone. The conglomerate appears in hollows [eroded into the Lower Paleozoic rocks], while the eminences are covered by limestone bands free from included pebbles".

The Thornton Force Formation is so named after the well-known waterfall near Ingleton first described by Playfair (1802). The Formation is very similar in age and lithology to the Red Hill Oolite of Furness, and both formations are overlain by similar deposits. However, there are significant differences, in rock-type and succession thicknesses of the two areas, which are discussed in greater detail in Chapter 9. Prior to the erection of this formation name the deposits were known as the Michelinia grandis Beds (Garwood & Goodyear, 1924).

Recently, the Institute of Geological Sciences have introduced the Kilnsey Limestone (Mundy & Arthurton, 1980, p33) which they correlate with the S_1 Subzone of Garwood & Goodyear (1924), thus it encompasses the Raven Ray Formation of this thesis. It is probable that this inadequately defined Formation also includes the Thornton Force Formation below and the base of the overlying Horton Limestone.

The first age-determination of Carboniferous strata, by means of biostratigraphic zones, was completed by Johns & Vaughan, 1906. They proposed that the Nappa Scar-Norber sequence of Crummack Dale should be placed at the top of the Syringothyris Zone (C) and base of the Seminula Zone(S) of the Bristol area (Vaughan, 1905). This correlation was supported by Garwood (1907) who then became dissatisfied with the Vaughan zones and published (1912) a distinctive biostratigraphic zonation of the Westmorland limestones. This scheme was extended to the Settle area by Garwood & Goodyear (1924). They proposed that the oldest deposits (Thornton Force Formation) could be correlated with the Upper Michelinia Zone and called the Formation the Michelinia Beds. This interpretation has remained unquestioned for many years. However, Waltham (1976) stated that the oldest rocks in the Ingleton area, the Michelinia Beds of Garwood & Goodyear, were of S_1 age. Ramsbottom (1973,1974) proposed that the Michelinia Beds were deposited during the transgressive phase of his Major Cycle 3; a cycle which covers the Michelinia grandis Zone and the Gastropod Beds (S_1 Subzone) of Garwood & Goodyear. George & others (1976) correlated this cycle with their newly defined Arundian Stage.

The Thornton Force Formation is intermittently exposed in river sections, at the heads of springs and in small quarries in the Ingleton area where the limestone was used as building stone. The Thornton Force Formation crops out only in the most deeply incised valleys near the North Craven Fault, where streams have eroded to, or below the unconformity with older Palaeozoic rocks. Usually the Formation is masked by substantial thickess of superficial deposits, both till and alluvium, and exposures tend to be sparse in consequence.

The Thornton Force Formation can be identified in the field by its characteristic hard-weathering, clean washed, pale grey calcarenites, which are often cross-laminated, by the abundance of lithoclasts and its prolific fauna. In good exposures it is a cliff-former. It rests unconformably on folded Lower Palaeozoic rocks and is overlain by distinctive dark grey fine grained calcarenites, often shaly, of the Raven Ray Formation. These weather more easily than the Thornton Force Formation, thus creating a conspicuous terrace which helps to identify the succession at this level.

The study area has been divided into six subareas (Fig.4.1.) to facilitate easier description of the Thornton Force Formation. The rock-types within each subarea are very similar, but between the subareas there are minor differences, not great enough to warrant their separation as distinct formations. The subareas are (1) the Ingleton Dales and the southwest, (2) Moughton Scars and Ribblesdale, (3) Silverdale, (4) Malham Moor and Littondale, (5) Wharfedale and (6) Stainforth in Ribblesdale. All subareas, except the last, lie north of the North Craven Fault.

4.1. Ingleton Dales and the Southwest

The Thornton Force Formation crops out in all the dales of the subarea, which are floored with Lower Palaeozoic rocks. The great number of springs at the unconformity and numerous small quarries provide excellent sections for studying the Formation.

The type-section of the Thornton Force Formation is at Thornton Force in Kingsdale (SD69487533), the most westerly valley of the subarea. The entire thickness of the Formation, 15.45m, is excellently exposed, overlying weathered slates of the Ingleton Group with a local relief of 0.20m. The formation consists mainly of pale grey calcarenites with a lithoclast rudite up to 0.85m thick at the base. The rudite lithoclasts are composed of slate, graywacke and vein quartz, a feature observed by both Playfair (1802) and Phillips (1829). The

lithoclasts vary greatly in size from 2mm to 530x200x200mm, and there is no calcareous component. The top 0.25m, of the rudite consists of a monolayer of graywacke boulders averaging 250mm in length. Above the

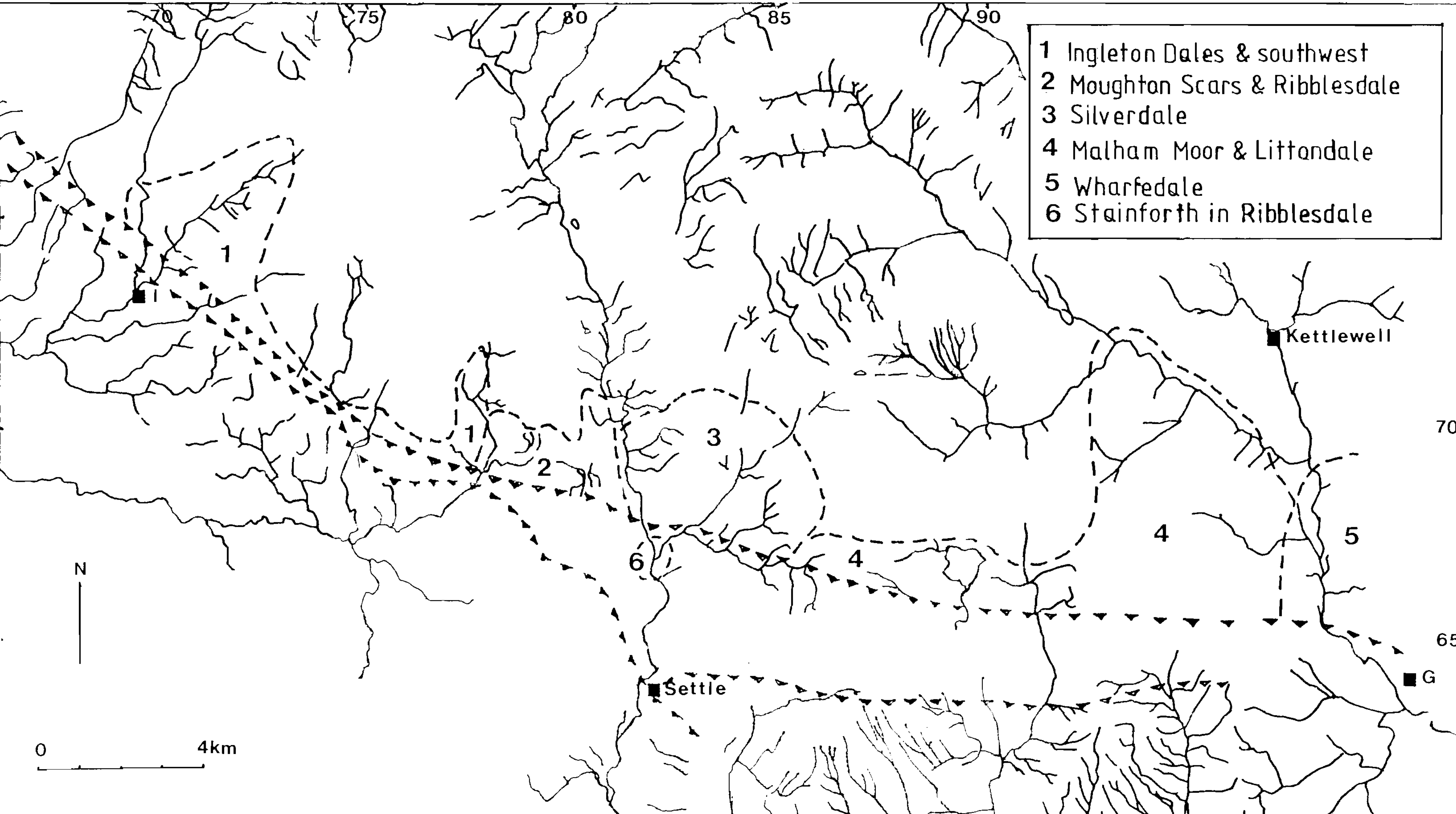


FIGURE 4.1 Map showing regions used for the description of the Thornton Force Formation.

rudite there are 14.60m of cross-laminated, mostly lithoclastic and bioclastic calcarenites. The first bed, 1.85m thick, is a virtually pebble-free, pale grey calcarenite, overlain by a thin, laterally impersistent shale 0.04m thick. At the base of the overlying bed there is a monolayer of isolated lithoclasts including sparse boulders to 500mm in length. Pebble-sized lithoclasts are abundant in the remainder of this 1.20m thick bed, occurring as discrete lamina cosets separated by lithoclast-free calcarenite cosets. Granule and pebble lithoclasts are sparse in the overlying 3.00m of calcarenite and were not observed in the next 4.55m of pale grey calcarenite. Lithoclasts occur in the overlying 2.00m bed, where they comprise approximately 5% of the rock. This bed has subdued relief of 15cm at the base and 40cm at the top. It is overlain by two beds of mid-dark grey calcarenite, together 1.60m thick. The lower bed has 15cm of relief on the upper bounding surface; one of the mounds contains Michelinia. The upper bed has greater relief on its upper surface, in the form of steep-sided, broad ridges 0.50m high (Plate 6a). This surface is disconformably overlain by subhorizontal, dark, grey-black, thinly bedded calcarenites-calcisiltites and shales of the Raven Ray Formation.

There are three other exposures of the Thornton Force Formation in Kingsdale where sections can be measured, all on the western side of the valley. There is intermittent poor exposure on the eastern slopes but no correlable horizons are revealed.

An excellent outcrop is provided by the abandoned quarry at SD69437512, where 9.9m of Thornton Force Formation are exposed. There is more poorly exposed limestone above the quarry section. The unconformity is not exposed in the quarry but occurs immediately below quarry-level in the track to the north. The unconformity, which has relief of 0.35m on its surface, is overlain by 1.40m of calcarenite packed with granule-lithoclasts and then by 2.55m of cross-laminated, lithoclast-free, bioclastic limestone. Capping this bed is a shale parting 0.02-0.08m thick. The overlying limestones are cross-laminated, pale grey calcarenites with laminae of lithoclasts. Immediately above the shale the calcarenite is oolitic; lithoclasts show their greatest concentration and size also at this level, decreasing rapidly up the succession and southwards along the quarry. The bulk of the lithoclasts are granule-sized (2-4mm) although there is a scattering of larger clasts (to 100x40mm) especially near the floor of the quarry. Most of the lithoclasts occur in lamina-cosets (30-40cm thick) and coating the frequent minor erosion surfaces which occur throughout the succession. Fossils are very sparse in this outcrop and none are in life position. The most conspicuous is an inverted colony of Michelinia grandis (first reported by Garwood & Goodyear, 1924,) which lies 1.55m above the shale parting.

South of the main quarry there are exposures of the Thornton Force Formation in some much smaller quarries. At SD69447501 a total of 6.45m of cross-laminated, pale grey calcarenite is exposed. The unconformity is obscured but graywacke crops out 1.50m below the quarry floor. The lowest 2.65m of limestone are virtually lithoclast-free, and correlate with the lithoclast-free calcarenite in the main quarry (Fig 4.4, 1B & 1C). The bed has an irregular top, coated with carbonate-cemented granule lithoclast sand. There are no signs of any shale parting. Above, the calcarenites are cross-laminated, with isolated lithoclasts in occasional thin laminae.

The final outcrop at which a section can be measured is a track-cutting at SD69407492. Here the unconformity is exposed, showing 0.45m of local relief. Rudite 0.35m thick, composed of pebbles (maximum 30mm) of slate, graywacke and vein quartz, and a 0.10m thick quartz and lithoclast arenite fill the relief in the unconformity. They are overlain by 13.7m of cross-laminated, pale grey calcarenite with quartz sand and lithoclast laminae 2-3cm thick at regular 0.20-0.30m intervals. The lithoclast laminae are visible only on weathered faces. Prominent bedding planes in the succession at this locality allow correlation with the previously described Kingsdale sections. The uppermost 6.5m of calcarenite are poorly exposed and there is no evidence of dark grey limestones of the Raven Ray Formation above.

South of this locality, the Thornton Force Formation is poorly exposed above Pecca Slate Quarry (SD69397481). The Formation dips steeply to the southwest because of the close proximity of the North Craven Fault and subsidiary faults. The limestone contains numerous granule lithoclasts and is heavily dolomitised. In Chapel-le-Dale the unconformity and overlying deposits of the Thornton Force Formation are well exposed at numerous localities, springs and small quarries. The limestones of the Formation are very similar to those described in Kingsdale, but there is a significant proportion of clastic deposits at the base of the Formation in this dale.

The most westerly exposure of the Thornton Force Formation at the northern side of Chapel-le-Dale is located just north of Beezelys Farm at SD70557506, at the heads of two adjacent springs. Unfortunately these outcrops are isolated and cannot be correlated accurately with those exposed farther up-valley. The unconformity itself is not exposed but cannot be far below as graywacke crops out in the stream course. The lowest 0.20m of limestone are virtually lithoclast-free, but the overlying 2.30m of mid grey, crinoidal calcarenite are variably lithoclastic. Lithoclasts are granule-sized although pebbles (maximum length 25mm) do occur on top of some beds and in lithoclast laminae. Caninia occurs 0.90m above the base of the section. In the same pasture 2.05m of Thornton Force Formation crops out at SD70457500. Unfortunately the gap between these mid grey, fine grained, bioclastic calcarenites above and the previously described limestones below is unknown.

Approximately 0.5km to the northeast the Thornton Force Formation reappears in a series of springs and small quarries along the unconformity between SD709754 and SD724765. In the first large pasture (Fig 4.5., 3A-K) there are 11 exposures of Thornton Force Formation, all of which can be correlated with the virtually complete section afforded by the small quarry at SD71287556. Here the Thornton Force Formation can be subdivided into three distinct units which can be traced both east and west along this side of the valley. The middle unit is the least variable and most distinctive; a quartz arenite. The lower unit exhibits great variation and the upper unit usually is limestone. At the quarry the succession is as follows:-

Till. The top of the Formation is obscured.

2.45m, <u>Upper unit</u>. Calcarenite with quartz sand laminae occurring in the lower 0.90m. Pebble and cobble lithoclasts occur throughout in laminae. Coral fragments common. Diffuse contact in quarry sharped by weathering.

1.30m, <u>Middle unit</u>. Quartz arenite. Lowermost 0.60m contain scattered lithoclasts and sparse pebble layers. Uppermost 0.70m,calcareous with corals and brachiopods in most calcareous laminae. Spring at base.
Sharp contact.

0.75m, <u>Lower unit</u> comprising:-
0.45m,rudite composed of weathered pebble-and cobble-sized graywacke lithoclasts in clay matrix.
0.30m, clay-mudstone, non-laminated.

Unconformity.
extensively weathered, steeply dipping Lower Palaeozoic slates.

Westward of this exposure there are only three small outcrops. At SD71267554, 2.60m of Thornton Force Formation are exposed, showing neither top nor base. The lowest bed seen is a pebble rudite 0.20m thick with a clay matrix. It is overlain by 0.70m of calcareous quartz arenite, with sparse pebble lithoclasts and carbonate lenses, and 0.25m of quartz arenite both belonging to the middle unit. The quartz arenite contains numerous calcareous lenses and becomes increasingly calcareous upwards. It is succeeded by 1.55m of pale grey, medium grained calcarenite with sparse graywacke pebbles in lenses and scattered throughout. <u>Syringopora</u> and poorly preserved bioclasts are common.

At SD71177550, 4.20m of the Thornton Force Formation lie unconformably on graywacke; the top of the Formation is obscured by till. At the base the lower unit consists of 1.20m of cobble rudite becoming increasingly calcareous upwards. It is overlain abruptly by the middle unit, 1.05m of lithoclast-free quartz arenite of which the uppermost 0.15m is calcareous. Overlying this is 1.20 of pale grey calcarenite with laminae of quartz sand and scattered pebble-sized lithoclasts, succeeded by 0.75m of coarse grained calcarenite with smaller and sparser lithoclasts and rich in large, abraded fragments of solitary corals including Palaeosmilia and Caninia. Both beds belong to the upper unit.

The most westerly exposure in the pasture, at SD71157548, is well exposed and complex. The Thornton Force Formation unconformably overlies overturned Ordovician slates in unusual fashion; the ends of thin beds of slate appear to be incorporated into the base of the lower unit, a rudite 0.38-0.68m thick. This rudite is composed of angular to rounded lithoclasts of medium grained graywacke, slate and vein quartz, of very variable size (2mm to 125x85x35mm), in a matrix consisting of lithoclast sand and silt. There is some imbrication of the larger lithoclasts, but most are randomly orientated. The overlying middle unit is thicker:

———	Upper Unit
0.55m,	Quartz arenite with sparse lithoclasts, pebbles concentrated in the top 0.05m.
0.20m,	Lithoclast rudite with a calcarenite matrix. Pebbles are coarsest at base (largest 150x55mm).
0.05m,	Slot, probably shale.
0.47m,	Calcarenite, pale grey, medium grained, bioclastic, containing rounded intraclasts (70x42mm, 80x35mm) derived from a similar type of limestone. Lithoclasts occur in lenses and in isolation. Lenses of coral hash and quartz films increase in frequency towards the top of the bed as lithoclast-size and quantity decreases.
0.58m,	Calcareous quartz arenite, cross-laminated. Lithoclasts, intraclasts, and coral and brachiopod hash occur in distinct lenses. Palaeosmilia, Syringopora, Lithostrotion, Caninia and Eomarginifera. Hummocky top to bed with hollows filled with a monolayer of graywacke cobbles and pebbles
———	Lower Unit.

The quartz arenite is abruptly overlain by 1.35m of cross-laminated, medium grained, pale grey calcarenite with scattered pebble-lithoclasts, quartz sand films and numerous large bioclasts. Syringopora, Palaeosmilia, Caninia, Lithostrotion and Carcinophyllum occur. At this point the succession becomes obscured by till; it is impossible to estimate the total thickness of the Thornton Force Formation present.

Eastwards of the quarry locality there are poor exposures of pebble rudite; 1.2m thick at SD71297557, 0.37m thick at SD71317558, and 0.40m thick at SD71337559. The rudites, exposed in local small hollows in the unconformity, are composed of alternating thin layers of cemented and uncemented cobble and pebble lithoclasts.

Almost the entire thickness of the Thornton Force Formation, 6.30m, is exposed at SD71357562, (Fig 4.5.,3F). The unconformity is not seen but cannot be far below. The section measured is as follows:-

——	Mid-dark grey, foetid calcarenites of the Raven Ray Formation
4.20m,	Limestone, pale grey calcarenite with sparse quartz laminae in the lowermost 0.50m, and discontinuous pebble layers throughout. Bioclastic, Lithostrotion, Caninia, Syringopora rich in upper 1.30m. Bed top irregular, burrowed and bioturbated.
0.50m,	Interlaminated quartz arenite and calcarenite with numerous pebble-sized intraclasts. Cross-laminated.
1.40m,	Quartz arenite, top calcareous. Pebble layer 10cm thick near base.
0.20m,	Pebble rudite.

Northeastwards the quality of the exposure deteriorates; only 0.60m of rudite, composed of alternating cemented and clayey pebble layers, are exposed at SD71427565. At SD71447566 (Fig. 4.5, 3H) exposure has improved and 2.40m of Thornton Force Formation are seen. A pebble rudite similar to that of the previous locality overlies weathered Ordovician slates unconformably and is overlain by 0.25m of pebbly quartz arenite. It is succeeded by 1.15m of pebble-free calcareous quartz arenite abruptly overlain by 0.50m of calcarenite packed with granule and small pebble lithoclasts. The remainder of the Formation is obscured by till.

To the northeast at SD71477568 5.60m, probably the major part of the Thornton Force Formation, are exposed. A gravel, 0.30m thick, of loose rounded pebbles, possibly derived from a weathered rudite, occurs approximately one metre above the highest exposed graywacke beds; the unconformity itself is not seen. The lowermost in situ bed is quartz arenite, here only 0.30m thick. Above it are 1.50m of calcarenite packed with lithoclasts, overlain by 3.50m of increasingly poorly exposed pale grey calcarenites. The contact with the overlying Raven Ray Formation does not crop out.

The most northeasterly exposure in this pasture occurs at SD71497572. There is considerable local relief on the unconformity and the quartz arenite (0.75m thick) is seen resting unconformably on Ordovician graywackes approximately 1.00m below adjacent graywacke ribs. The arenite is succeeded by 1.00m of pale grey lithoclastic calcarenite and then poorly exposed beds of lithoclast-free and lithoclast-rich calcarenite. All of these beds wedge out to the northeast against the rising unconformity in a distance of only 25 metres.

In the next pasture, above Twisleton Dale House, the unconformity and overlying deposits are not well exposed; there are only four clear outcrops. At the most southwesterly exposure (SD71827590), 2.15m of Thornton Force Formation are seen. 0.40m of sandy calcarenite with lenses of pebble lithoclasts on top overlies 0·20m of cobble-pebble rudite; the unconformity is not seen. Above, the remainder of the exposure comprises calcarenite with layers of pebble-lithoclasts 10-20cm thick at irregular intervals.

At SD71867593 (Fig. 4.6.,4B) the unconformity again is not exposed, but a greater thickness, 7.65m, of Thornton Force Formation is visible; the contact with the overlying Raven Ray Formation is not seen:-

3.00m, Limestone, calcarenite, fine grained, pale grey. Sparsely lithoclastic, abundant corals and local concentrations of crinoids.

0.55m, Sandstone, calcareous quartz arenite, coral-rich (large fragments of Michelinia, Syringopora and Palaeosmilia).

Cobble-layer on bed top (max. clast sizes, graywacke 210x180x70mm, slate 750x230x35mm).

2.65m, Limestone, calcarenite with lenses of pebble-cobble lithoclasts.

0.15m, Limestone, sandy calcarenite.

0.70m, Limestone, calcarenite with sparse pebble and cobble lithoclasts (maximum 155x80x70mm). Large fragments of coral common. 0.40m, Sandstone, calcareous quartz arenite with pebbles which passes laterally into calcarenite with sand films and sparse cobble lithoclasts (maximum 160x85mm) to northeast, away from ridge in unconformity.

0.30m, Limestone, calcarenite, packed with lithoclasts and large coral fragments.

The exposure at SD71837591 is very small and only 1.90m of pale grey, medium grained, bioclastic calcarenite with pebble lenses are seen resting unconformably on weathered graywacke beds. However, at the most northeasterly exposure in this pasture (SD71907595, Fig. 4.6., 4D) an excellent section is provided by Dry Gill. The exposure was first described by Hardcastle (1889). He observed that there were two feet of conglomerate formed of rounded Silurian pebbles overlain by one foot of clayey shale. Above there were three feet of calcareous shale and shaly limestone and then 4-6 inches of coralline limestone succeeded by 3-4 feet of coarse conglomerate, that is alternating bands of limestone and increasingly finer grained lithoclasts.

Today, the succession is well exposed and is described below in detail. Unfortunately the contact with the poorly exposed Raven Ray Formation above is obscured by a till veneer.

0.60m, Limestone, crinoidal, coarse grained calcarenite with numerous pebble-granule lithoclasts and coral fragments.

0.80m, Limestone, similar to above.

0.50m, Limestone, similar to above.

0.46m, Limestone, 2 beds of lithoclast-free calcarenite separated by a shale parting.

1.40m, Limestone, calcarenite, cross-laminated, fossiliferous. Irregular top with sparse cobble-pebble lithoclasts stranded on bed top.

0.50m, Limestone, similar to above.

0.75m, Limestone, crinoidal calcarenite, faintly cross-laminated. Branching Lithostrotion coral colonies and scattered graywacke cobble-lithoclasts.

1.15m, Limestone, many thin impersistent beds separated by shale partings which contain flattened solitary corals and shell debris. Top bed, 0.40m thick, contains small colonies of branching Lithostrotion.

0.45m, Sandstone, laminated quartz arenite, increasingly calcareous upwards. Contains sparse pebble lithoclasts, locally concentrated to form a pebble rudite.
Sharp contact.

0.40m, Silty-shale, rusty, thinly laminated, unfossiliferous. Sparse 5mm sized graywacke and quartz lithoclasts. On north side of outcrop silty-shale passes into a bioturbated shale with numerous rootlets.
Gradational contact.

0.80m, Rudite, poorly sorted, rounded and angular clasts mainly of graywacke in a clay matrix. Largest clasts 105mm in length, smallest sand-sized.
Unconformity, local minor relief.
Near vertical, interbedded Ordovician slates and graywackes.

Six relatively persistent laminae of pebble lithoclasts were observed in the lower part of the Thornton Force Formation in the first three localities in this pasture; they could not be identified at Dry Gill. The lithoclast layers do not appear to maintain a constant horizon suggesting that there has been some folding or draping of the strata over the irregular pre-Carboniferous topography of this area.

To the northeast, in Twisleton Pasture, there are only two exposures of the Thornton Force Formation. At the most southwesterly exposure (SD72087606) the unconformity is not seen and the lowest bed is a very fine grained, pale grey calcarenite 1.65m thick, containing sparse lithoclasts and quartz sand films. The top of the bed is irregular with hollows 8-11cm deep and 30cm wide, filled with a monolayer of boulders whose maximum dimensions are 195x160x135mm. Above, there are 0.55m of cross-laminated, coarse grained, bioclastic calcarenite with lithoclasts in chaotic arrangement dispersed throughout. Slate (maximum 340x60mm), fine grained graywacke (430x120mm) and coarse grained graywacke (215x250mm) lithoclasts are arranged mostly parallel to bedding. The cross-lamination dips to the southwest. Large coral colonies, including Syringopora, Michelinia and Lithostrotion, occur amongst the lithoclasts. Very sparse, stranded, boulder-sized lithoclasts (750x310x300mm) occur on top of the bed (Plate 3d). The overlying bed (0.70m thick) is a fine grained calcarenite with sparse pebble lithoclasts and a few quartz laminae. Syringopora and branching Lithostrotion occur near the base. The bed is parallel-laminated in the middle, but cross-laminated above and below. At the top of the outcrop are 4.20m of mid grey, very fine grained, cross-laminated, bioclastic calcarenite with sparse pebble lithoclasts. Limestones of the Raven Ray Formations crop out above, but the contact is not exposed.

At the most easterly exposure on the northern side of Chapel-le-Dale (SD72147613) graywacke crops out 2.50m above the base of the previous exposure of the Thornton Force Formation. 2.10m above this, 2.00m of cross-laminated, slightly foetid, mid grey, fine grained calcarenites are exposed. The beds are bioclastic and contain sparse lithoclasts (maximum 30x12x3mm). The cross-lamination is low angle to both southwest and northeast. Limestone of the Raven Ray Formation are exposed 0.75m above the highest bed; the contact between the two formation is not seen.

Several exposures of the Thornton Force Formation are located along the opposite side of Chapel-le-Dale between Skirwith Quarry (SD70887378) and the spring head at SD726756. At a group of small exposures in the vicinity of the old Ingleton reservoir calcareous quartz arenite again occurs within the succession. At the most westerly exposure of the group (SD71377466, Fig. 4.7.,7A) there are 10.40m of limestone. Unconformable on Ordovician slates are 2.45m of pale grey, fine grained calcarenite overlain by 1.80m of calcareous quartz arenite which becomes increasingly calcareous upwards and eastwards. Large plant fragments (maximum size 450x200mm) lie on the bedding planes. Above there is

1.00m of cross-laminated, coarse grained, crinoidal calcarenite with numerous quartz sand laminae. Corals, particularly semi-massive Lithostrotion, are common. Overlying there are 5.15m of mid grey calcarenite fining upwards and containing very little lithoclastic material. Here the Thornton Force Formation is overlain by limestones of the Raven Ray Formation. The contact, an undulose bedding plane, is poorly exposed.

Immediately adjacent to the locality described 1.80m of calcareous quartz arenite crops out. Beyond, at SD71387467, the unconformity is approximately 1.00m higher than at the previous locality. It is poorly exposed, has no observable relief, and is overlain by 1.60m of lithoclastic and bioclastic pale grey, medium grained calcarenite. A monolayer of rounded pebble and cobble lithoclasts (maximum 120x40mm) occurs at 0.85m. Above an unexposed interval of 1.00m, in which the calcareous sandstone could occur, are 3.35m of poorly exposed mid grey,crinoidal calcarenite with sparse lithoclasts and some quartz sand at the base. The upper part of the Thornton Force Formation is not exposed here.

The remaining exposure in this area is at SD71397467 (Fig.4.7.,7C). There is no calcareous sandstone at this locality. At the unconformity, exposed approximately 1.20m above its level in the previous exposure, a monolayer of rounded cobbles of graywacke and angular fragments of slate fill small hollows. The maximum relief on the unconformity at this locality is 1.60m (Plate 2b) where a spine of graywacke protrudes through the lowest thin beds of limestone. The lowermost 3.80m of the Formation are pale grey, medium grained calcarenites, locally bioclastic with crinoids, brachipods and corals, and with sparse lithoclasts throughout. Above an unexposed interval of 0.90m are 0.60m of mid grey, cross-laminated crinoidal calcarenite and then a gap of 0.30m, succeeded by 2.50m of cross-laminated, mid grey calcarenite which is very bioclastic. The top 1.30m are very crinoidal and granule-lithoclasts occur throughout. The contact between the Thornton Force Formation and the poorly exposed overlying Raven Ray Formation is an undulose bedding surface.

No calcareous sandstone was observed northeast or southwest of this group of exposures. In the southwest, in the vicinity of Skirwith Quarry, the Thornton Force Formation is thickly developed; it appears to thin generally to the northeast against a series of gradually rising ridges of pre-Carboniferous rock. The excellent exposure afforded by Skirwith Quarry totally reveals the greatest thickness of the Thornton Force Formation in Chapel-le-Dale; both the top and the base of the Formation can be identified. The top is marked by a distinctive irregular bedding surface which probably is the result of modern weathering and solution beneath till. The succession is described in detailed below:-

5.80m, Limestone, poorly exposed, mid grey, well sorted calcarenites. Bioclastic, sparsely lithoclastic (granules and pebbles). Irregular top.

2.55m, Limestone, cross-laminated, pale grey calcarenite with sparse small lithoclasts and sand films concentrated in the lower 0.15m.

3.75m, Limestone, to prominent irregular bedding plane coated by shale film. Cross-laminated, medium grained calcarenite with numerous granule-pebble lithoclast laminae (Plate 3b). Intraclasts common (40-50mm diameter, maximum 190mm) between 0.90m and 1.55m. Lithoclast content decreases upwards.

1.35m, Limestone, pale grey, fine grained calcarenite with layers packed with granule and small pebble lithoclasts (maximum 10mm). Oolitic where lithoclast-free.

Unconformity with relief approximately 0.50m. Vertical Ordovician graywackes below.

A series of small exposures occur in Skirwith Pasture and in adjoining pastures. At SD70947387 (Fig. 4.7., 6B), 11.00m of Thornton Force Formation are exposed. The unconformity lies in an unexposed interval of 1.80m between the highest graywacke and the lowest limestone, 2.30m of pale grey calcarenite in three beds. There are very few lithoclasts either isolated or in laminae below the topmost 0.50m which is a calcarenite packed with granule and sparse pebble lithoclasts. There is no exposure for the next 2.00m and then 0.60m of pale grey, fine grained calcarenite with concentrations of lithoclasts and fine sand films. The irregular top of this bed is overlain by a thin shale, which is marked by a prominent spring level. Pale grey, fine grained calcarenite, 1.10m thick, with pebble and granule lithoclasts and coral fragments dispersed throughout overlies the shale. A further 5.00m of mid grey, slightly coarser calcarenite with infrequent sand films and dispersed lithoclasts completes the exposure. There is a pronounced terrace at the top.

The outcrop deteriorates northeastwards and at SD70937389 only the lowest 0.15m of the 0.50m of calcarenite packed with granule lithoclasts seen at the previous locality is exposed along with 0.10m of the underlying calcarenite with sparse pebble and granule lithoclasts.

At SD70947391, a much more extensive outcrop reveals 9.20m of Thornton Force Formation. The unconformity is concealed in an unexposed interval of 0.90m between slates and the lowermost limestone, a pale grey calcarenite 0.20m thick. The overlying granule-pebble rudite, 0.15m thick, correlates with the pebbly limestone at SD70947387 (Fig. 4.7., 6B and 6D). Above there are 3.30m of poorly exposed pale grey calcarenite succeeded by 5.65m of poorly exposed mid grey calcarenite to the top of the terrace.

Northeastwards, at SD70947393, the unconformity is exposed and there appears to be a compaction drape in the overlying limestones. The lowest bed of pale grey calcarenite, 0.70m thick, contains a layer of coarse pebbles, cobbles and boulders (maximum 390x130x125mm; 295x180mm) at 0.35m. This entire bed pinches out on both sides against flanking graywacke ridges, in a distance of 3.70m. It is overlain by 3.10m of pale grey, fine grained calcarenite with sparse pebble and granule lithoclasts, which in turn are overlain by a thin shale. Above the shale, which forms a spring line, there are 4.60m of mid grey, cross-laminated, fine grained calcarenite to the top of the terrace. Sparse lithoclasts and bioclasts occur throughout. 5.60m of Thornton Force Formation are exposed at SD70957397 (Fig. 4.7.,6F) separated from the highest graywacke by an unexposed interval of 3.10m. The exposure comprises 1.20m of pale grey, fine grained calcarenite with dispersed lithoclasts above which lie 4.40m of poorly exposed, mid grey, fine grained calcarenites with sparse granule lithoclasts to terrace level.

The exposure deteriorates northeastwards and at SD70967399, 6.60m of intermittently and poorly exposed Thornton Force Formation can be seen to comprise 2.45m of pale grey limestone overlain by 4.15m of mid grey limestone.

Approximately 120m to the northeast, there are two closely adjacent exposures, neither of which reveals the unconformity. At SD71067417, 1.85m of pale grey, cross-laminated, bioclastic, fine grained calcarenite are overlain by 4.20m of mid grey, fine grained calcarenite. Lithoclasts (pebble and granule size) are scattered throughout. In the adjacent exposure at SD71117419, 1.80m of pale grey, fine-medium grained calcarenite containing numerous bioclasts and sparse tiny lithoclasts, and with an irregular top, are overlain by 1.75m of poorly exposed, bioclastic, mid grey, fine grained calcarenite with very sparse lithoclasts. The unconformity does not crop out between these two localities and graywackes are first exposed some distance below.

A further series of small exposures of Thornton Force Formation occurs in the vicinity of Ten Pound Gill. At SD71667482, 2.70m of mid grey, fine grained calcarenite with sparse granule lithoclasts crop out 3.30m above the highest graywacke beds. The quality of exposure improves eastwards and at SD71817496 (Fig. 4.8.,8B), although the unconformity is concealed, 0.20m of mid grey, foetid and shaly, fine grained calcarenite are overlain by 4.60m of cross-laminated, mid grey, coarse grained calcarenite. Above this are 1.05m of mid grey, shaly, fine grained calcarenite with a large branching Lithostrotion colony near the base. The top of this bed is the contact between the Thornton Force Formation and the overlying Raven Ray Formation. It shows irregular relief of 0.15m. At SD71867498, 9.00m of Thornton Force Formation are exposed. The unconformity does not crop out. The lowestmost 1.65m of mid grey, fine grained calcarenite, are overlain by mid grey, medium grained calcarenite becoming finer grained upwards, which comprises the remainder of the exposure. Scattered small lithoclasts occur throughout the sequence. Above are limestones of the Raven Ray Formation, but the contact is not exposed.

At Ten Pound Gill (SD71907501), the next exposure to the east, the unconformity again is concealed. The non-exposed interval between the highest graywacke and the lowest limestone is 1.05m. Shaly limestones, 0.50m thick, are overlain by 0.05m of laminated shale, which is succeeded by litharenite (0.04m) and shale (0.03m). Above is a cobble-pebble rudite 0.40m thick with a monolayer of flat cobbles (maximum size 230x70mm) on top. It is succeeded by 2.55m of mid grey calcarenite comprising beds, 0.50m thick, with bioturbated and burrowed tops. Sand-sized lithoclasts occur throughout. Above an unexposed interval of 0.95m there are 3.65m of mid grey calcarenite containing sparse large pebble lithoclasts (60x12mm) and numerous granule lithoclasts in layers and lenses. Gastropods (bellerophontids) are common. The top is a slightly undulose bedding surface having relief of 0.02 - 0.05m. It is overlain by limestones of the Raven Ray Formation.

East of Ten Pound Gill the thickness of the Thornton Force Formation decreases rapidly. At SD72017516, an irregular surface on graywacke shows a local relief of 0.35m. Poorly sorted cobble-pebble-granule rudite fills this relief but is cut out in places. Clasts in the rudite average 20mm in diameter, with a maximum of 90x90mm. Above an unexposed interval of 0.30m there are 4.60m of mid grey, medium grained calcarenite, which are cross-laminated and bioclastic (containing Caninia, Michelinia, Syringopora, Palaeosmilia and numerous large crinoids and brachiopods) between 0.80m and 2.75m. Lithoclasts are uncommon throughout and particularly sparse in the uppermost 0.55m of limestone.

Eastwards, at SD72037519 the unconformity is 1.80m higher than at the previous locality, although local relief at the exposure is only 0.10-0.20m. 0.70m of pale grey, crinoidal calcarenite with large fragments of Lithostrotion and Syringopora and sparse lithoclasts overlie the unconformity. A layer of graywacke pebbles up to 60x25x25mm in size occurs on the top of the bed and is overlain by 0.10m of shale. The remaining 2.50m of limestone are mid grey, cross-laminated, fine-medium grained calcarenites with lenses of granule lithoclasts, sparse graywacke pebbles, crinoids and small sops of Syringopora.

Eastwards the unconformity rises a further 1.60m at SD72077524, where there is local relief of 1.00m. In the deepest hollows the overlying crinoidal, pale grey, medium grained calcarenite contains numerous lenses of granule lithoclasts, small pebbles, large solitary and branching corals, and brachiopods. A cobble-pebble layer 0.35m above the unconformity is succeeded by 1.15m of crinoidal, pale grey calcarenite and this in turn by 1.25m of fine grained, mid grey, sparsely lithoclastic calcarenite. Limestones of the Raven Ray Formation are sporadically exposed above.

The unconformity continues to rise eastwards; at SD72107525 it has risen a further 3.55m and is overlain directly by the Raven Ray Formation; a crest must occur just beyond, since the Thornton Force Formation is seen again at SD72157530. Here is comprises 0.65m of pale grey, coarse grained, bioclastic calcarenites containing coral, brachiopod, bivalve and crinoid fragments and dispersed granule lithoclasts, and unconformably overlying Ordovician slates. A layer of pebbles (maximum length 63mm) occurs on top of the bed. Above, are 0.45m of mid grey, bioclastic calcarenite with scattered graywacke cobbles and pebbles (maximum 80x42mm). There appears to be compaction draping of the limestones over the Lower Palaeozoic rocks, and the Thornton Force Formation, Raven Ray Formation and lower Horton Limestone dip steeply to the northeast.

There are no more measurable exposures of the Thornton Force Formation in Chapel-le-Dale, although it is possible that the Thornton Force Formation occurs at the head of the spring at SD726756, where blocks of pale grey, crinoidal calcarenite with lenses of granule lithoclasts are found in the stream.

In Jenkin Beck the Thornton Force Formation crops out at one locality, immediately north of the North Craven Fault zone. The gentle dip of 5° to the northeast exposes 10.75m of limestone between SD71277286 and SD71457293. The limestones are unconformable on the late Ordovician Coniston Group. The contact appears to be planar over most of its length but local relief of up to 1.00m can be demonstrated. It is overlain by 2.20m of medium bedded, cross-laminated, fine to medium grained, pale grey calcarenites which are crinoidal and lithoclastic. The lithoclasts, mostly less than 5mm in length, are angular at the base and concentrated in small hollows in the unconformity and in sparse lithoclast laminae. Above an unexposed interval of 2.40m are 2.65m of thickly bedded, pale grey, medium grained, bioclastic calcarenites. The upper bedding surface of the top bed is irregular. There is no exposure for the next 1.80m, above which are 1.70m of mid grey, medium grained calcarenite without lithoclasts. Vegetation obscures the contact with the overlying limestones of the Raven Ray Formation.

The Thornton Force Formation crops out poorly in the adjacent spring, but neither top nor base can be distinguished and no section was measured. The limestones appear to be similar to those described above.

Beyond, the Thornton Force Formation is unexposed for 4km. It reappears in Clapdale where there are two exposures in Clapham Beck, the first near Moses Well (SD751702), the second near the footbridge (SD752703). At the first locality, Moses Well, 2.90m of dolomitised limestone, with abundant granule lithoclasts of grey shale and pyrite in the bottom 0.50m, rest unconformably on calcareous shales of the Coniston Group. There is at least 1.00m of relief on the unconformity. Succeeding the dolomitised limestones there are 0.40m of dark grey calcisiltite and 1.10m of mid grey calcarenite with sparse granule lithoclasts. There is a pronounced bedding plane at the top of the mid grey calcarenites which marks the roof of a small cave, Moses Well. Possibly there is a thin shale at this point. Overlying it are 8.90m of mid grey, fine grained calcarenite which becomes increasingly poorly exposed in the wooded bank above the cave.

At the second locality, the dark grey calcisiltite crops out twelve metres below the footbridge. It is 0.50m thick, and overlain by 1.30m of mid grey, coarse grained calcarenite with layers and lenses of bioclastic debris. The top of this bed correlates with the roof of the cave at the previous locality. Above are 1.75m of pale grey, fine grained calcarenite and then an unexposed interval of about 5.50m, above which beds of dark grey, fine grained calcarenite crop out. This limestone, thin to medium bedded with a foetid matrix, is probably part of the Raven Ray Formation.

At Cat Hole (SD74857001), approximately 0.5km to the west of Clapham Beck and close to the North Craven Fault, 8.60m of Thornton Force Formation are exposed. Dolomitised limestones with calcite-filled vugs lie unconformably on the Coniston Group. There is approximately 0.20-0.30m of local relief. A thick veneer of till obscures the top of the Formation.

The next exposures of the Thornton Force Formation are in Crummack Dale. The most westerly of the outcrops is in Nappa Scars below Norber Brow (SD768696). The outcrop was first described in detail by Garwood & Goodyear (1924). They observed that there were at least 50 feet of grey limestones of which the lowest five feet were unfossiliferous. They described the fauna present noticing that the least abraded forms occurred in limestone nodules (intraclasts).

Three sections were measured at Nappa Scars (Fig.4.10,11A,11B, and 11C). At the most westerly of the three (SD76736957), the unconformity is not exposed. Details of the succession are listed below.

	Prominent terrace with Raven Ray Formation limestones above. Contact with the Raven Ray Formation not seen.
3.65m,	Limestone, cross-laminated, mid grey, medium grained calcarenite containing granule lithoclasts in lenses and laminae. Intraclasts common between 0.45m and 1.70m (Plate 4d)
3.65m,	No exposure.
8.95m,	Limestone, variably lithoclastic and intraclastic, cross-laminated, medium grained, mid grey calcarenite. Common pebble-sized intraclasts between 0 and 1.40m.
2.70m,	Limestone, cross-laminated, coarse grained, mid grey calcarenite. Lithoclastic. Corals, brachiopods and pebble-sized intraclasts common.
0.60-	Limestone, mid grey, very fine grained calcarenite

0.80m, with sparse lithoclasts. Erosive contact with overlying bed (Plate 4b).

The middle section at Nappa Scar (SD76876975) is the most complete and best exposed. A total of 21.95m of the Formation are seen unconformably overlying mudstones of the Coniston Group. The contact with the Raven Ray Formation above is not exposed but probably occurs at a pronounced break in slope immediately above the highest beds of Thornton Force Formation. The succession is described below:-

6.85m,	Limestone. Mid grey, coarse grained, cross-laminated, crinoidal calcarenite with layers and lenses of pebble-granule lithoclasts throughout.
9.00m,	Limestone. Mid grey, fine to coarse grained, cross-laminated calcarenites locally richly intraclastic and containing layers and lenses of lithoclasts. Slate and fine grained graywacke boulder-lithoclasts (maximum 580x170mm) occur 2.90m above the base, and are succeeded by bed of cobble-boulder sized intraclasts up to 260x125mm.
1.25m,	Litharenite composed of granules, with cobble-sized intraclasts, lenses of pebbly calcarenite and brachiopods.
2.05-2.15m,	Rudite, composed of granule-pebble lithoclasts, rounded and well-sorted (10-20mm).
0.30-0.40m,	Limestone. Mid grey, lithoclast-free, cross-laminated calcarenite.
1.30m,	Rudite, composed of granule and small pebble lithoclasts in a carbonate cement (Plate 4a).
1.10m,	Limestone, pale grey, cross-laminated, fine grained calcarenite with sparse pebble-granule lithoclasts.
0.50m,	Carbonate-cemented graywacke boulders (maximum 520x320x250mm) filling hollows in unconformity.
∿∿∿	Unconformity, up to 0.50m of local relief.
	Poorly exposed steeply dipping mudstones of the Coniston Group.

The eastern section at Nappa Scar (SD76926976) is is the most lithoclastic. The unconformity is cut in mudstones of the Coniston Group and has a local relief of 0.10-0.25m. Overlying it are 8.80m of granule litharenite and pebble rudite, mostly planar cross-laminated. Disruption of this cross-lamination takes the form of tapering pits, probably water-ejection structures. 3.30m above the base is a bed of calcarenite 0.15m thick, and discontinuous calcarenite lenses occur in the upper 2.00m. Above are 1.50-2.00m of rounded boulders and cobbles of parallel-laminated quartz arenites and siltstones from the Horton Formation lying in a mush of the same rocks, or locally, in a pebbly calcarenite matrix. The largest boulders are; siltstone 1600x1200x300mm, incompletely exposed; graywacke 2050x1950mm and 950x840x230mm, incompletely exposed (Plate 4c). The boulder bed is overlain by 0.50-1.00m of cobble-sized intraclasts in a calcarenite matrix. Sparse graywacke clasts (850x210mm and 1200x150mm) occur at the base of this bed. The succeeding 1.00m is composed of calcarenite with numerous pebble and granule lithoclasts and pebble-sized intraclasts, then 3.50m of medium-coarse grained, cross-laminated, mid grey calcarenite with lenses of granule and sparse pebble lithoclasts, and local concentrations of intraclasts. The next bed, 0.55m thick, is composed of pebble-cobble sized intraclasts in calcarenite. The overlying 4.00m of mid grey calcarenite contain sparse granule lithoclasts, but apparently no intraclasts. There is no exposure for the next 3.30m, above which foetid calcarenites of the Raven Ray Formation are seen.

Northwards from Nappa Scar the bed-rock is largely obscured by thin till but it is clear that the unconformity rises sharply, the Thornton Force Formation abuts it and is overstepped by the Raven Ray Formation. The rise forms a steeped-sided ridge whose summit line is seen at SD768710, beyond which the unconformity descends to the remaining exposure in this first subarea, at Austwick Beck Head (SD776718). Here, 8.20m and 8.10m of Thornton Force Formation are exposed at the southwest and northeast springs respectively; the two springs are only 20m apart. At the southwesterly spring the Thornton Force Formation overlies the Silurian Horton Formation. There is 0.20-0.30m of relief on the unconformity. The lowest bed is a pebble-cobble rudite 1.20m thick. Most of the lithoclasts are rounded, equant graywacke although sparse, elongate and flattened slate pebbles occur. The lithoclasts lie parallel to bedding at the top of the bed. Above is 0.05m of shale and then 1.65m of mid grey calcarenite with numerous sand-sized lithoclasts.

Next, there are 0.07-0.10m of shaly limestone with an irregular top, and then 0.35m of mid grey calcarenite with scattered pebble lithoclasts.

At the northeastern spring 0.15m of pebble rudite with a clay matrix overlies the Horton Formation. No relief was observed on the unconformity. Above the rudite are 1.05-1.10m of mid grey calcarenite with layers of graywacke pebbles; slate pebbles are uncommon. Overlying this are 0.20-0.25m of shaly limestone with sparse pebbles and then 1.80m of cross-laminated, mid grey calcarenite with sparse lithoclasts, the top of which correlates with the top of the 0.35m calcarenite at the southwesterly spring (Fig 4.11., 12). Above, at both springs, are 4.85m of poorly exposed, fine grained, mid grey calcarenite with sparse pebble- and sand-sized lithoclasts in lenses. The overlying limestones are members of the Raven Ray Formation. The contact between the two Formations is not exposed.

4.2 Moughton Scars and Ribblesdale

There is a series of exposures of the Thornton Force Formation at the base of Moughton Scars from eastern Crummack Dale to Ribblesdale. The Formation is considerably thinner and much less lithoclastic than exposures in the Ingleton Dales and southwest subarea.

The only exposure in eastern Crummack Dale is a gulley near White Stone Wood (SD781705) where 10.65m of mid grey, medium-coarse grained calcarenites with sparse granule lithoclasts crop out. An overturned colony of massive Lithostrotion occurs at 7.40m above the base and gastropods are common at the top of the sequence. The unconformity is not exposed but graywackes crop out in the stream bed about 6m below.

To the southeast, the Formation is next exposed at SD78606990 where there is 1.40m of relief on the unconformity. 8.90m of medium bedded, bioclastic, medium grained, mid grey calcarenite unconformably overlie the Silurian Horton Formation. The base of the succession is rubbly and contains small pebble lithoclasts. Above, the lithoclasts are much smaller and sparser as the limestone becomes increasingly bioclastic.

Lithostrotion and Syringopora are common along a bedding plane 3.50m above the base. The top of the Formation is obscured by till, but probably is defined by a sharp break in slope immediately above the highest beds, above which rubbly beds of the Raven Ray Formation crop out.

At SD78806995, 7.60m of Thornton Force Formation are exposed to the level of the terrace. The unconformity is approximately 2.25m higher than at the previous locality. The Formation consists of medium-thickly bedded, mid grey, medium grained calcarenites with sparse lithoclasts. An overturned massive Lithostrotion occurs in the top bed.

Beyond, at SD79506980, there are 6.3m of mid grey, fine grained calcarenite with sparse small pebble and granule lithoclasts. The unconformity is not exposed. The top of the Formation is delineated by a pronounced terrace at this locality.

The next three sections were all measured in the neighbourhood of Moughton Nab. At SD79666965 (Fig. 4.12., 14A) the unconformity is not exposed but the Horton Formation crops out only 1.50m below the lowest limestones. 4.10m of limestone are seen. The lowest 2.35m are mid grey, slightly foetid, fine grained calcarenite with sand-sized weathered lithoclasts. The limestones are very bioclastic, containing crinoids, gastropods and much shell hash. They are separated from the overlying 1.75m of dark grey, very fine grained, bioclastic calcarenite by a very prominent bedding plane. Above there are limestones of the Raven Ray Formation. A second strong parting, much excavated by solution, marks the contact between the two Formations.

The unconformity is not exposed at SD79706960 although graywackes crop out only 1.50m below the lowest limestones. There are 1.80m of poorly bedded, slightly foetid, mid grey calcarenite without lithoclasts, and 1.55m of very bioclastic, slightly foetid, dark grey, fine grained calcarenite above. There is a marked change in lithology at the bedding plane separating the overlying Raven Ray Formation from the Thornton Force Formation.

The unconformity is seen at the third exposure on Moughton Nab (SD79806966). There is approximately 0.15m of local relief. 2.70-2.85m of mid grey, bioclastic calcarenite and 1.50m of overlying dark grey, fine grained calcarenite comprise the Thornton Force Formation at this locality.

North of Moughton Nab, another series of sections was measured under Moughton Scars in Ribblesdale. At the first, above Dry Rigg Quarry (SD799699), 2.35-3.65m of Thornton Force Formation are exposed. There is at least 1.30m of relief on the unconformity at this locality (Plate 1c); the lowest bed of sparsely lithoclastic dolomite is from 0.70-2.00m thick. It is overlain by 1.65m of dark grey, fine grained calcarenite entirely free of lithoclasts.

At the next locality (SD800701) the Thornton Force Formation has increased in thickness. There is at least 0.70m of relief on the unconformity, which is covered by 0.20-0.90m of sparsely lithoclastic dolomite. Above the dolomite there are 5.30m of mid grey, fine-medium grained calcarenite with sparse pebble and granule lithoclasts. Bellerophontids are common. The junction with the overlying Raven Ray Formation is marked by an irregular bedding plane.

The most northerly exposure of Thornton Force Formation in Ribblesdale is between SD801704 and SD801705, above Arcow Wood. Beds of the Silurian Horton Formation are separated by an unexposed interval of 1.60m from 6.95m of mid grey, medium grained calcarenites. Pebble lithoclasts and gastropods are common at the base of the exposure but decrease in quantity upwards. The top of the Formation is marked by a prominent terrace. The unconformity rises steeply to the north over the next 250m, cutting out the entire thickness of the Thornton Force Formation.

On the eastern side of Ribblesdale, where the ground is thickly blanketed by till, there are no exposures of the Thornton Force Formation.

4.3 Silverdale

This subarea contains a few problematical exposures at which sections were measured. The rocks described below may not all belong to the Thornton Force Formation. There are three isolated areas of outcrop; a group of discontinuous exposures northwest of Neals Ing, an exposure near Silverdale Barn, and a third at the resurgence of Roughlands-Fornah Gill.

The first of these areas (SD832691) covers parts of two pastures. Pre-Carboniferous rocks are very sparsely exposed in the more southerly pasture, which is dominated by a large, semicircular terrace. In a spring at the southern end of the terrace (SD83226913) loose blocks of pebbly limestone overlie Silurian graywackes. The unconformity is probably hereabouts. The only exposure in the terrace consists of 1.70m of limestone with lithoclasts: it comprises, in ascending order: 0.40m of pebble rudite with coarse coral debris (clisiophyllids, Lithostrotion and Syringopora) in a calcarenite matrix; 0.35m of pebble-free, mid grey calcarenite; 0.55m of calcarenite, packed with pebbles ranging from 4mm to 40mm in diameter with a dominant mode from 10-20mm; 0.40m of mid grey calcarenite with sparse granule lithoclasts. There are no exposures across the sloping, till-covered top of the terrace and up its backslope for the next 9.10m, above which the outcrop resumes with 2.65m of mid grey, medium grained calcarenite with sparse lithoclasts. This is overlain by 0.45m of very fine grained, pale grey calcarenite with very sparse granule lithoclasts. The top of this bed is a conspicuous bedding plane, above which well bedded, closely jointed, pale grey limestones crop out. These upper limestones outcrop sporadically in the backslope into the next pasture to the north, but too poorly to establish any continuity. The wall between the two pastures is unusually high (over 2 metres), making correlation even more difficult.

In the northern pasture there is a prominent outcrop of vertical graywacke below the unconformity. Ribs of graywacke protrude 3 metres above adjacent ground level. South of the graywacke belt, limestone crops out at SD83356928 where the following poor sections can be deciphered:

	<u>Limestone</u> Conspicuous bedding plane
0.45m,	Pale grey calcarenite with layers and lenses of lithoclasts
1.65m,	Dark grey calcarenite, locally rich in pebble lithoclasts and with gastropods and corals.
0.60m,	Concealed
0.50m,	Dark grey, fine grained calcarenite
4.50m,	Concealed
1.50m,	Pebble-cobble rudite with calcareous matrix; clasts rounded and poorly sorted, average 10-20mm long in lower half, 25-30mm ranging up to 60mm in upper half. Pre-Carboniferous rocks not seen.

The unconformity rises sharply over the graywackes, cutting out the whole of the above section and 4.00m of overlying limestones before the outcrop disappears beneath a large drumlin. At the point of disappearance the unconformity is approximately 375m above sea level.

At the northern end of the drumlin, alongside Silverdale Barn (SD83866965) there is an extensive poor exposure at an elevation of 340m OD. The unconformity is not seen although cleaved siltstones of the Silurian Horton Formation crop out just below the lowest limestones, 3.40m of fine grained, dark grey calcarenite with sparse lithoclasts. The calcarenites are slightly foetid and corals (particularly phaceloid <u>Lithostrotion</u>) are common at the base. Above are sporadic exposures of foetid, rubbly limestones, probably members of the Raven Ray Formation.

The remaining exposure in Silverdale, at an elevation of 375m OD, is at the resurgence of Roughlands or Fornah Gill (SD845694). 7.50m of thin bedded, mid grey, medium-fine grained calcarenite overlie Silurian graywacke. The limestones are very crinoidal but contain no lithoclasts. The top of the limestones is obscured by thick till.

4.4. Malham Moor and Littondale

There are hardly any outcrops of the Thornton Force Formation in this very large subarea. The Formation is either obscured by till and alluvium or erosion has not reached sufficient depths to reveal the deposits.

There are two exposures at Black Hill (SD866665). The unconformity is not seen, but Silurian graywacke crops out only 1.00m below the lowest limestones. Approximately 3.00m of Thornton Force Formation, cross-laminated, bioclastic, mid grey calcarenites, with granule lithoclasts of graywacke and vein quartz, 2-5mm in length, are exposed.

There are no more exposures in the neighbourhood of Black Hill or Capon Hall, although O'Connor (1964) suggested that the prominent scarp running behind Capon Hall towards Highfold Scar, with several springs along it, may mark the unconformity. Also Dalton (1872) described outcrops, now obscured, of "limestone conglomerate" and abundant Silurian pebbles in sandy limestones in the vicinity of Capon Hall.

The next existing outcrops are located in upper Gordale. They are very poor. At SD91306570, there is about 0.50m of dolomite overlain by thin bedded, slightly foetid, dolomitised, mid grey calcarenite. About 1.65m of dolomitised calcarenite is exposed at SD91096590 and SD91086592 on either side of the beck. Dark grey, slightly foetid calcarenite, with quartz clasts 3mm in size, is exposed at SD91296758. Downstream, just north of the North Craven Fault (SD911657), strongly cleaved mudstones of the Silurian Horton Formation are exposed. There are two more exposures near Malham Moor Lane at SD94556568 and SD94756515. The total of Thornton Force Formation in this region is approximately 3.00m.

O'Connor (1964) reports that blocks of "basal conglomerate" containing pebbles of Silurian slate in limestone matrix were found at Great Close Mire, along the eastern shores of Malham Tarn. The unconformity probably is not far below surface. No such blocks were observed during the present investigation.

There is a series of poor exposures of pale grey and mid grey calcarenites in the bed of the River Skirfare, near SD961699 (Fig 4.14, 20), approximately 7km to the northeast. There are four exposures in all in the southern bank of the river. It is impossible to determine the stratigraphical gaps between individual exposures because of the varying dip of the beds. The coarse grained, bioclastic calcarenites contain crinoids, disarticulated brachiopods (including Spirifera,Martina and Echinoconchus), sparse poorly preserved corals and algae. Coated grains are common.

The remaining exposure in this subarea is in Cowside Beck approximately 3km to the northeast. The outcrop is near Arncliffe, at SD928717. Only 2.60m of limestone are exposed between alluvium and till; they are quite clearly part of the Thornton Force Formation. The coarse grained, mid grey calcarenites are very fossiliferous and contain numerous coated grains.

4.5 Wharfedale

There is only one exposure of rocks equivalent to the Thornton Force Formation in this subarea, at Mill Scar Lash (SD979664) where limestone is brought to the surface by an east-west anticlinal fold. The outcrop represents the northern limb of that fold. Dakyns (1893) suggested that lower Palaeozoic rocks might occur in the river bed close-by under a covering of drift and alluvium.

Garwood & Goodyear (1924) identified Michelinia grandis and Chonetes carinata in the lowermost beds and suggested that they were part of the Michelinia Zone. In the overlying beds they recognised Lithostrotion martini, a fossil diagnostic of their overlying Productus Subzone.

The following section, totalling 16.15m, is exposed at Mill Scar Lash;

1.50m, Pale grey, coarse grained, bioturbated calcarenite.

0.05m, Black shale.

2.00m, Mid grey, coarse grained, cross-laminated calcarenites with numerous bioclasts (crinoids, Palaeosmilia, athyrid brachiopods, algae) and coated grains.

2.00m, Dolomitised calcarenite, most intensely dolomitised between 0.55m and 1.30m.

2.00m, Mid grey, fine grained calcarenites (biomicrites) forming medium-thin beds separated by shale beds. Silifified bioclasts (especially Syphonophyllia and Palaeosmilia) are common.

0.80m, Mid grey, fine grained calcarenite in two beds.

1.85m, Black and dark grey, fine grained calcarenite (biomicrite) in medium beds separated by shale partings.

0.45m, Dark grey, fine grained calcarenite in a single bed.

2.70m, Dark grey, fine grained calcarenite comprising 10 wedging beds with shale partings. Burrowed. Solitary corals, chonetid brachiopods, crinoids and bryozoan are common.

0.40m, Thinly bedded, dark grey, fine grained calcarenites and impersistent shales.

0.50m, Single bed of mid grey, fine grained calcarenite with a mounded surface.

0.05m, Persistent black shale.

0.90m, Black, foetid, fine grained calcarenite (biomicrite) in a series of thin beds separated by shale partings.

0.95m, Dark grey, fine grained calcarenite comprising 2 beds.

The unconformity is not exposed.

Lower Palaeozoic rocks probably occur not far below and have been recovered from the Department of Energy Borehole located at SD972664 in Wharfedale.

4.6 Stainforth Force

The sixth and final subarea, the only one to lie south of the North Craven Fault, contains but a solitary outcrop, at Stainforth Force

(SD817672). Here the unconformity is not reached but there are extensive outcrops of the Thornton Force Formation from the confluence of Stainforth Beck and the River Ribble, up the latter almost to the packhorse bridge (SD817673). Even in its incomplete state, this is undoubtedly the thickest development of Thornton Force Formation, 20.0m occurring between the base of the overlying Raven Ray Formation and the top of a bed of limestone in the river whose thickness cannot be determined.

Garwood & Goodyear (1924) identified Zaphrentis konincki, Caninia subibicina, Lophophyllum meathopense, Chonetes carinata and Michelinia grandis in the beds and stated that the exposure at Stainforth Force revealed the most complete development of the Michelinia Zone anywhere in the Settle area.A similar fauna was identified by Jefferson (1980) who also observed that the rock-types are different from those north of the North Craven Fault.

The lowest beds exposed are thick bedded, dark grey, sparsely lithoclastic, medium grained calcarenites, 1.30m thick, in which bioclasts are very sparse. Overlying them are 3.10m of mid grey, sparsely bioclastic and intraclastic calcarenites above which 4.70m of thin and medium bedded calcisiltites with shale partings occur. The lowermost 2.60m of the calcisiltite are dark grey and lithoclastic. Succeeding the calcisiltites are 1.80m of thinly bedded, mid grey, slightly foetid, fine grained calcarenite with shale interbeds, and then 6.50m (most of the Force) of thickly bedded, dark grey, medium grained calcarenite. Algal coated grains and intraclasts are common at this level. Above, there are 0.10m of persistent black shale and 2.30m of slightly foetid, dark grey, medium grained, crinoidal calcarenite overlain by a 0.05m thick persistent shale. The top of the calcarenite bed is irregular with relief of 0.05-0.25m, and it appears to be an erosion surface. Overlying it are thinly bedded, dark grey to black, fine grained calcarenites-calcisiltites and shales of the Raven Ray Formation.

As can be seen from the above descriptions the Thornton Force Formation is moderately to well exposed in the valleys of the northwestern part of the area. It is increasingly infrequently and poorly exposed to the south and east as the veneer of till and alluvium in the valley bottoms increases and because erosion has not reached sufficient depths to reveal the deposits.

The northern limit to the Formation can be defined with greatest certainty in the Ingleton Dales, Crummack Dale and Ribblesdale where the deposits can be seen to thin towards, and wedge out against, ridges of Lower Palaeozoic rocks. However, its occurrence in isolated inliers, as at Austwick Beck Head (SD776718), imply that local small embayments occurred linked to the more extensive sea to the south and west.

4.7 Figured Sections Through The Thornton Force Formation

1.	Thornton Force and Kingsdale Beck	SD695753-695749
2.	Twisleton End, Chapel-le-Dale	SD705751
3.	Twisleton Scars, Chapel-le-Dale	SD709754-716757
4.	Twisleton Dale House, Chapel-le-Dale	SD718758-719759
5.	Twisleton Pastures, Chapel-le-Dale	SD723763-724765
6.	Skirwith Quarry, Chapel-le-Dale	SD709738
7.	Old Ingleton reservoir springs, Chapel-le-Dale	SD714746
8.	High Howeth, Chapel-le-Dale	SD717748-722752
9.	Jenkin Beck	SD713728
10.	A. Clapham Beck, Clapdale	SD752703
	B. Cat Hole, Clapdale	SD749700
11.	Nappa Scars, Crummack Dale	SD768697
12.	Austwick Beck Head, Crummack Dale	SD776718
13.	White Stone Wood, Crummack Dale	SD782705
14.	Moughton Nab, Ribblesdale	SD798697
15.	Foredale Quarry, Ribblesdale	SD801703
16.	Stainforth Bridge, Ribblesdale	SD817672
17.	Black Hill	SD865665
18.	Upper Gordale	SD911656
19.	Mill Scar Lash, Wharfedale	SD980665

20.	Scar Gill Barn, Littondale	SD961699
21.	Cowside Beck, Arncliffe	SD928716
22.	Silverdale	SD835691, 838696 and 845695.

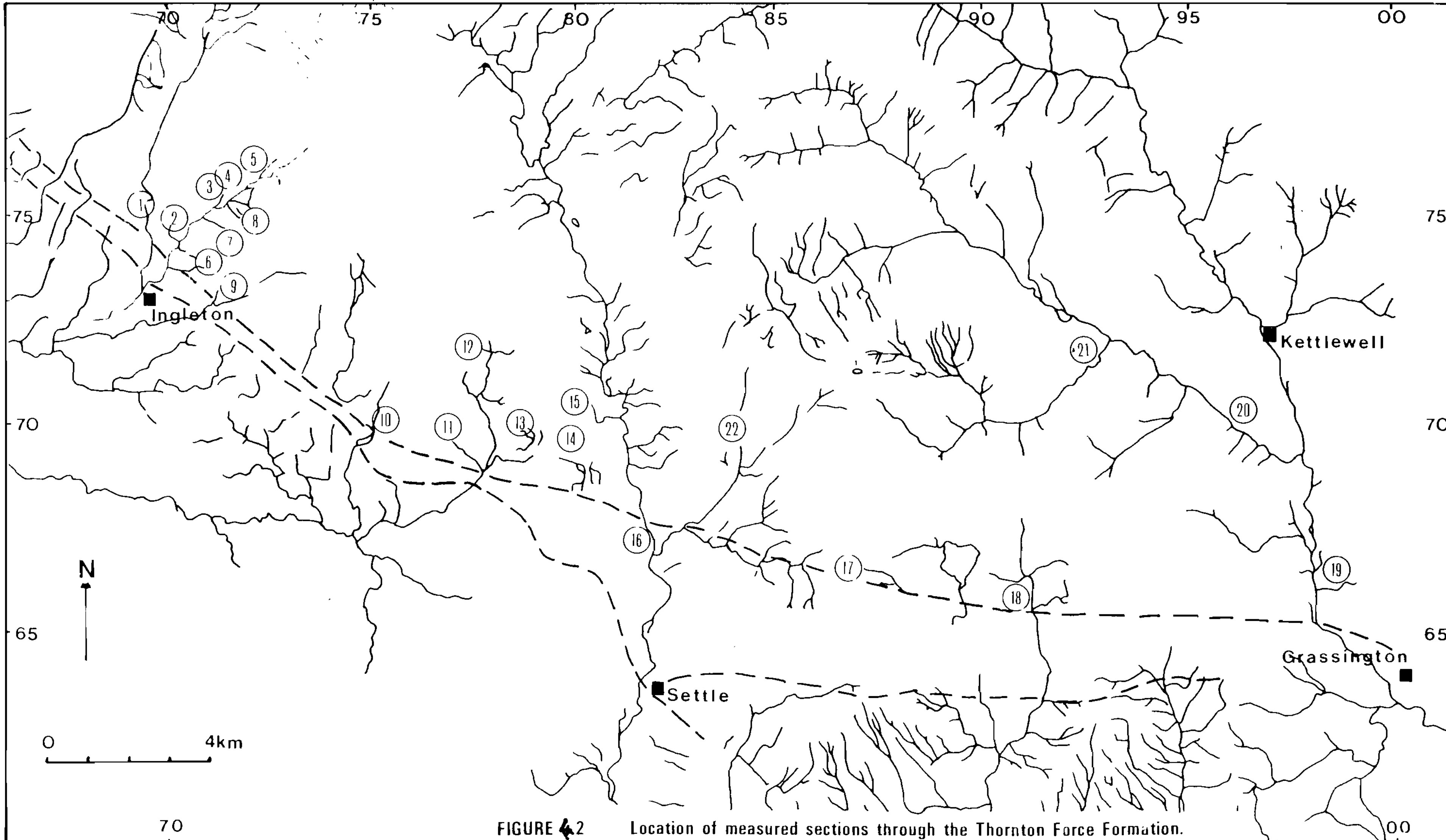
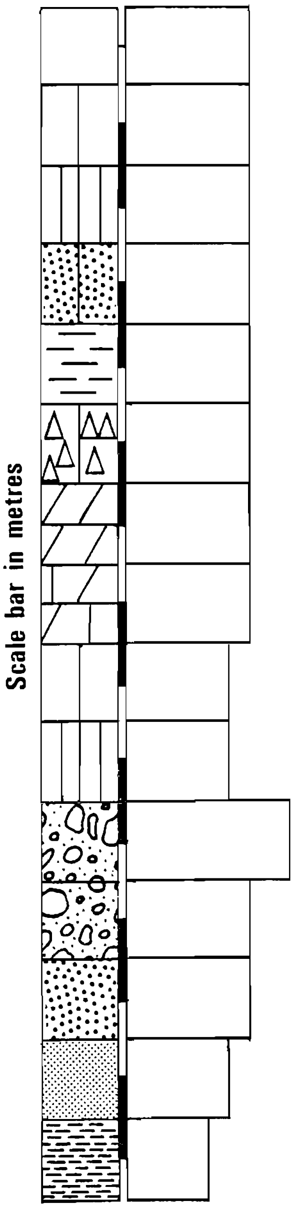


FIGURE 4.2 Location of measured sections through the Thornton Force Formation.



Pale grey calcarenite

Mid grey calcarenite

Dark grey calcarenite

Calcarenite with quartz sand

Calcarenite with shale films

Lithoclastic calcarenite

Dolomite

Dolomitic limestone

Mid grey calcisiltite

Dark grey calcisiltite

Pebble, cobble or boulder rudite

Granule arenite

Fine grained quartz sand

Fine grained quartz silt

Shale

unspecified bioclasts	lithoclasts
bivalves	lithoclast layers or lenses
brachiopods	bioturbation
corals	siliceous
crinoids	coated grains
gastropods	ooliths
algae	concretions
bryozoa	intraclasts
plant remains	foetid

Raven Ray Formation

FIGURE 4.3 Key to symbols used in figured sections through the Thornton Force Formation.

Figures 4.4. - 4.14. Measured sections through the Thornton Force Formation. (Lowermost bed of limestone is shown resting on graywacke where the contact with the underlying Lower Palaeozoic rocks is exposed)

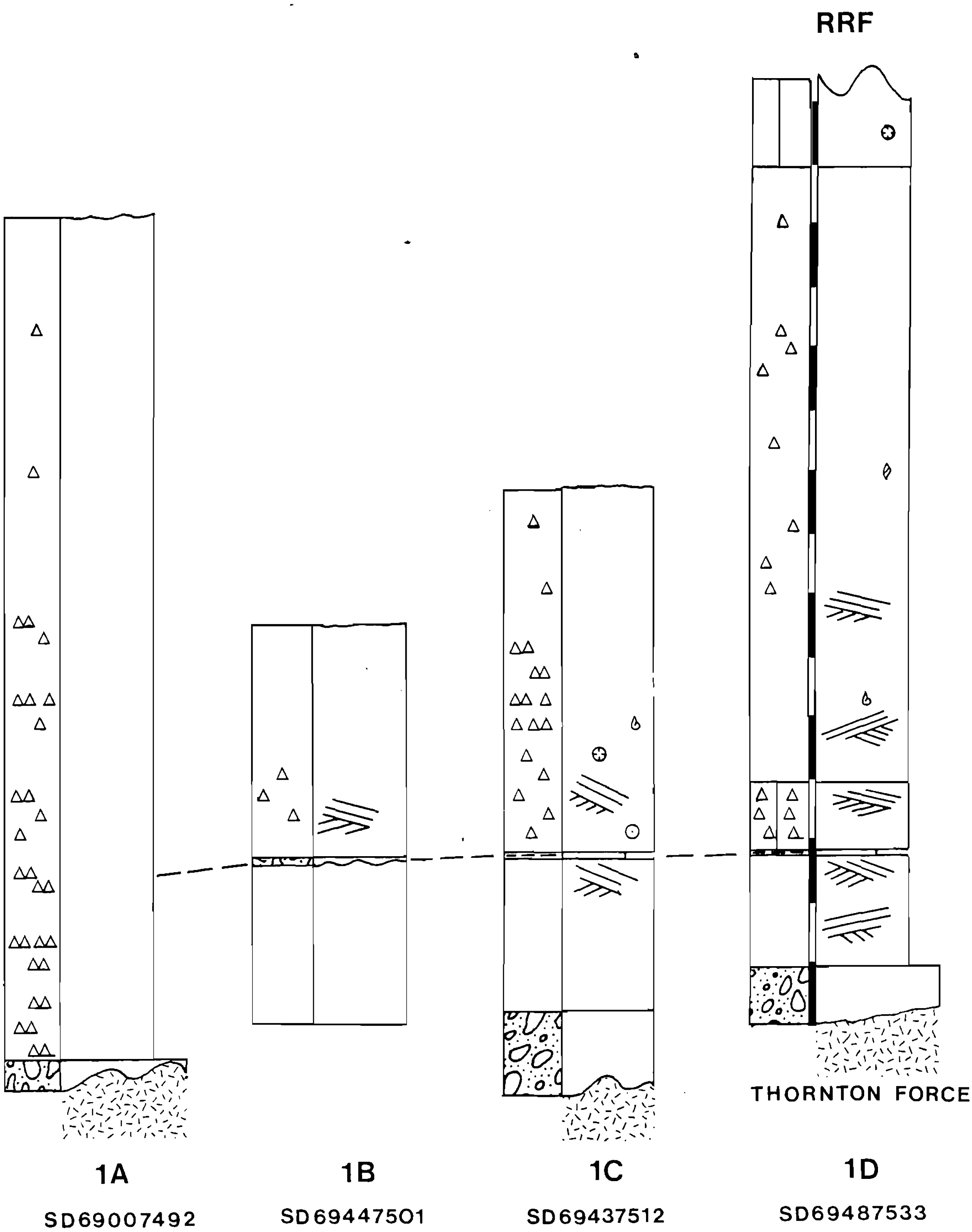

RRF
THORNTON FORCE
1A
SD69007492
1B
SD69447501
1C
SD69437512
1D
SD69487533

FIGURE 4.4

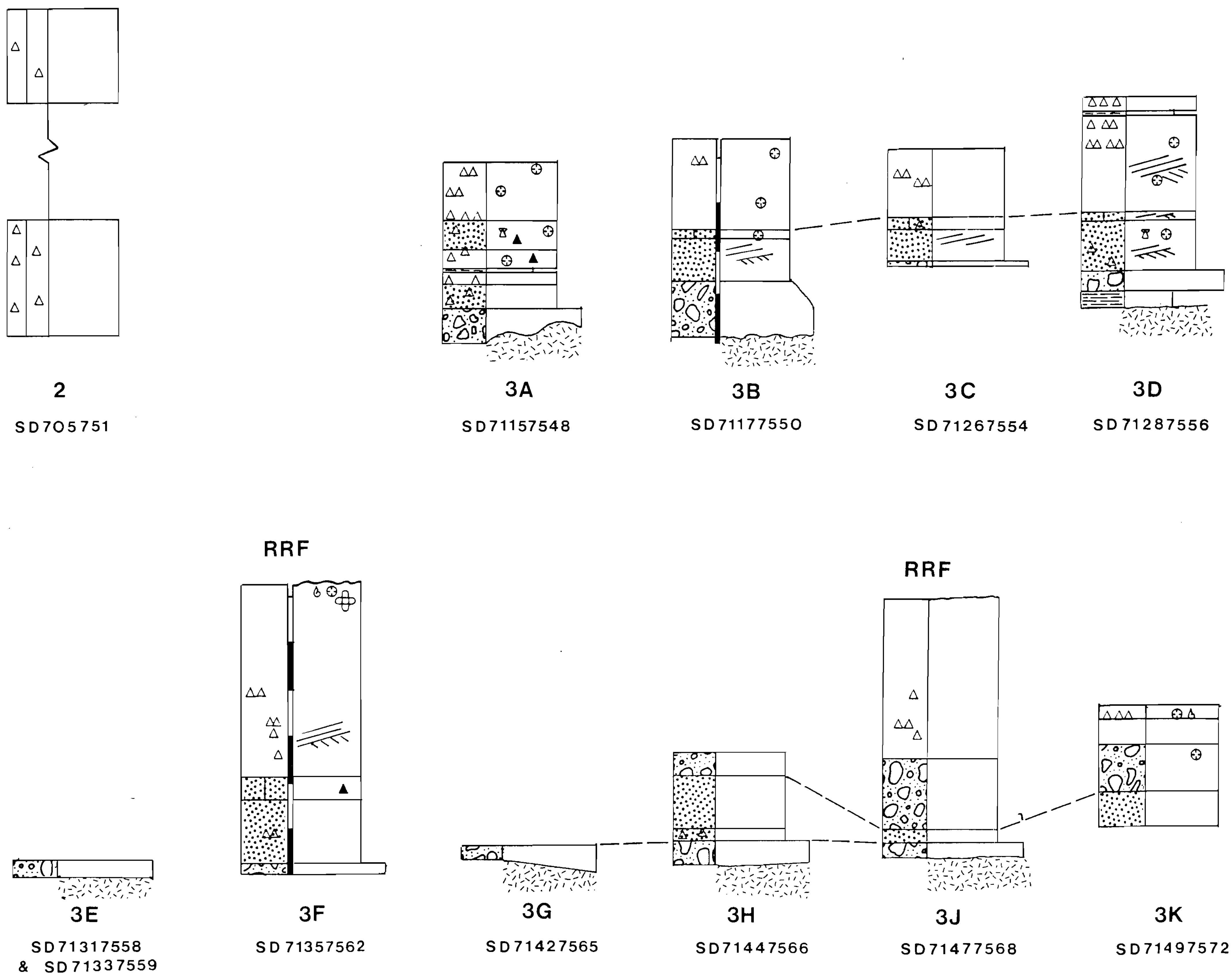

2
SD705751
3A
SD71157548
3B
SD71177550
3C
SD71267554
3D
SD71287556
RRF
RRF
3E
SD71317558
& SD71337559
3F
SD 71357562
3G
SD71427565
3H
SD71447566
3J
SD71477568
3K
SD71497572

FIGURE 4.5

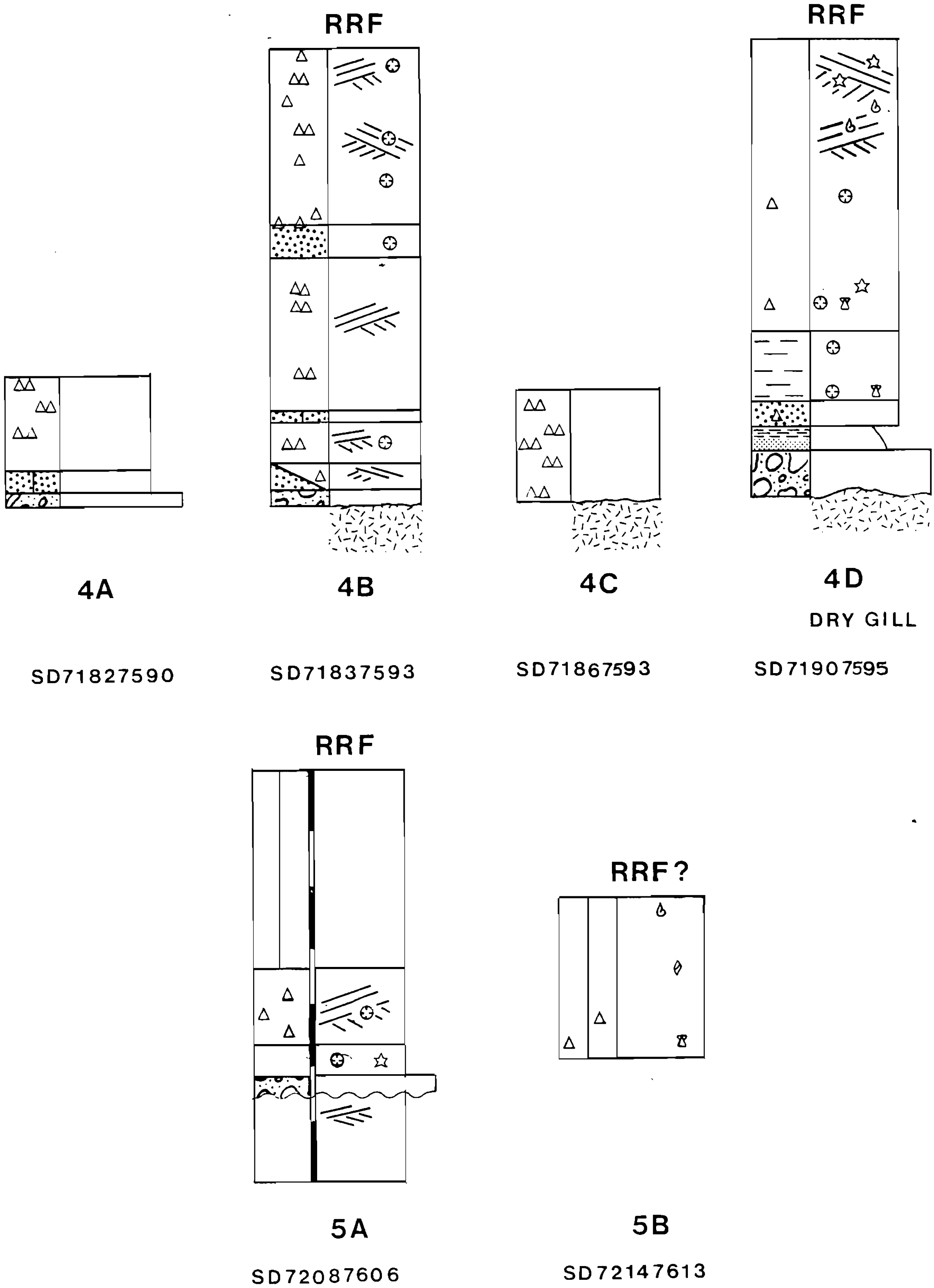

RRF
RRF
4A
4B
4C
4D
DRY GILL
SD71827590
SD71837593
SD71867593
SD71907595
RRF
RRF?
5A
5B
SD72087606
SD72147613

FIGURE 4.6

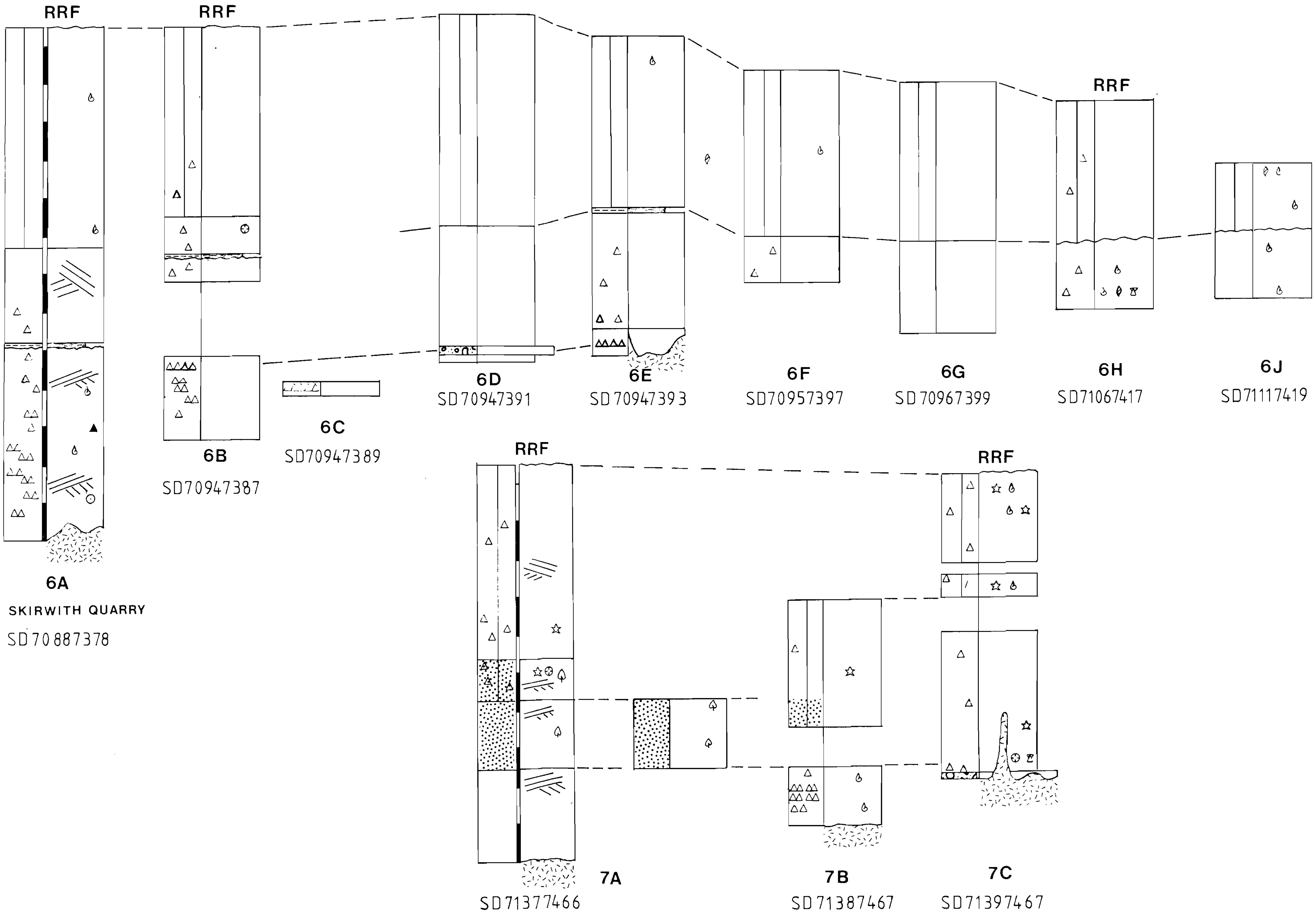

RRF
RRF
RRF
RRF
RRF
6A
SKIRWITH QUARRY
SD70887378
6B
SD70947387
6C
SD70947389
6D
SD70947391
6E
SD70947393
6F
SD70957397
6G
SD70967399
6H
SD71067417
6J
SD71117419
7A
SD71377466
7B
SD71387467
7C
SD71397467

FIGURE 4.7

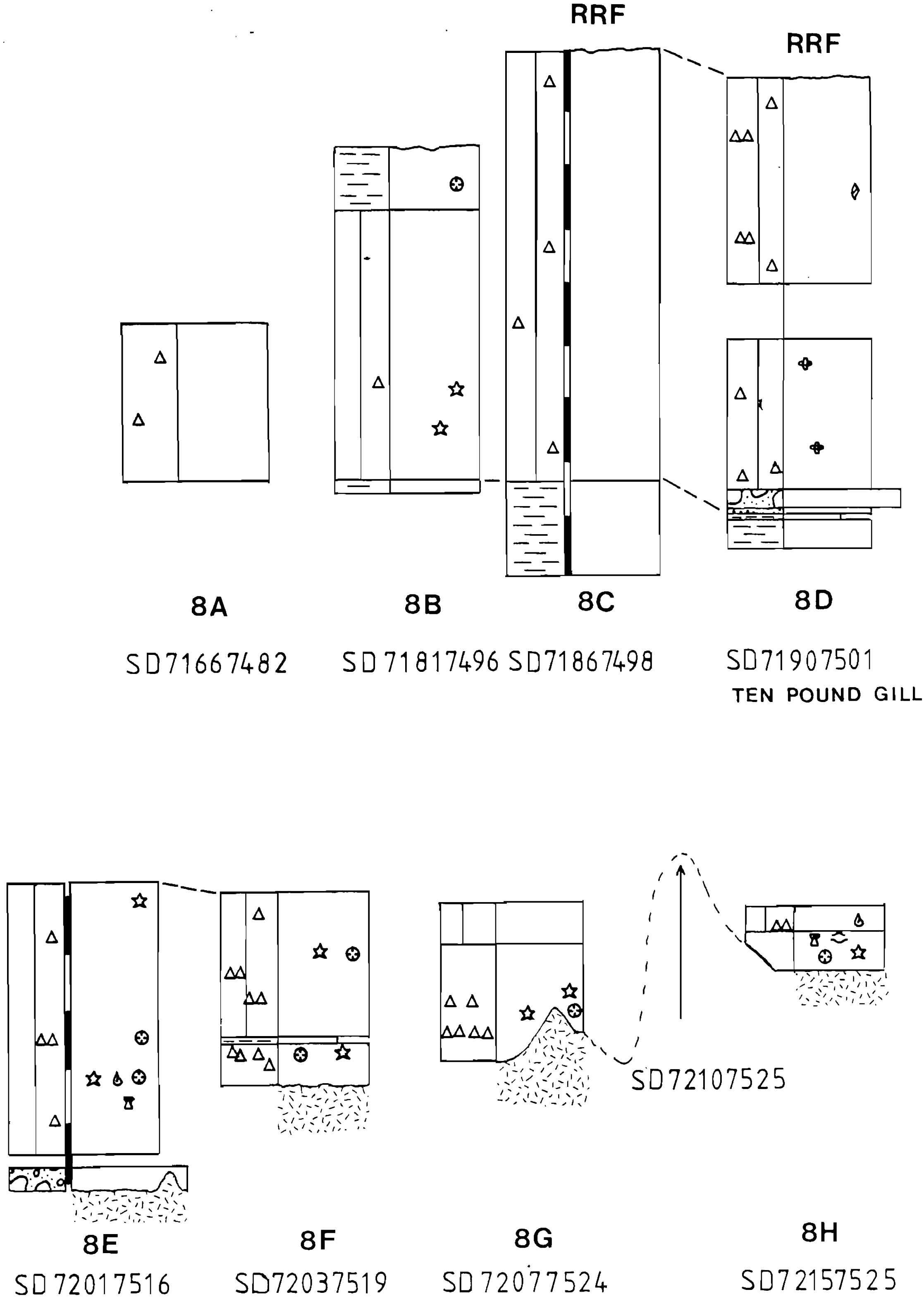

RRF
RRF
8A
SD71667482
8B
SD 71817496
8C
SD71867498
8D
SD71907501
TEN POUND GILL
SD72107525
8E
SD 72017516
8F
SD72037519
8G
SD 72077524
8H
SD72157525

FIGURE 4.8

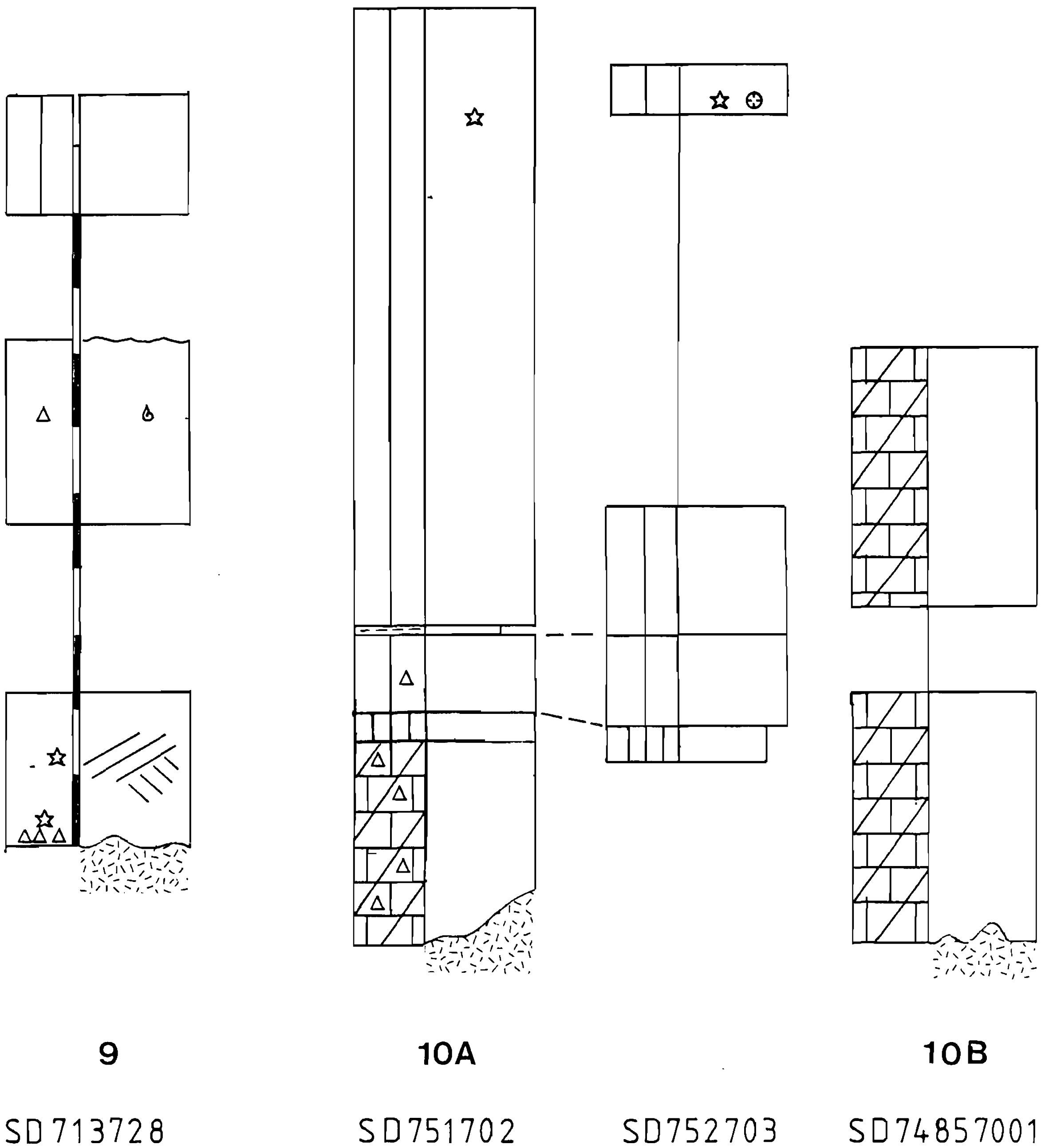


FIGURE 4.9

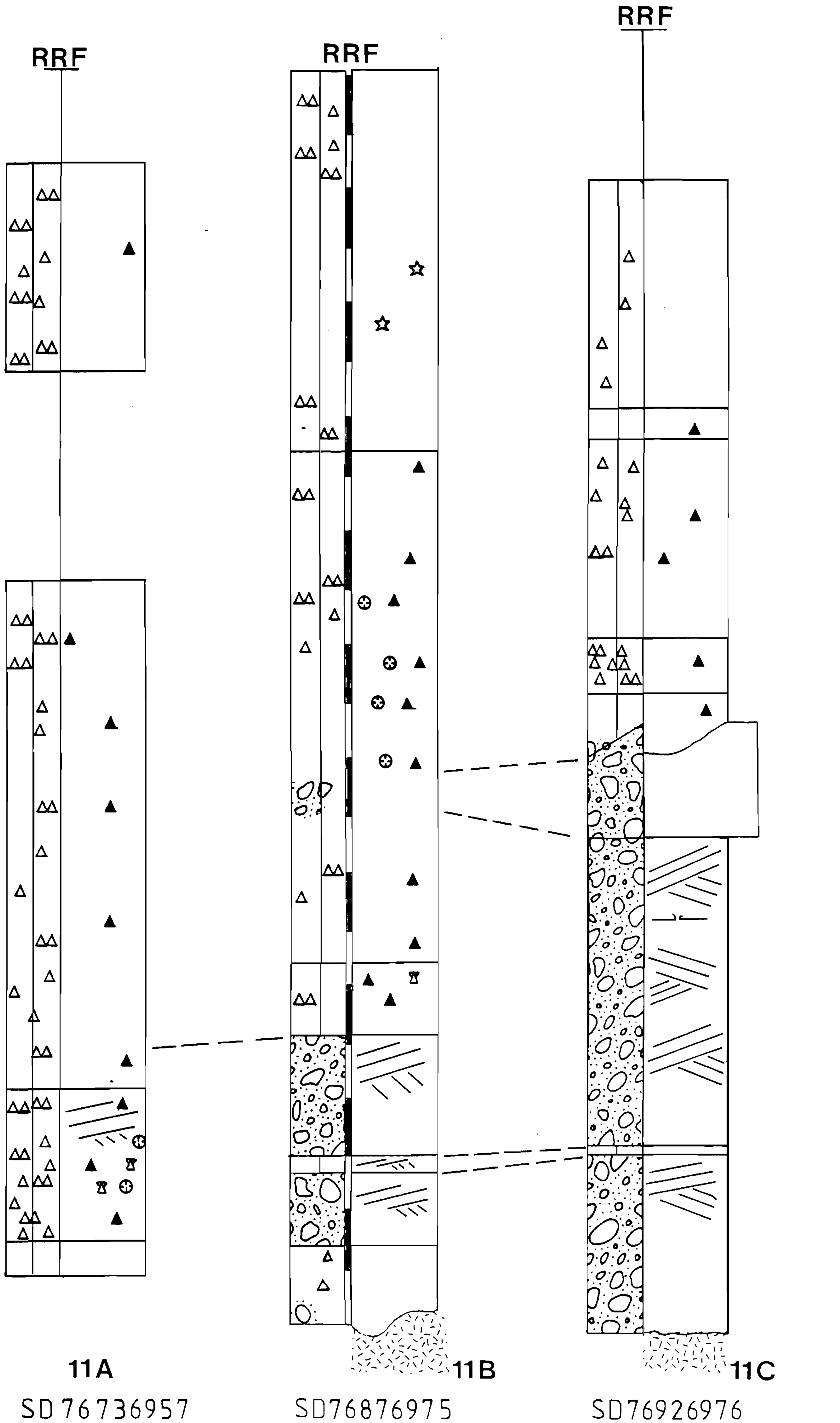
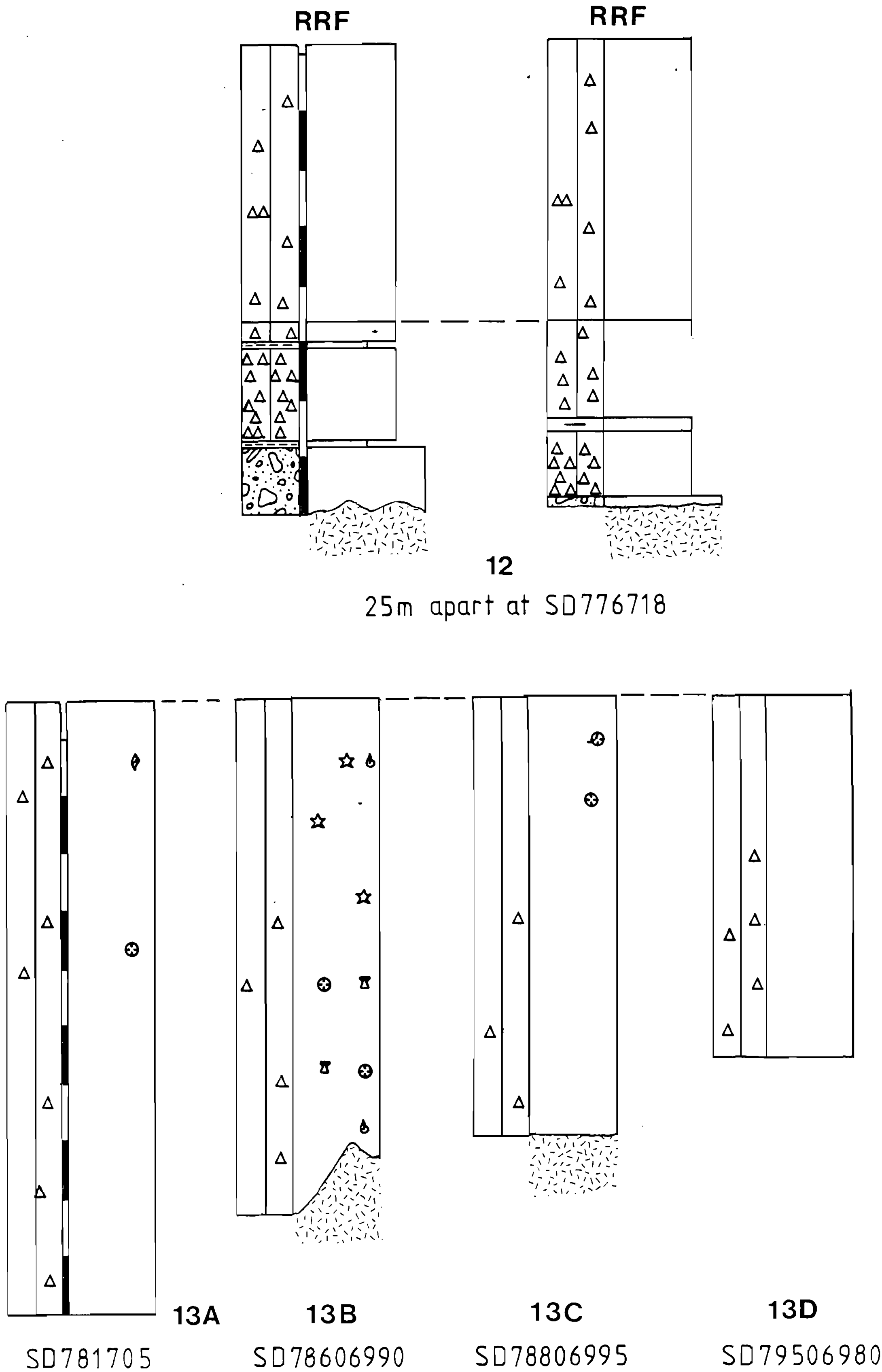


FIGURE 4.10



RRF
RRF
12
25m apart at SD776718
13A
13B
13C
13D
SD781705
SD78606990
SD78806995
SD79506980

FIGURE 4.11

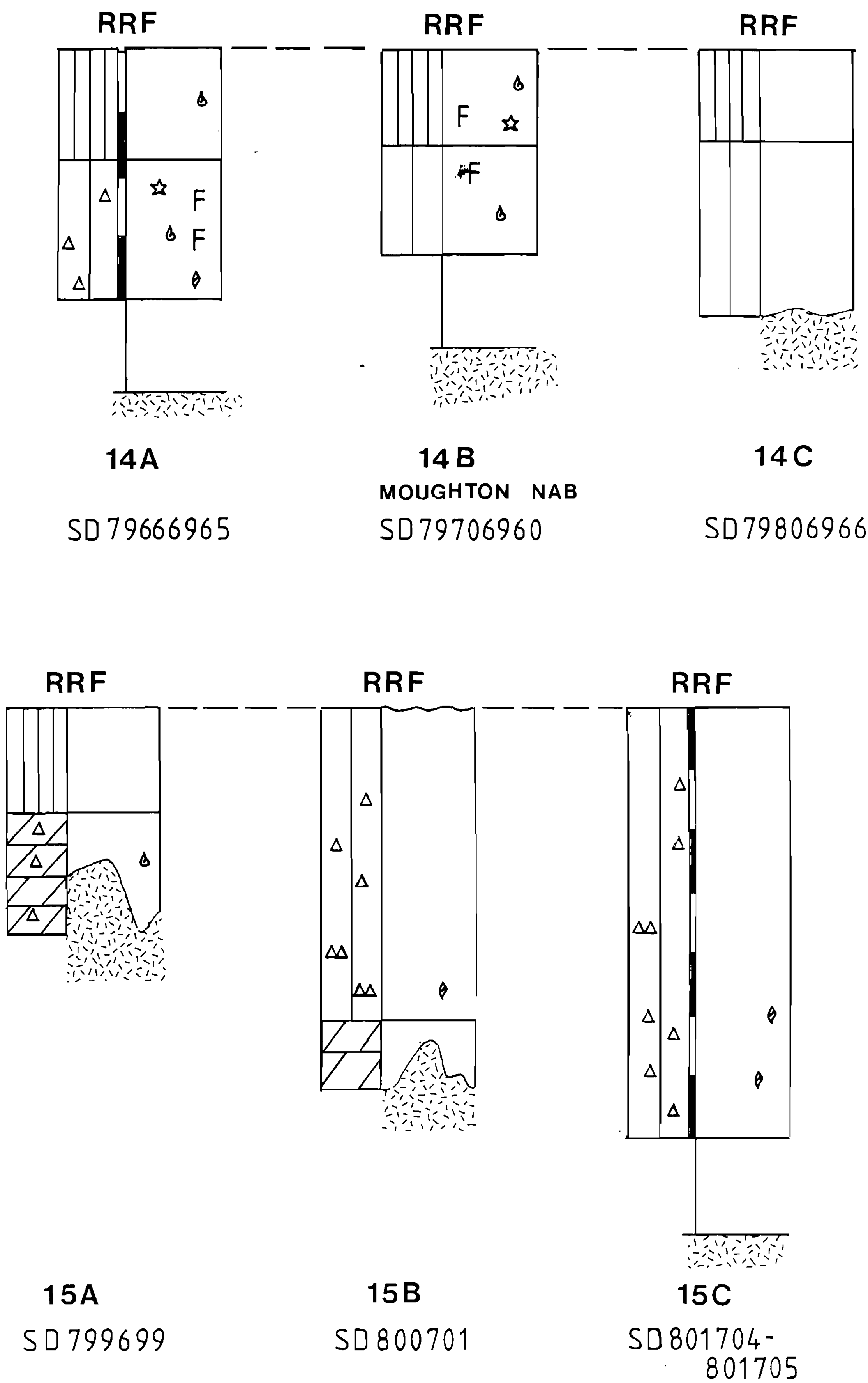

RRF
RRF
RRF
14A
SD 79666965
14 B
MOUGHTON NAB
SD 79706960
14 C
SD 79806966
RRF
RRF
RRF
15A
SD 799699
15B
SD 800701
15C
SD 801704-
801705

FIGURE 4.12

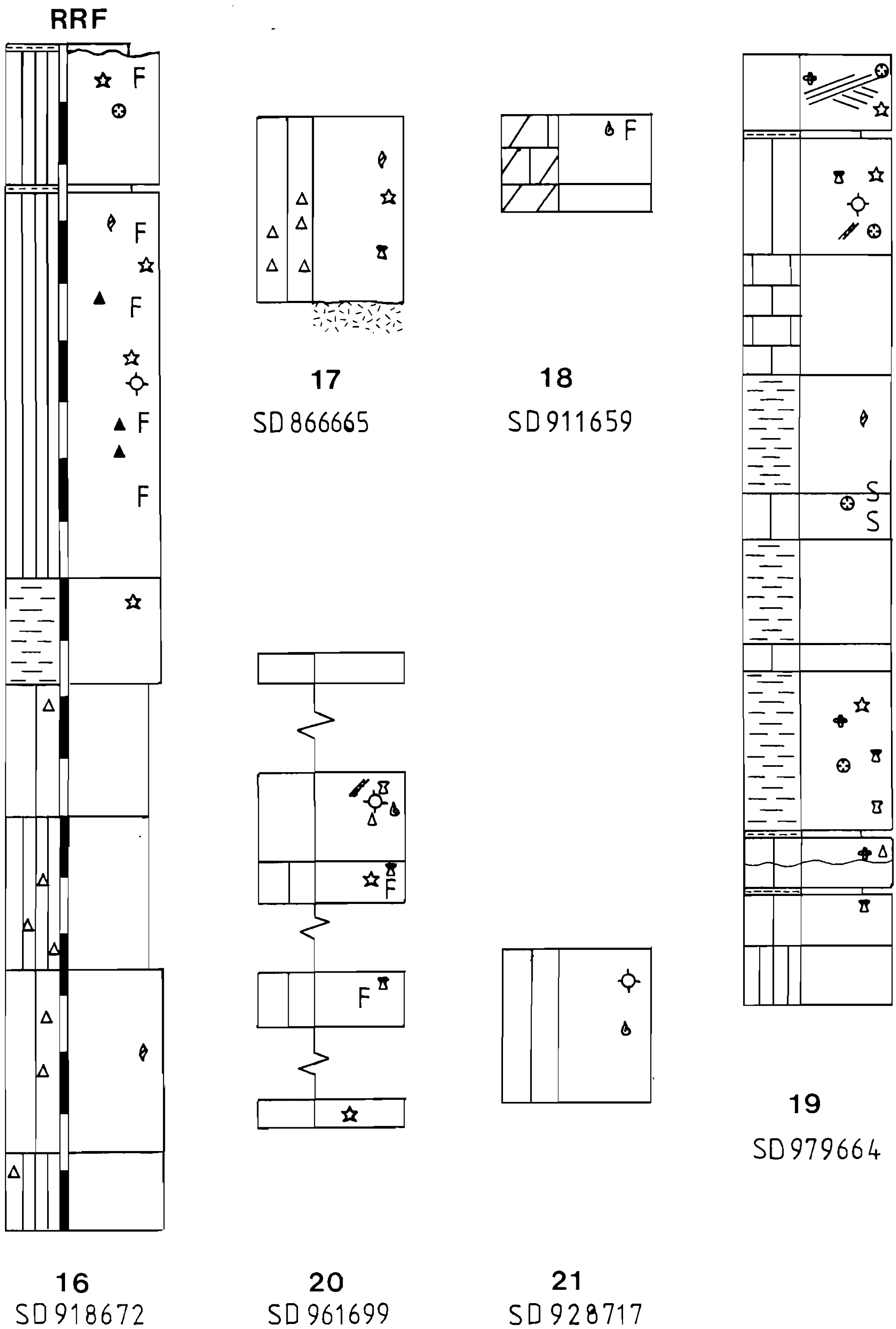

RRF
16
SD 918672
17
SD 866665
18
SD 911659
19
SD 979664
20
SD 961699
21
SD 928717

FIGURE 4.13

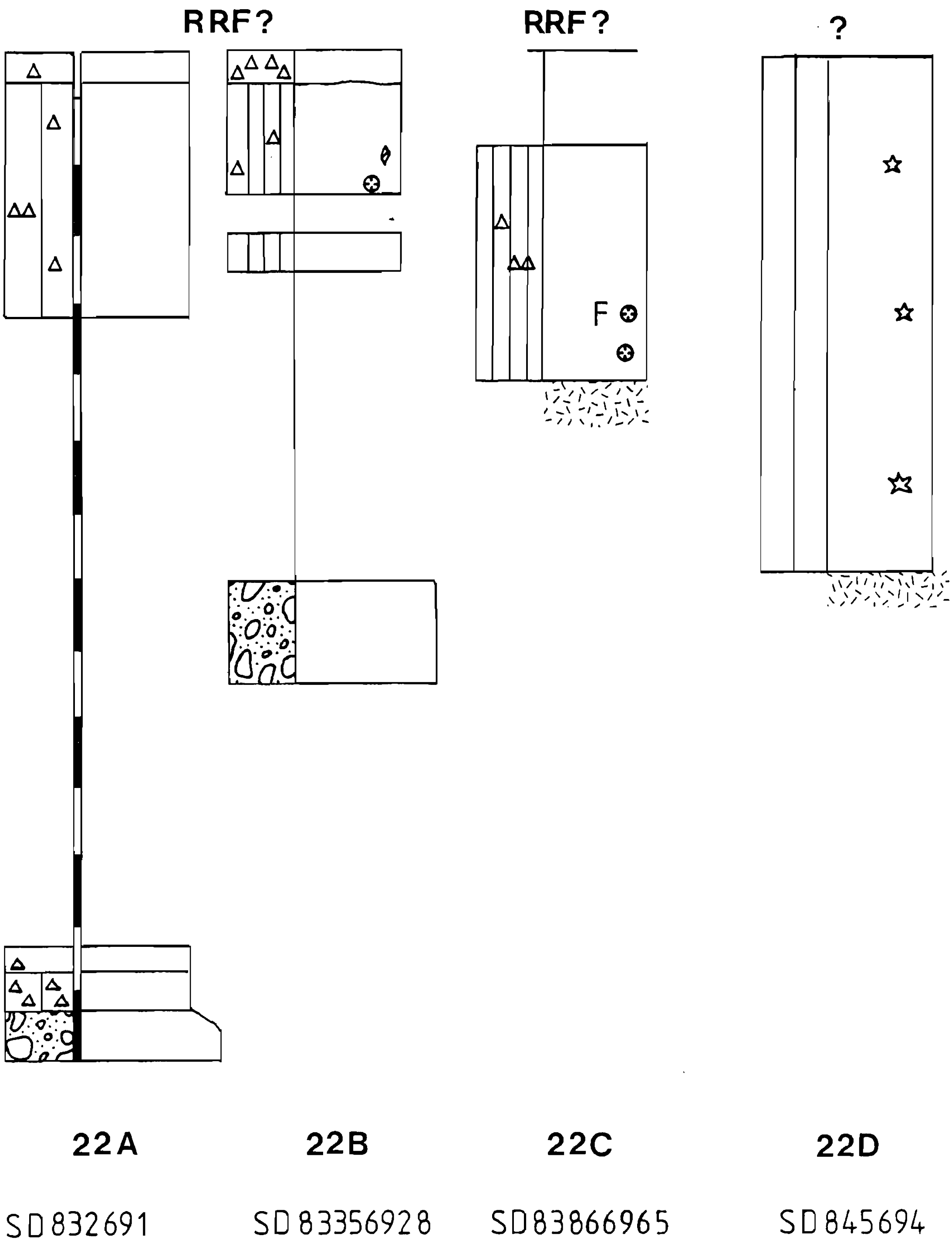

RRF?
RRF?
?
F
22A
22B
22C
22D
SD 832691
SD 83356928
SD 83866965
SD 845694

FIGURE 4.14

CHAPTER FIVE

THE DOUK GILL FORMATION

The Douk Gill Formation is a newly recognised formation limited to the area around Horton-in-Ribblesdale. It rests unconformably on Ordovician and Silurian rocks, against which it wedges out in a southerly direction. It is overlain, apparently conformably, by foetid calcarenites assigned to the Raven Ray Formation. Much of its outcrop area is thickly mantled by till and alluvium, so that there are few exposures, all in stream sections. These have been briefly described by earlier authors, Phillips (1828), Dakyns & others (1890), Garwood (1922), and Garwood & Goodyear (1924). At least two of the outcrops so described are now apparently buried beneath the waste dumps of Horton Quarry. The Douk Gill Formation probably is the lateral equivalent of the Thornton Force Formation but in view of its dissimilarity and geographical separation, it is accorded separate status.

The type section is in Douk Gill (Plate 5a), Horton-in-Ribblesdale (SD816725), where the following section is seen:-

Flat-based limestone of the Raven Ray Formation

	0 to 0.34m	Dark grey shale with coal, 8cm, @ 12cm below the top, and thin shelled bivalves and pyrite nodules in the basal 1cm (Plate 5b).
1.70-1.85m	0.60 to 0.75m	Fine grained calcarenite rich in productids and with sparse lithoclasts up to 20mm; lowest 5-10cm mottled; top undulose with hollows 15cm deep and 2-3m long.
	0.95m	Parallel laminated fine grained calcarenite below shale parting 50cm above base, overlain by calcilutite passing rapidly upwards into calcarenite.
	0.15m	Very fine grained calcarenite passing upwards into calcilutite with laminated silty micaceous shale parting at top.
	0.25m	Shale and shaly limestone, considerably bioturbated.
	0.90m	Calcilutite, rubbly weathering, considerably bioturbated.

3.15m	0.90	Calcilutite, as above, shale film at top.
	0.12m	Shale.
	0.60m	Calcilutite, as above, with 'birdseye' fenestrae.
	0.38m	Calcilutite, as above, shale film at top.
	0.75m	Laminated mid grey fine grained calcarenite,richly bioclastic, sparse lithoclasts.
	0.05m	Calcareous shale.
	0.20m	Mid grey fine grained calcarenite.
3.25m	0.30m	Shale and shaly limestone.
	0.55m	Shelly calcilutite, slightly sandy.
	0.40m	Mid grey fine grained calcarenite, sandy at base.
	0.05m	Laminated quartz arenite.
	0.50m	Mid grey fine grained calcarenite.
	0.45m	Mid grey fine grained calcarenite.
	0.08m	Shaly limestone.
	0.40m	Bioturbated calcilutite.
1.60m	0.60m	Calcilutite, shale parting at top.
	0.12m	Calcareous shale, corals at base.
	0.40m	Bioturbated calcilutite, mounded top.
	0.05m	Shale filling hollows.
	0.15m	Calcilutite, flat base, mounded top.
	0.02m	Shale.
1.13m	0.24m	Quartz arenite, parallel and ripple cross laminated.
	0.17m	Calcilutite, bioturbated.
	0.10m	Quartz arenite, bioturbated.
	0.11m	Calcilutite, top mounded with shale parting above.
	0.12m	Quartz arenite.
	0.17m	Calcilutite, bioturbated.
	2.30m	Quartz arenite, flat bedded, slightly calcareous (mostly below water level in a large plunge pool).
5.90m	2.10m	Thin beds (12) of fine grained calcarenite/calcisiltite with bioturbated tops and lenses of granule lithoclasts. One bed richly fossiliferous.
	1.50m	Mid grey medium-fine grained calcarenite in three beds, pyritic, top of middle bed has _Syringopora_ in mounds.
		Unconformity - relief 0.20m
	Slates -	Ingleton Group.

The Douk Gill Formation is exposed at few other localities and nowhere is it as thickly developed or so well exposed. At Brackenbottom

Farm (SD817721), 4.85m of the Formation are exposed. It is difficult to correlate so thin a sequence but it probably is equivalent to the top of the quartz arenite and overlying thin interbedded sandstones and limestones. Calcilutites typical of the upper part of the Douk Gill Formation at Douk Gill are not well developed at Brackenbottom Farm (Fig. 5.3.).

A large fragment of slate in the stream behind the farm may be in situ, this indicating the approximate position of the unconformity. Some 20m upstream is the lowermost exposure of the Douk Gill Formation, a flat pebble rudite (0.20m thick), composed of rounded pebbles 5-6cm in length. Above are three beds of sandy limestone, totalling 1.60m, with phaceloid Lithostrotion occurring on top of the lowermost bed. The sandy limestones are overlain by 0.20m of grey shale which is succeeded by 0.13m of very fine grained calcarenite with a shale film on top. Above this are two more beds of sandy limestone (0.30m and 0.10m thick) overlain by 0.10m of shale which coarsens upwards into a parallel laminated quartz arenite. Resting on the arenite are two beds of mottled, pale grey, medium to very fine grained calcarenite (together 1.00m thick). Gastropods are common in the lower bed. Next there are 0.15m of shaly limestone with an irregular top overlain by 0.18m of pale grey calcilutite filling the relief in the underlying bed. This is succeeded by 0.11m of thinly laminated, calcareous shaly sandstone, 0.11m of calcisiltite-calcilutite and finally 0.65m of mid grey fine grained calcarenite. The remainder of the Douk Gill Formation is obscured.

The remaining exposure on the eastern side of Ribblesdale is at Dub Cote Gill (SD819718) where approximately 15.70m of the Formation are exposed. The unconformity itself is not seen but Silurian graywackes crop out adjacent to red rudite at SD818717, alongside the stream.

The exposure was first described by the Geological Survey (Dakyns & others, 1890). They reported 20 feet of conglomerate, the upper 5 feet being calcareous and the remainder red conglomerate. At the lowest exposure at this locality there at least 1.5m of red stained flat pebble rudite. The layers of rounded pebbles and cobbles are composed predominantly of graywacke and some slate (derived from the Ingleton Group). Above the red rudite there are 2.85m of very similar but grey-green rudite. Unfortunately the contact between the two rudite-types is not exposed.

Overlying the poorly exposed green rudite the following sequence is visible:

0.40m	Slate pebble rudite
1.48m	Graywacke pebble-cobble rudite.
0.16m	Slate pebble rudite, shaly matrix.
0.20m	Lithified graywacke, coarse pebble rudite (Plate 5c).
0.50m	Pebble rudite, fine sand-shale matrix.
0.40m	Boulder-cobble rudite, lithified sand matrix, in places only 1 boulder thick. Maximum lithoclast size 600x170x90mm.

All the beds are wedging and laterally impersistent and approximately 15m to the north the sequence is completely different (Fig.5.3) and comprises:-

1.00m	Calcareous quartz arenite grading up in to shaly mudstone. Small pebble lithoclasts. Top of bed correlates with top of previous section.
0.55m	Graywacke pebble-cobble rudite with shale matrix.
1.35m	Calcareous quartz arenite, sparse pebble-cobble lithoclasts.

The outcrop continues upwards into the Raven Ray Formation as follows:-

———	Flat based limestones, dark grey calcarenites attributed to the Raven Ray Formation.
0.06m	Black, thinly laminated paper shale.
0.35m	Dark grey calcilutite.
0.70m	Similar to above, irregular top.
0.25m	Mid grey, fine grained calcarenite, disarticulated brachiopods parallel to bedding. Irregular top.
0.45m	Mid grey, fine grained calcarenite, cross-laminated with few pebble-sized lithoclasts.

	0.15m	Similar to above.
	0.35m	Similar to above, with common pebble-sized lithoclasts.
	0.40m	Mid grey, fine grained calcarenite, scoured top.
	0.04m	Sand film, discontinuous.
	0.30m	Mid grey, very fine grained calcarenite.
	0.04m	Shale parting.
	0.12m	Mid grey calcisiltite-calcilutite.
	0.65m	Similar to above.
	0.22m	Mid grey fine grained calcarenite.
	0.45m	Thin bedded mudstone.
	0.50m	Mid grey very fine grained calcarenite-calcisiltite, mottled.
	0.85m	No exposure.
	0.85m	Beds (3) of mid grey fine grained calcarenite, mottled and with scattered pebbles.
	0.43m	No exposure.
0.46m	0.12m	Black shale, laminated.
	0.08m	Quartz arenite, parallel laminated.
	0.06m	Quartz arenite, graded.
	0.10m	Mid grey fine grained calcarenite, pebbly.
	0.10m	Black shale.
0.83m	0.45m	Mid grey fine grained calcarenite, pebbly, bioclastic.
	0.14m	Fine pebbly rudite, lithified shale matrix.
	0.09m	Green laminated mudstone.
	0.15m	Mid grey fine grained calcarenite, sparse quartz sand.

The only remaining present-day exposure of the Douk Gill Formation occurs on the western side of the valley at Gillet Brae (SD800719). The total thickness of the Formation is only 6.05m (Plate 5d).

The section was first described by Phillips (1828) as follows:- "fragments of quartz and slate in calcareous paste rest on upturned slates and are overlain by 4 feet of shale with hard beds, 1 foot 6 inches of slate, quartz and pyrite conglomerate, 2 feet of lumpy shale, 3 feet of lumpy limestone, 5 feet of laminated shale and then 25 feet of limestone in the lower limestone scar above". The Geological Survey (Dakyns & others, 1890) also described the section in very similar terms to those of Phillips. The section now visible at Gillet Brae is:

	—	Flat lying dark grey calcisiltites, calcarenites and thin shales of the Raven Ray Formation.
	0.04m	Black shale, thins to the south.
	0.07m	Calcisiltite, lens thinning rapidly to north.
	0.07m	Black, thin, poorly laminated shale, with 2cm coal @ 4cm below top.
1.23m	0.45m	Mid grey fine grained calcarenite, laminated, top undulose. Pyrite nodules in top 3cm. Bed thins to north.
	0.10m	Black shale laminated.
	0.50m	Dark grey calcilutite, sparsely bioclastic.
	0.25m	Siltite, calcareous, bioturbated becoming bituminous, pyritic bioclastic calcarenite with sparse quartz silt at top.
1.35m	0.25m	Black very fine grained quartz siltstone.
	0.50m	Black shale, very thinly laminated.
	0.35m	Fine grained quartz arenite, more shaly upwards. Contains plant fragments.
	1.40m	Buff-grey calcisiltite-calcilutite, nodular surface.
	0.35m	Shale-siltstone, burrowed and bioturbated top and base, sparse pebble-sized graywacke lithoclasts.
	0.45m	Rudite, lithified shale matrix, pyritic.
	0.65m	Grey shale, burrowed and bioturbated, pebble lithoclasts.
	0.10m	Quartz arenite, graded bed, pebbles and pyrite at base.
1.80m	0.20m	Green-grey shale, poorly laminated.
	0.10m	Quartz arenite.
	0.10m	Grey shale.
	0.20m	Rudite, lithified.
		Unconformity near horizontal. Steeply dipping Silurian graywackes.

The thin coal occurring just below the top of the Formation at Gillet Brae probably correlates with the coal at the top of the Formation at Douk Gill. Correlating the remainder of the section is problematical.

The Geological Survey (Dakyns & others, 1890), Garwood (1922), and Garwood & Goodyear (1924) described exposures north of Gillet Brae which are no longer available. The Geological Survey observed 8 feet (2.5m) of pebbly limestone resting on 11 feet (3.5m) of red conglomerate unconformably overlying slate 200m north of Gillet Brae at the head of a small stream near which Horton Quarry was opened in 1889. Garwood (1922) and Garwood & Goodyear (1924) described the fauna, rock-types and possible origins of deposits now obscured by waste-tips from Horton Quarry. Garwood had observed two beds, each only 2 inches (0.05m) thick, occupying a small depression in the surface of the vertical slates when the quarry was opened. The two beds contained an unusual fauna. The lower bed, laminated siltstone, contained the gastropod *Viviparus* and also thin shelled bivalves, and Garwood proposed that this deposit was laid down in a small pond on the surface of a continent. It was overlain by another very thin bed containing fish and plant remains, which he suggested to be of estuarine origin. Unfortunately, the deposits appear to have had a very small lateral extent and there is no record of similar rock-types in the exposures today.

Figured Sections Through the Douk Gill Formation

1.	Douk Gill	SD816725	3.	Dub Cote Gill	SD819718
2.	Brackenbottom Farm	SD817721	4.	Gillet Brae	SD800719.

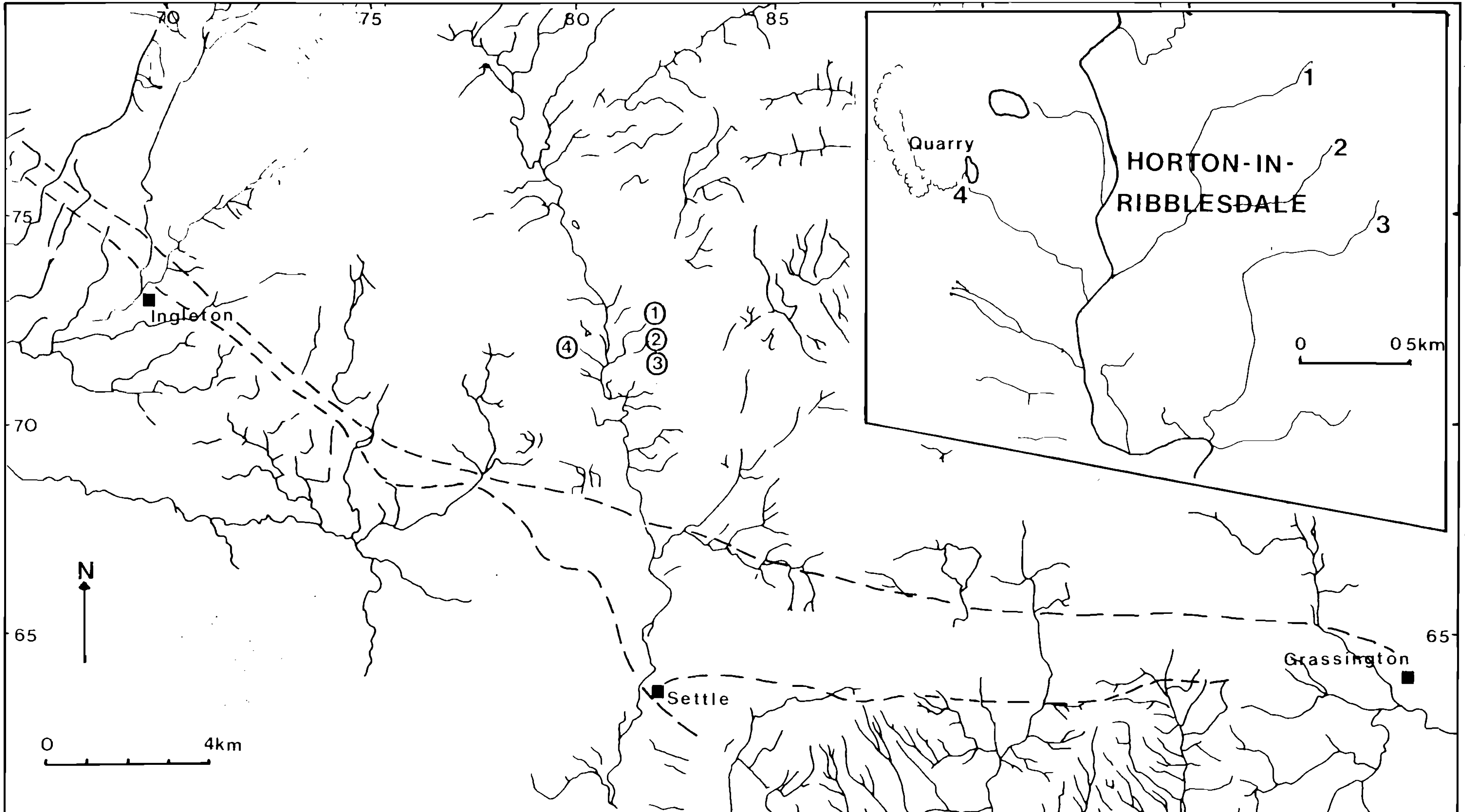


FIGURE 5.1 Location of measured sections through the Douk Gill Formation.

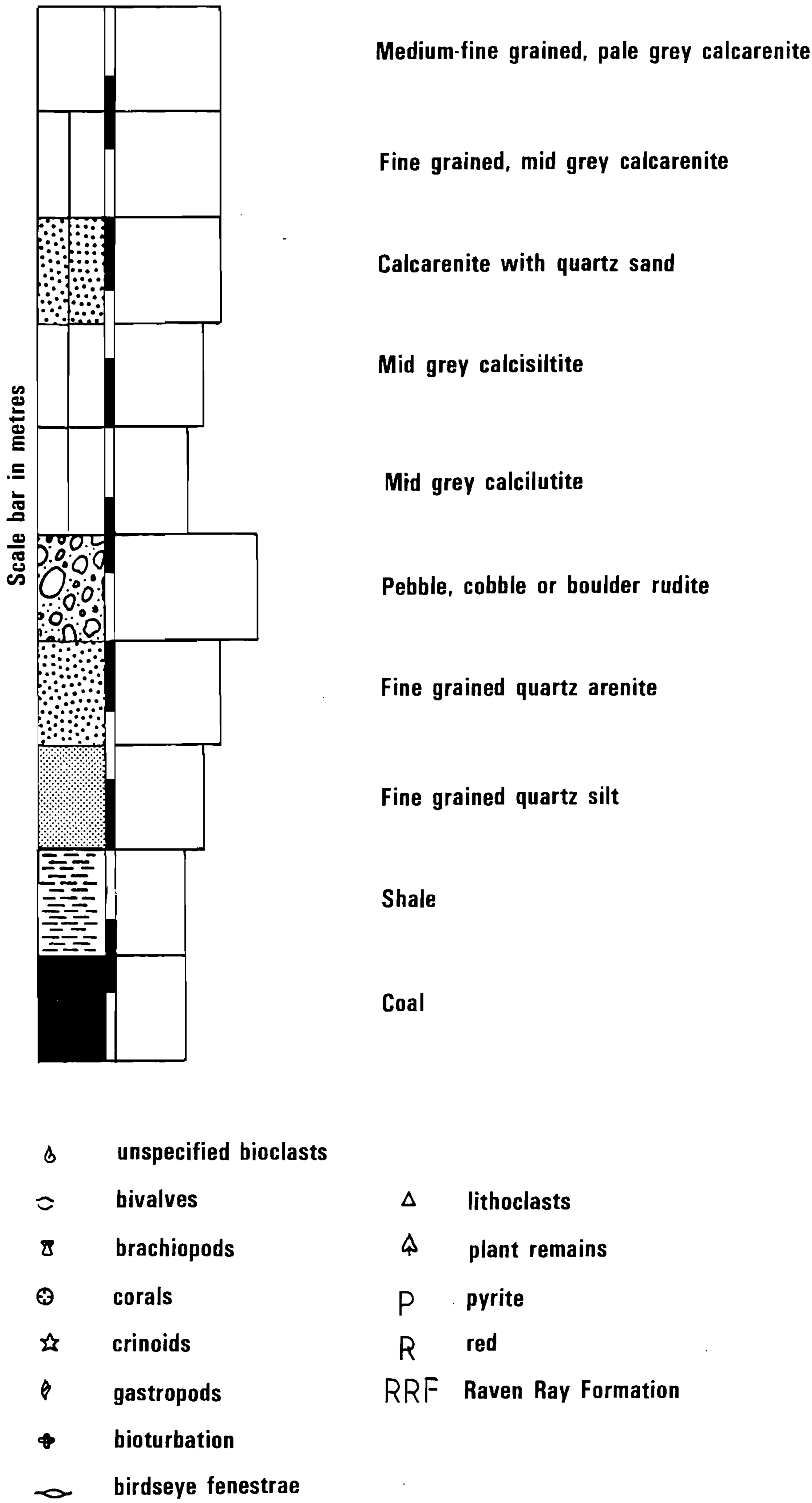


FIGURE 5.2 Key to symbols used in figured sections through the Douk Gill Formation.

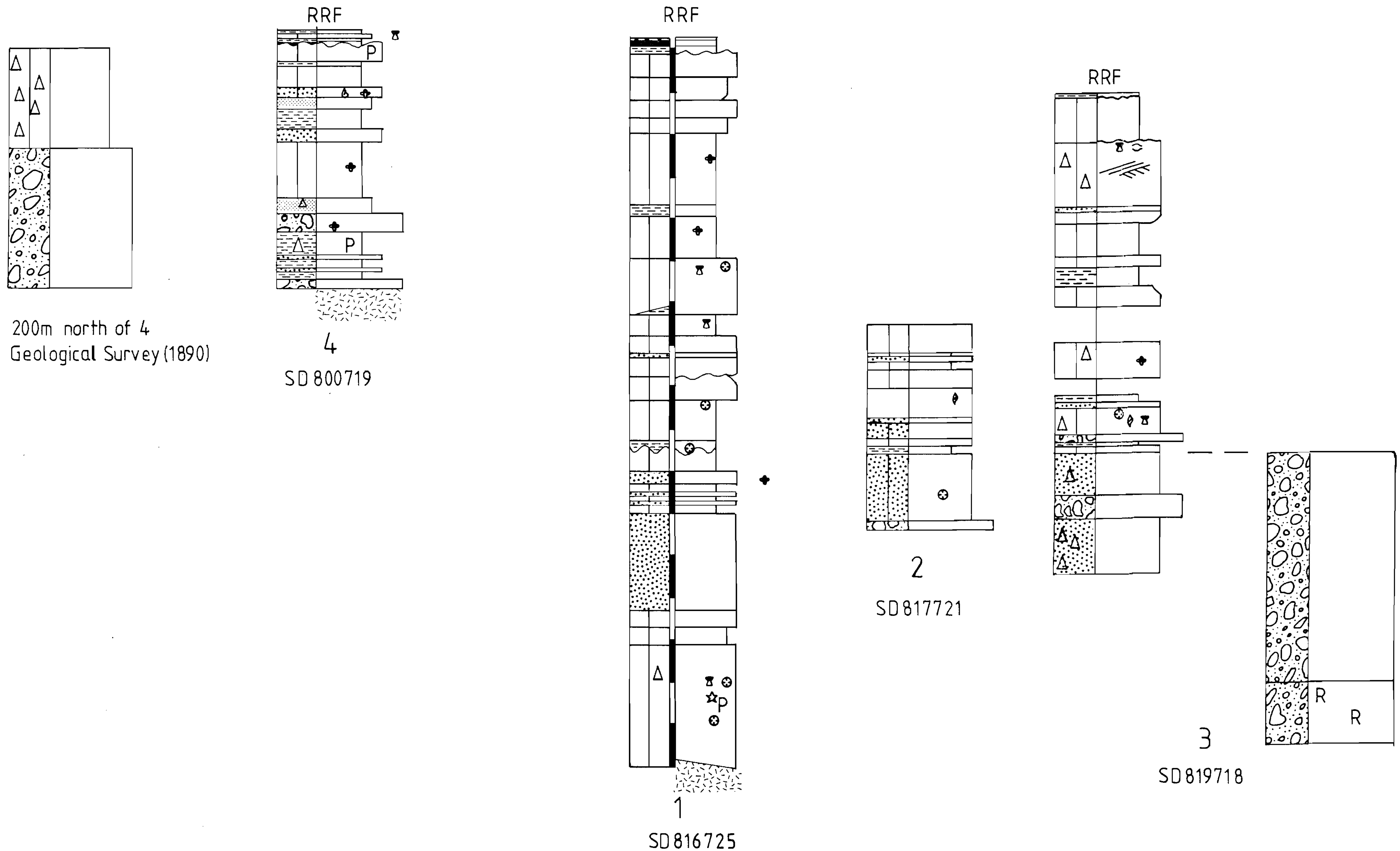

RRF
RRF
RRF
P
P
P
R
R
200m north of 4
Geological Survey (1890)
4
SD 800719
1
SD 816725
2
SD 817721
3
SD 819718

FIGURE 5.3

CHAPTER SIX

THE RAVEN RAY FORMATION

The Raven Ray Formation is the second formation of the Great Scar Group. It overlies the Thornton Force Formation disconformably over most of the study area, overstepping it in Chapel-le-Dale, Crummack Dale and Ribblesdale to rest directly upon Lower Palaeozoic rocks. In the vicinity of Horton-in-Ribblesdale the Raven Ray Formation overlies the Douk Gill Formation, apparently conformably. It is overlain everywhere by the Horton Limestone, apparently conformably as far east as Ribblesdale, but with slight disconformity in Wharfedale.

The Raven Ray Formation was first referred to, as the Gastropod Beds, by Garwood & Goodyear (1924). The Formation was described as a series of interbedded dark limestones and foetid shales which were exposed above Thornton Force, in Chapel-le-Dale, and under Norber Brow. The beds contain a sparse mixed fauna with only a few gastropods. There was no species characteristic of this subzone. However, Garwood & Goodyear (1924) found it "convenient to retain the name 'Gastropod Beds' applied to this horizon farther north, [although] it is not especially applicable to this horizon in West Yorkshire". Garwood & Goodyear found it difficult to determine the upper limit of the Formation as dark limestones continue up into the overlying beds.

The Raven Ray Formation compares closely with the Dalton Beds of Furness (Rose & Dunham, 1979). The two Formations are very similar in age and rock-type, and appear to be overlain by similar deposits. Black limestones and interbedded foetid shales are exposed extensively around Dalton-in-Furness.

Recently, the Institute of Geological Sciences has designated a new formation, the Kilnsey Formation (Mundy & Arthurton, 1980, p33). The formation is equivalent to the S_1 subzone of Garwood & Goodyear (1924) and encompasses the Raven Ray Formation. The Kilnsey Limestone is poorly defined at present and may include some part of the underlying Thornton Force Formation and overlying Horton Limestone.

There are few good exposures of the Formation; the best are in quarries and stream sections. Usually the Raven Ray Formation lies at a prominent break in slope and is masked by a substantial thickness of superficial deposits. Consequently outcrops tend to be sparse. The Formation rarely forms a conspicuous terrace because of its relative thinness in comparison to the overlying limestones and because of the superficial deposits. The occurrence of closely jointed, white-weathering limestones at the base of the overlying Horton Limestone has proved a reliable and useful guide to the succession at many localities.

It has proved difficult to identify the Raven Ray Formation away from its type section (Raven Ray, Kingsdale) because of the paucity of exposure and the rapid minor changes in lithology. The study area has not been divided into subareas, as with the Thornton Force Formation, because of the uneven distribution of exposures and the general similarity in rock-types. The locations of measured sections are shown in Figure 6.1.

The type-section of the Raven Ray Formation is in Kingsdale between the top of Thornton Force and Raven Ray (SD696754). The Raven Ray Formation disconformably overlies the Thornton Force Formation at Thornton Force, and is approximately 11.00m thick at this locality. The section observed is as follows:-

	Pale grey medium and thick bedded calcarenites of the Horton Limestone.
0.02m	Shale (Plate 6d.)
1.15m	Limestone, 3 beds of foetid, dark grey fine grained calcarenite separated by persistent black shales of irregular thickness. Solitary corals and brachiopods occur.
0.10m	Limestone, shaly black calcarenite.
0.02m	Shale, persistent and black

0.30m	Shale, persistent and black fine grained calcarenite -calcisiltite.
0.04-0.12m	Shale, persistent and black.
1.05m	Limestone, thinly bedded, black, foetid calcarenites separated by impersistent shale films. Bed tops are bioturbated.
1.75m	No exposure.
0.60m	Limestone, two beds of black calcisiltite. Bed tops bioturbated and burrowed below overlying shales.
0.25m	Limestone, persistent fine grained, dark grey calcarenite-biomicrite with an irregular top. Brachiopods and crinoid ossicles and stems are common.
1.15m	Limestone and shale, alternating foetid, black calcarenites (0.10-0.20m thick) and black shales (0.02-0.10m thick). Both are laterally impersistent. (Plate 6c).
0.80m	Limestone, six thin beds of laterally impersistent black, foetid, sparsely fossiliferous calcisiltite separated by shale films.
0.10m	Shale, persistent and black. Locally it bifurcates to include calcilutite lenses up to one metre in length and 7cm thick (Plate 6b)
0.45m	Limestone, persistent black calcarenite and two impersistent shale films.
0.05m	Shale, black and persistent.
0.95m	Limestone, laterally impersistent thin beds (averaging 0.10m) rich in colonial corals, brachiopods, crinoids and gastropods. The beds fill the 0.50m of relief on the top of the Thornton Force Formation, filling the hollows and draping over the ridges (Plate 6a).

There are no more exposures of the Raven Ray Formation in Kingsdale at which sections could be measured. The next exposure of the formation is at Twisleton End (SD703750). There seems to be a gentle northeast dip as far as the fault which lines up with the Nook on Ingleborough. A total of 7.80m of mid grey and dark grey calcarenite is exposed. The lowermost 4.30m are slightly foetid and the remainder are coarser grained and crinoidal. There is a gap of 3.75m between these beds and the lowest beds identifiable as the Horton Limestone.

The Raven Ray Formation can be traced by very poor exposures to Twisleton Scar (Plate 7a),where at SD71357562, only the very base of the Formation is seen, resting on the Thornton Force Formation. The contact is irregular but sharp, apparently with some bioturbation across it. The overlying limestones of the Raven Ray Formation are black, foetid, fine grained calcarenites-biomicrites with very sparse lithoclasts. At the next locality (SD71647587) the Raven Ray Formation is approximately 6.00m thick. It overlies the Ingleton Group unconformably, having overstepped the Thornton Force Formation onto the rising graywacke ridge in this area. The bioclastic limestone is cross-laminated throughout (Plate 6b).

In the next pasture, at SD71667587, the Raven Ray Formation is about 8.60m thick. Two beds of typical foetid, dark grey calcarenite are separated from each other by about 6.00m of mid grey, cross-laminated coarse grained, crinoidal calcarenite. At this locality there is poor exposure of the Thornton Force Formation below and the Horton Limestone above, but neither contact is revealed.

Another exposure in this pasture is above Twisleton Dale House (SD71747587). Local small-scale quarrying has resulted in good exposure of 4.65m of limestone. The lowermost 3.00m are coarse grained, mid grey, bioclastic limestones. They are cross-laminated and contain crinoid and coral hash, including Lithostrotion basaltiforme, as well as sparse granule-lithoclasts. The top 1.65m comprise poorly exposed fine grained, foetid calcarenites. The contact with the overlying Horton Limestone is not exposed.

There is a series of exposures in the next pasture. At SD72087606 4.80m of dark grey, medium grained, bioclastic calcarenite are poorly exposed. The limestones overlie the Thornton Force Formation but the contact is not seen.

At SD71287621 the level of the unconformity has risen sharply so that the Raven Ray Formation now rests directly upon the Ingleton Group. There are only 3.00m of Raven Ray Formation exposed and the base of the

Horton Limestone is not seen. The level of the unconformity continues to rise so that the Formation thickness is reduced to 1.20m over a distance of only 30m. At the next locality (SD72317628), immediately beyond the graywacke mound, 1.90m of Raven Ray Formation crop out above poorly exposed Thornton Force Formation. The top of the exposed Raven Ray Formation correlates with the top of the previous section.

The next exposure is at Ullet Gill (SD72357632), where there are 4.75m of Raven Ray Formation. The Thornton Force Formation is not exposed; there is a till-filled gap of 3.50m between the highest slate and lowermost limestone. The section measured is described below from top to base.

	Horton Limestone-mid grey, closely jointed, fine grained calcarenite. The contact with the underlying Raven Ray Formation, a bedding plane, is poorly exposed.
2.55m	Limestone, medium bedded, dark grey calcarenite rich in shell hash and containing Syringopora and Lithostrotion.
0.90m	Limestone, bioclastic dark grey calcisiltite.
1.30m	Limestone, dark grey, thinly bedded and rubbly weathering crinoidal calcarenite. Bed tops are bioturbated.

On the south side of the dale the Raven Ray Formation is intermittently and poorly exposed at a few localities. There is a very poor exposure behind Skirwith Quarry (SD709738). Above the quarried Thornton Force Formation the ground rises gently to a prominent platform, probably the top of the Raven Ray Formation. There are poor exposures of rubbly, nodular, dark grey, foetid, fine grained calcarenites and calcisiltites with lenses of bioclasts. Above the platform closely jointed, mid and pale grey, bioclastic calcarenites of the Horton Limestone are exposed through the till veneer. There are approximately 11.60m of Raven Ray Formation at this locality.

The next exposure of the Raven Ray Formation is adjacent to White Scar Cave (SD714747). The Formation overlies the Thornton Force

Formation at this locality. The contact between the two Formations is poorly exposed but appears to be undulose. The lowermost 5.00m are typical of the Raven Ray Formation (Fig 6.4, 6). The thin beds are sparsely bioclastic, foetid, dark grey, fine grained calcarenites and calcisiltites. The top bed is irregular with 0.10-0.30m of relief. This surface is extensively exposed in the floor of a small quarry. It is intensely burrowed and colonised by <u>Michelinia</u>, <u>Syringopora</u>, <u>Lithostrotion</u>, <u>Caninia</u> and <u>Palaeosmilia</u>.. Overlying it are 3.30m of cross-laminated, coarsed grained, dark and mid grey calcarenite with numerous brachiopods, in turn overlain by 5.55m of dark grey, foetid, rubbly weathering, fine grained calcarenites and calcisiltites typical of the Raven Ray Formation. The total thickness at this locality is 13.85m. The overlying limestones are closely jointed and pale grey weathering.

There is a series of exposures in the pastures below High Howeth between SD71637477 and 72157530. At the first, (SD71637477), the quality of the exposure is poor. Approximately 5.00m of dark grey calcisiltites are seen below an abrupt bedding plane, above which lie closely jointed, pale grey weathering calcarenites of the Horton Limestone.

At SD71667482 the Raven Ray Formation overlies the Thornton Force Formation with a relief of 0.10-0.20m at the contact. The lowest 2.40m of Raven Ray Formation comprise cross-laminated and burrowed, mid grey, fine grained calcarenite. There is a pronounced, fossiliferous, rubbly horizon 1.20m from the base. It contains squashed corals, brachiopods, and crinoids. The remainder of the Formation, 1.15m of thin bedded, dark grey, foetid, fine grained calcarenites-biomicrite, is typical of the of the Raven Ray Formation.

At SD71797494 there is 0.15m of relief on top of the Thornton Force Formation. The lowest 1.80m of the Raven Ray Formation are very fine grained, fossiliferous, dark grey calcarenites with an <u>in situ</u> colony of branching <u>Lithostrotion</u> 0.40m above the base. Overlying the calcarenites are 0.40m of foetid calcilutite-sparse biomicrite, separated by a gap of 0.35m from the base of the Horton Limestone, which is locally dolomitised.

Up valley, the Raven Ray Formation becomes partially veneered with till but is poorly exposed at SD71817496 where occasional, thin rubbly beds of black, foetid, fine grained calcarenite-biomicrite protrude through the grass. There can be only about 3.00m of the Formation at this locality. Above, pale grey weathering, closely jointed limestones of the Horton Limestone are exposed.

At Ten Pound Gill (SD71837504) the section observed is as follows:-

	Horton Limestone, closely jointed, pale grey weathering calcarenite.
1.00m,	Limestone, 3 beds of dark grey, fine grained calcarenite with irregular bedding surfaces.
0.20m,	Shale, grey and brown, finely laminated at top and base. Irregular top, and upper laminated shale locally removed.
0.75m,	Limestone, 2 beds of dark grey, fine grained calcarenite with irregular bedding surfaces.
1.65m,	Limestone, medium-thin beds of mid grey, medium grained calcarenite separated by persistent shale beds and films.

The contact with the underlying Thornton Force Formation is poorly exposed; no relief was visible.

The top of the Raven Ray Formation was revealed in an excavation at SD71917513. The 1.50m of limestones exposed are typical of the Raven Ray Formation; thin bedded, dark grey, slightly foetid, fine grained calcarenites, burrowed and bioturbated throughout. They are overlain by locally dolomitised, pale grey weathering limestones with gastropods and Syringopora, belonging to the Horton Limestone.

Beyond, at SD72107525, the Raven Ray Formation is very poorly exposed. There are 3.10m of slightly foetid, dark grey, fine grained calcarenite-biomicrite with many brachiopods. Above, there is no exposure for the next 5.90m until a small spring where closely jointed, pale grey weathering calcarenites crop out. Beyond, the exposure continues to deteriorate. At SD72157530 beds of the Raven Ray Formation crop out 2.80m above a local ridge of graywacke. It is possible that there is no Thornton Force Formation at this locality. The lowest bed of Raven Ray Formation, 0.50m thick, is a bioclastic and lithoclastic, dark grey, medium-fine grained calcarenite with a layer of lithoclast-pebbles at the top. The overlying 1.65m is not exposed; above it comes 0.35m of black, foetid calcisiltite. Poorly exposed, closely jointed, mid grey calcarenites belonging to the Horton Limestone occur 2.40m above.

Beyond, there is no exposure northeastwards as far as Light Water Spring (SD73257587). The bed at the base of the spring, 0.80m thick dark grey, slightly foetid, fine grained calcarenite, probably is part of the Raven Ray Formation. The overlying 1.40m comprise poorly bedded dolomite. This probably is the junction with the overlying Horton Limestone. Thickly bedded, closely jointed, pale grey calcarenites occur above.

The most northeasterly exposure of the Raven Ray Formation in Chapel-le-Dale is at God's Bridge (SD733763), at an altitude of 224m O.D. The succession observed, described from top to base, is as follows:-

1.60m,	Limestone, bioclastic, dark grey, fine grained calcarenite containing numerous gastropods.
1.30m,	Limestone, dark grey, bioturbated and burrowed fine grained calcarenite. The beds have collapsed probably through erosion of an underlying shale.
0.50m,	No exposure. Resurgences occur at this horizon; probably shale.
1.00m,	Limestone, thick bed of rubbly and platy weathering, dark grey, fine grained calcarenite containing abundant solitary and colonial corals eg Lithostrotion, Syringopora. Many springs occur at the base of this bed.
3.05m,	Limestones, medium-thin bedded, dark grey and black, slightly foetid, intensely bioturbated, crinoidal calcisiltite. Beds are strongly jointed parallel to local faults.

The next exposure is at SD731763, one hundred metres downstream from the base of the limestone, where slates were observed. Also at least 2.0m of limestone occur above the succession described in the next pasture but access was not possible.

The subsurface exposures of Meregill Skit (SD734765), at an altitude of 238m O.D. have been described by Brook and others, 1981. Meregill Skit is a large submerged pot with a debris cone floor at -15m (ie. approximately level with God's Bridge) and the continuing slope opens into a bedding passage at -20m. This has been followed for 180m to a maximum depth of -27m, therefore, there are at least 12m extra of limestone whose identity is unknown.

The Raven Ray Formation is poorly exposed in Jenkin Beck (SD714729), the basal contact with the underlying Thornton Force Formation obscured by till, and the top faulted against Horton Limestone. Within the outcrop a lower exposure of 2.15m of medium bedded, slightly foetid, dark grey, medium grained calcarenite-biomicrite is separated by an unexposed thickness of 3.20m from an upper exposure of 2.65m of medium and thick bedded, slightly foetid, fine grained calcarenite. In both exposures impersistent shaly partings separate the limestones at about 0.20m intervals. The total thickness here must be greater than 8 metres.

The Raven Ray Formation is extensively exposed in Newby Cote Quarry (SD733707), where 17.70m of the Formation can be seen, underlying the Horton Limestone (Plate 7c). Unfortunately, the floor of the quarry is buried in soil on domestic refuse and quarry waste, so that its identity is unknown. There are no outcrops downhill from the quarry and nothing is seen of the Thornton Force Formation within a kilometre. There is a much greater thickness of Raven Ray Formation at this exposure, located south of the North Craven Fault, than in the outcrops to the north.

Horton Limestone, closely jointed, thick bedded, mid and pale grey, fossiliferous calcarenite containing numerous coated grains.

0.88m, Limestone, mid grey, slightly foetid calcarenite. Small colonies of Lithostrotion and meandering burrows occur on the irregular shale-coated upper bedding surface.

0.84m, Limestone, rubbly weathering, dolomitic, fossiliferous calcarenite passing laterally into a thin calcarenite with a shale at its base.

1.10m, Limestone, midgrey, slightly foetid calcarenite containing brachiopods in the lowest 0.10m. Diphyphyllum occurs in the middle of the bed and vertical burrows are common in the top 0.20m.

0.37m, Limestone, rubbly weathering, bioclastic, black calcarenite overlain by a shale film.

0.88m, Limestone, variably lithoclastic calcarenite, cross-laminated in the quartz-rich layers.

0.10m, Limestone, thin, bioturbated, black fine grained calcarenite bed with a shale film on top.

0.33m, Sandstone, calcareous quartz arenite with much coral debris. Bed is intensely burrowed and bioturbated immediately below overlying shale. Locally the lowermost 0.12m are shaly and fill the relief on underlying bedding surface.

0.06m-
0.22m. Sandstone, calcareous quartz arenite with vestiges of lamination and bioclastic layers; top irregular.

0.26m, Sandstone, intensely bioturbated and burrowed, calcareous quartz arenite-siltite with vestiges of parallel lamination.

0.05m, Shale, black.

0.07m, Limestone, black, silty fine grained calcarenite.

0.02m, Shale, black.

0.85m, Limestone, foetid, locally pyritised, bioturbated fine grained calcarenite with undulose top.

0.44m, Shale, thinly laminated and black. The top is truncated and there is a maximum of 0.10m relief.

0.02m, Sandstone, fine grained quartz arenite.

0.04m, Shale, thinly laminated and black.

0.22m, Sandstone, cross-laminated, calcareous quartz arenite grades into underlying silty calcarenite. Both rock-types infill the relief on the underlying bed.

0.20-

0.36m, Limestone, bioturbated and burrowed, black, fine grained calcarenite with an undulose top.

2.05m, Limestone, medium bedded, dark grey foetid, fine grained calcarenite with impersistent shale partings. Bed tops are bioturbated below shales.

1.50m, Limestone, dark grey, fine grained calcarenite overlain by a shale film. 0.90m, Limestone, black, fine grained calcarenite with persistent shale film on top.

6.20m, Limestone, medium-thick beds of dark grey, poorly sorted, foetid, medium and fine grained calcarenites separated by irregular and impersistent shale partings. Vestiges of lamination.

In Clapdale, the Raven Ray Formation is poorly exposed near SD751705. The Formation probably is about ten metres thick at this locality but no section could be measured. The limestones are similar to outcrops of the Formation in Chapel-le-Dale and Kingsdale, bedded at 0.10-0.30m intervals and composed of foetid, dark grey, fine grained calcarenites with some micrite coated clasts visible. Thin shales occur on wavy bedding planes. Opposite the entrance to Ingleborough Cave (SD754710) there is a pronounced bedding contrast in a small beck-side scarp, where closely jointed, poorly and thickly bedded, pale grey weathering calcarenites abruptly overlie rubbly weathering, dark grey, medium and thinly bedded, foetid calcarenites. This is the Raven Ray Formation—Horton Limestone contact.

The Formation is intermittently and poorly exposed in Crummack Dale. Three outcrops, separated by small faults, occur above Nappa Scars under Norber Brow. The most westerly (SD767696) is the most completely exposed and the thickness of the Formation is 16.95m.

Horton Limestone-pale grey, closely jointed, thickly bedded calcarenites.

8.10m, Non-exposure, scree-slope concealing probable Horton Limestone.

1.00m, Limestone, mid grey, medium grained, cross-laminated calcarenite, extensive terrace at this level.

0.85m, Limestone, mid grey, fine grained calcarenite.

4.40m, Limestone, sparsely lithoclastic, medium bedded, dark grey, very fine grained calcarenite.

0.90-
1.40m, Limestone, mid grey, medium grained calcarenite infilling and overlying scoured top of underlying bed. A layer of granule-lithoclasts occur on the top of the bed.

1.85m, Limestone, sparsely lithoclastic, fine to medium grained, mid grey calcarenite. The scoured top has relief of 0.50m.

4.30m, Limestone, medium bedded, sparsely lithoclastic, patchily cross-laminated, coarse grained calcarenite containing lenses and layers of lithoclasts.

2.20m, Limestone, thick bedded, cross-laminated, bioclastic, mid grey, coarse grained calcarenite.

2.45m, Limestone, slightly, foetid, bioclastic, dark grey, fine to medium grained calcarenite.

The Raven Ray Formation is separated from the Thornton Force Formation by a 1.65m interval of non-exposure.

16.20m of the Formation are intermittently exposed in the middle section (SD768697, Fig 6.7., 12B). The section comprises the following:-

Horton Limestone, pale grey weathering, closely jointed calcarenites.

7.50m, Non-exposure, scree slope.

2.00m, Limestone, dark grey, slightly foetid, fine grained calcarenite with layers of granule lithoclasts.

2.45m, Non-exposure.

3.15m, Limestone, intermittently lithoclastic and bioclastic, mid grey, medium to coarse grained calcarenite.

3.05m, Limestone, sparsely lithoclastic, foetid, mid grey, fine grained calcarenite.

2.10m, Limestone, sparsely lithoclastic, mid grey, fine grained calcarenite.

4.45m, Limestone, sparsely lithoclastic, mid grey, fine grained calcarenites overlying poorly exposed Thornton Force Formation. The limestone is cross-laminated at the base and intraclastic in the top 1.00m.

The eastern section above Nappa Scar (SD769698) is very poorly exposed. Nothing is seen for 2.70m from the top of the Thornton Force Formation, above which the following section was recorded:-

	Horton Limestone, pale grey weathering, closely jointed beds of calcarenite.
0.50m,	Non-exposure.
2.20m,	Limestone, sparsely lithoclastic, bioclastic and rubbly weathering, mid grey, fine to medium grained calcarenite with sparse solitary corals.
0.40m,	Non-exposure.
0.60m,	Limestone, sparsely lithoclastic, dark grey, fine grained calcarenite.
4.50m,	Non-exposure.
3.45m,	Limestone, sparsely lithoclastic, cross-laminated, mid grey, medium to fine grained calcarenite with isolated pebbles of graywacke (24x15x15mm maximum).
4.50m,	Non-exposure.
0.50m,	Limestone, quartz-rich medium grained, mid grey calcarenite.

Limestones, probably of the Raven Ray Formation, are seen between SD768702 and SD768705 along the western side of the dale. At SD768702 there are about 5.00m of mid grey, sparsely lithoclastic, fine grained calcarenite exposed. The limestones become less pebbly upwards and at the western end of the outcrop are cross-laminated to both north and south. Unfortunately neither the Thornton Force Formation nor the Horton Limestone are exposed. This creates problems in correlation.

At the next locality (SD768704), the succession is completely different (Fig. 6.8.,13B). 3.00m of mid grey, coarse grained calcarenite overlie 13.00m of poorly exposed boulder rudite. The Silurian graywacke boulders average one to two metres in length. They are wedged against a ridge of Silurian graywacke. The calcarenites contain sparse large boulders to 2.6x2.0x1.8m and many smaller cobble and pebble lithoclasts in the basal 1.40m (Plate 9a). However, only 25 metres to the north, the wedge of boulders has decreased in thickness to 10.40m and the overlying mid grey, coarse grained calcarenite is very bioclastic. Numerous sops of *Lithostrotion* and *Syringopora* occur together with broken brachiopod valves and gastropods replaced with ferroan calcite. The limestones contain fewer large lithoclasts and small lithoclasts become much more common. At SD768705 the lens of boulders has wedged out and the upper bed of calcarenite rests directly on Silurian graywackes. There are no boulders at the base, and lithoclasts, although common, are restricted to pebble- and granule-sizes.

Northwards, beyond the localities so far described, the unconformity rises sharply (Chapter 3 p34) and the Raven Ray Formation wedges out against graywackes. However, in the vicinity of Austwick Beck Head the unconformity is lower and poorly exposed Raven Ray Formation recurs. Above the main springs of Austwick Beck Head (SD776718) there are at least 8.00m of Thornton Force Formation, separated by a wide till slope from the next exposure, dark grey, fine grained calcarenite. Although not foetid, the thin bedding and rubbly weathering are characteristic features of the Raven Ray Formation . No thickness was measured.

The Raven Ray Formation is poorly exposed at the head of Crummack Dale (SD778722). There are no beds with characteristics of either the Thornton Force Formation or the Horton Limestone exposed. The lowermost 3.50m comprise medium bedded, mid grey calcarenites with thin, impersistent shale lenses. The beds are sparsely bioclastic and very bioturbated. Above there are 4.45m of thickly bedded, mid grey, fine grained calcarenite to a prominent bedding plane. The overlying limestones rapidly become obscured by till.

South of the graywacke ridge, the Formation is poorly exposed around Moughton Scars. At White Stone Wood (SD781705) there are approximately 4.70m of dark grey, fine grained calcarenite resting on Thornton Force Formation. The thinly bedded limestones are foetid and rubbly weathering, but no shale films were seen on the irregular bedding planes. The top of the Formation is defined by a pronounced bedding plane which weathers back to form a terrace. Above, there are closely jointed, white weathering limestones.

On Moughton Scars above Wharfe, the Raven Ray Formation is not exposed. Usually there is a till-covered sloping terrace above outcrops of Thornton Force Formation, but where the till is very thin pale grey limestones appear to overlie the Thornton Force Formation directly. At SD795698, there is a poor outcrop in the terrace of rubbly weathering, thin bedded, bioclastic, black, fine grained calcarenite 1.30m thick. Beyond this poor exposure, towards Moughton Nab, dark and mid grey, rubbly, thin beds become better exposed. At Moughton Nab (SD79666965) there are 1.90m of dark grey, bioclastic, fine grained, foetid calcarenite. The top bed, 0.70m thick, contains a profusion of Lithostrotion colonies. At SD79706960, also at Moughton Nab, 2.40m of similar limestone are separated from the underlying Thornton Force Formation by a pronounced parting, along which considerable solution has occurred. The coral bed, 1.00m thick at this locality, persists around the Nab. It consists essentially of a monolayer of Lithostrotion colonies 1.00-1.50m in diameter and up to 1.0m high. Some colonies appear to be right-way-up; others, however, are inverted.

The Raven Ray Formation is next exposed at the bottom of Foredale Limestone Quarry (SD800701). The Formation comprises only three beds, which total 2.40m, separated by impersistent shale partings. The lowest bed rests on the irregular top of the underlying Thornton Force Formation. It, and the middle bed, are slightly foetid, dark grey, very fine grained calcarenites with gastropods. The top bed is dark-mid grey, medium grained calcarenite with numerous coral colonies, including Lithostrotion and Syringopora. The Raven Ray Formation is separated from the overlying closely jointed, pale grey weathering Horton Limestone by a pronounced bedding plane.

The Formation is very poorly exposed above Arcow Wood Quarry (SD801704). There are approximately 2.90m of rubbly weathering, poorly bedded, foetid, dark grey, fine grained calcarenite forming a gentle terrace. Above there are limestones typical of the Horton Limestone. Only a short distance to the north graywacke is seen directly beneath Horton Limestone; the Raven Ray Formation must abut the graywacke ridge.

Beyond the ridge the Formation is next exposed at Gillet Brae (SD80037195) where is overlies the Douk Gill Formation. There are 4.45m of dark grey, fine grained calcarenite and calcisiltite exposed:-

	Horton Limestone, poorly bedded, closely jointed, white weathering calcarenites.
0.70m,	Limestone, dark grey, fine grained calcarenite containing numerous brachiopod valves and large crinoid ossicles. Top irregular with hollows 30cm deep and 5 metres in length filled with colonies of Lithostrotion and Syringopora.
0.60m,	Limestone, dark grey, fine grained calcarenite.
0.10m,	Shale, persistent, black and laminated.
1.75m,	Limestone, three wedging beds of dark grey, fine grained calcarenite separated by impersistent shale films.(Plate 7d).
0.01m,	Shale, black, filling undulose surface of underlying bed.
0.04m-0.13m,	Limestone, wedge of dark grey calcilutite with pyrite nodules and an undulose top.
0.05m,	Limestone, laminated dark grey, fine grained calcarenite. 0.05m, Shale, black.
1.10m,	Limestone, two beds of dark grey, fine grained calcarenite overlying the shale and coal at the top of the Douk Gill Formation.

The Raven Ray Formation - Horton Limestone contact is exposed in Horton Quarry (SD80007198). Three beds of Raven Ray Formation, totalling 1.85m, are exposed at the bottom of the quarry face. The lowest bed, 0.70m thick, is black calcilutite. The remaining two beds are sparsely lithoclastic, fine grained, dark grey calcarenites with gastropods. The top of the uppermost bed (0.70m thick) is irregular with hummocky relief of 0.30-0.40m. This is correlated with the similar surface in Gillet Brae.

Limestones of the Raven Ray Formation are exposed in Blind Beck (SD801731), north of Horton-in-Ribblesdale, close to the line of the Sulber Fault, which probably accounts for the variable dip. The black weathering limestones extend for 85 metres along the stream, showing only a metre or so of outcrop at any one point; correlation is not easy (Fig 6.9,20B and 20B). The following succession can be pieced together:-

1.80m,	Limestone, poorly exposed, slightly foetid, dark grey, fine grained calcarenite.
0.85- 0.95m,	Limestone, dark grey, fine grained calcarenite containing an overturned colony of <u>Lithostrotion</u> at the base.
0.55m,	Limestone, black, foetid, fine grained calcarenite with a shale film on top.
0.40m,	Limestone, black calcilutite.
0.70m,	Limestone, medium-thick bedded, black, foetid, fine grained calcarenite cropping out at the base of the section near the culvert.

Neither top nor base of the formation are exposed at this locality.

At Douk Gill Scar (SD816725) the Raven Ray Formation conformably overlies the coal at the top of the Douk Gill Formation. 5.05m of medium-thick bedded, mid grey, fine grained calcarenite with disarticulated brachiopod valves and gastropods are exposed. The top of the Formation is marked by a very prominent bedding plane. Above it are poorly bedded, white weathering limestones of the Horton Limestone, containing massive <u>Lithostrotion</u> just above the contact.

The Raven Ray Formation overlies the laminated paper shale at the top of the Douk Gill Formation at Dub Cote Gill (SD819718). The Formation is 5.90m thick.

	Horton Limestone, pale grey weathering, closely jointed, medium grained calcarenite.
3.35m,	Limestone, three thick and very thick beds of mid grey, coarse grained calcarenite.

0.30m, Limestone, single bed of foetid, very fine grained calcarenite.

2.25m, Limestone, four medium and thick beds of laminated, sparsely lithoclastic, slightly foetid, mid grey, fine grained calcarenite separated by shale films.

South of the North Craven Fault, the Raven Ray Formation is exposed in the banks of the River Ribble above Stainforth Bridge (SD818672). Undulating thin and medium beds of black, foetid fine grained calcarenite and calcisiltite, separated by irregular shale films occur, extensively masked by stream debris. A shale, 0.10m thick, fills the relief in the top of the Thornton Force Formation. The thickness is difficult to measure because of the dip of 9-12^{o} towards 345^{o}N and the incomplete exposure; however, it is in the order of 11.50m. Upstream, higher in the succession, the beds gradually become thicker, averaging 0.30-0.50m, until the section is obscured by till and alluvium.

The Silverdale outcrops present considerable difficulties. They are mostly masked by till at the critical levels and none of the limestones exposed are characteristic of the Raven Ray Formaion. It is possible that the Formation was not deposited in this region. Only one bed, 0.95m thick, may be attributed to this Formation. It is dark, rubbly weathering, slightly foetid, fine grained calcarenite, which crops out above Silverdale Barn (SD83876965). It is isolated, occurring 1.45m above the highest exposure of Thornton Force Formation and 1.25m below pale grey, shelly, coarse grained calcarenites, probably Horton Limestone.

There are approximately two metres of thin and medium bedded, dark grey, slightly foetid calcarenite exposed in the stream close to the base of Malham Cove (SD898642). This locality is south of the North Craven Fault and very close to the Mid Craven Fault. The black limestones are overlain by thick, poorly bedded, pale grey weathering, jointed calcarenites of the Horton Limestone, which form Malham Cove.

The exposure in Gordale is also very poor. However, isolated beds of foetid, dark grey, fine grained calcarenite crop out in the vicinity of SD911660. These beds may be part of the Formation.

There are a number of outcrops of the Raven Ray Formation in Wharfedale and Littondale. The top of the Formation and the contact with the overlying Horton Limestone are exposed in Howgill, Kilnsey (SD968672). Only the uppermost 0.80m of the Raven Ray Formation crop out, comprising bioclastic, foetid, dark grey, fine grained calcarenite. The top is eroded with mounds 0.10-0.20m high and 0.50m wide. Lithostrotion and Syringopora occur in many of the mounds. The overlying Horton Limestone is less well bedded and weathers mid-pale grey.

The upper part of the Formation is well exposed at the base of Kilnsey Crag (SD974684) where there are 7.55m of dark grey limestone. The top of the Raven Ray Formation is irregular with up to 0.20m of relief on the surface. This surface is prominent and can be traced all round the base of the Crag (Plate 8b) as a conspicuous slot.

	Horton Limestone, poorly bedded, jointed, pale grey weathering calcarenites.
2.35-2.55m,	Limestone, poorly bedded, foetid, dark grey, fine grained calcarenite with discontinuous shale partings.
1.80m,	Limestone, medium bedded, foetid, dark grey, fine grained calcarenite. 0.35m, Non-exposure.
0.30m,	Limestone, foetid, mid grey, fine grained calcarenite.
0.15m,	Shale, finely laminated, black and persistent.
1.85m,	Limestone, six thin beds of foetid, dark grey, very fine grained calcarenite-calcisiltite.
0.45m,	Non-exposure.
0.30m,	Limestone, foetid, dark grey, fine grained calcarenite.

Limestones between the base of the crag and the outcrop of the Thornton Force Formation at Mill Scar Lash are not exposed anywhere in the area. However, Wilson & Cornwell (1982, p.62 Fig.2) indicate that there are 8 metres of Kilnsey Limestone (Raven Ray Formation) separated by an interval of 40 metres from 4 metres of dark limestone, probably equivalent to the Thornton Force Formation at Mill Scar Lash. The base of the Dinantian limestones occurs about ten metres below.

Limestones, probably of the Raven Ray Formation, were temporarily exposed at the bottom of Cool Scar Quarry (SD969675) but this lower level is being infilled at present. Foetid, dark grey, fine grained calcarenites and shales now occur only in large loose blocks.

On the eastern side of Wharfedale the Raven Ray Formation is poorly exposed at the bottom of Conistone Gorge (SD983675). 2.95m of foetid, mid grey, bioclastic calcarenite with intensive bioturbation in the top bed occur immediately below a shale film which separates them from poorly exposed, closely jointed, pale grey weathering limestones of the Horton Limestone.

The next exposure is in Sleets Gill (SD961695) in Littondale. There are isolated exposures below the road, consisting of one or two thin beds of foetid calcilutite. Outcrop is essentially continuous above the road, but much disturbed by small faults. Only the bottom part of the outcrop can be assigned to the Raven Ray Formation. It consists of very dark grey, foetid, fine grained calcarenite in thin impersistent beds. A shale (0.12m thick) occurs in a slot at the base of the exposure. Diphyphyllum and Caninia are common in the top bed, which lies in fault-contact with massive dolomitised Horton Limestone.

The Raven Ray Formation is poorly exposed in Cote Gill (SD946701). It is represented by slightly foetid, medium and fine grained, mid grey calcarenites with Lithostrotion. No section could be measured at this exposure because of the variable dip, small scale faulting and intermittent exposure. However, the Formation is at least 2.50m thick.

At the base of Arncliffe Clowder (SD940708) the Raven Ray Formation is intermittently exposed in the stream below a prominent spring line, which may indicate the base of the Horton Limestone. 6.65m of thin and medium bedded, foetid, dark grey, fine grained calcarenite, with occasional impersistent shaly partings, are seen. The limestones are locally intensely bioturbated. There is a till-filled gap of 4.50m to the spring level.

At Yew Cogar Scar (SD841634) the top of the Raven Ray Formation and the contact with the overlying Horton Limestone are exposed. Two beds, totalling 1.40m, consist of dark grey, fine grained calcarenite, with an impersistent shale parting filling relief of 0.25m on the top bed. The contact between the two Formations forms a conspicuous slot in the Scar (Plate 8a) and bears close resemblance to the equivalent horizon at Kilnsey Crag (p 111).

Limestones comparable to the Raven Ray Formation crop out at Scaleber Force (SD841634), south of the Mid Craven Fault. (Fig.6.11.). Recent dating, by means of foraminifera, places the base of the Scaleber Force Limestone in the Arundian Stage (Fewtrell, Ramsbotton & Strank, 1981.) although it is possible that some of the higher beds should be assigned to the Holkerian and Asbian Stages. The Scaleber Force Limestones may, therefore, include some parts equivalent to the Thornton Force Formation and Horton Limestone. The succession is considerably thicker (30.5m) than at any exposure north of the Mid Craven Fault. It is complex and terminates immediately below Scaleber Bridge. On the opposite side of the bridge bedded dolomitised limestones overlie more cherty limestone.

The following succession is seen:-

3.55m, Limestone, poorly exposed, black, foetid, fine grained calcarenite with irregular shale partings. Chert nodules and chert-filled burrows are common.

0.65m, Limestone, black, fine grained calcarenite with impersistent shale films, chert nodules, chert veins and silicified corals.

0.95m, Limestone, black, fine grained calcarenite with 0.05m thick chert layer on top of the bed.

0.02mm, Shale, black persistent.

1.10m, Limestone, thin and medium bedded, black, fine grained calcarenite with shale partings and disseminated chert in the top bed.

0.45m, Limestone, black calcilutite.

0.60m, Limestone, thinly bedded, black, fine grained calcarenites with shale partings.

0.25m, Shale, black and laminated.

1.65m, Limestone, poorly exposed, medium bedded, black fine grained calcarenite with impersistent shale wisps.

0.40m, Limestone, black calcilutite.

0.85m, Limestone, black, foetid, fine grained calcarenite with 0.05m thick shale film filling hollows in the irregular top.

0.25m, Limestone, black calcilutite.

0.60m, Limestone, thinly bedded, black, foetid, fine grained calcarenite with shale films.

1.90m, Limestone, medium bedded, black, fine grained calcarenite.

0.65m, Limestone, thinly bedded, black, fine grained calcarenite with shale partings.

0.30m, Limestone, black calcilutite.

0.60m, Limestone, intensely bioturbated, nodular, black, fine grained calcarenite.

0.15m, Limestone, black calcilutite.

1.30m, Limestone, medium bedded, bioturbated, nodular and mottled, black, fine grained calcarenites and shale films.

0.85m, Limestone, medium bedded, black, fine grained calcarenites separated by shale films.

0.40m, Shale, black, with lenses of bioturbated calcarenite.

0.25m, Limestone, black calcilutite.

0.20m, Shale, black.

1.50m, Limestone, thinly bedded, black, fine grained calcarenites.

0.20m, Non-exposure.

2.85m, Limestone, medium bedded, black, foetid, fine grained calcarenites separated by shale partings. Beds are intensely burrowed and bioturbated.

2.45m, Limestone, medium bedded, burrowed and bioturbated, black, fine grained calcarenites separated by platy, unfossiliferous shales.

1.25m, Shale, black, platy and unfossiliferous.

5.35m, Limestone, thin and medium bedded, foetid, black, fine grained calcarenites separated by black, calcareous shales 0.05-0.15m thick. Beds are intensely bioturbated immediately below the shales.

6.1 Measured Sections Through The Raven Ray Formation

1.	Raven Ray, Kingsdale	SD695753.
2.	Twisleton End, Chapel-le-Dale.	SD703750.
3.	Twisleton Scars, Chapel-le-Dale.	SD71357562-71747587.
4.	Twisleton Pastures, Chapel-le-Dale.	SD72087606-72357632.
5.	Skirwith Quarry, Chapel-le-Dale.	SD709738.
6.	White Scars, Chapel-leDale.	SD714747.
7.	High Howeth, Chapel-le-Dale.	SD71637477-72157530.
8.	Light Water Spring, Chapel-le-Dale.	SD73257587.
9.	God's Bridge, Chapel-le-Dale.	SD733763.
10.	Jenkin Beck.	SD714729.
11.	Newby Cote Quarry, Newby.	SD733707.
12.	Nappa Scar, Crummack Dale.	SD767696-769698.
13.	Western Crummack Dale.	SD768702-768705.
14.	Austwick Beck Head, Crummack Dale.	SD778722.
15.	White Stone Wood, Crummack Dale.	SD781705.
16.	Moughton Scars.	SD795698.
17.	Moughton Nab, Ribblesdale.	SD79666965-79706960.
18.	Foredale Quarry. Ribblesdale.	SD800701-801704.
19.	Gillet Brae and Horton Quarry, Ribblesdale.	SD80037195 and SD80007198.
20.	Blind Beck, Ribblesdale.	SD801731.
21.	Douk Gill Scar, Ribblesdale.	SD816725.
22.	Dub Cote Gill, Ribblesdale.	SD819718.
23.	Malham Cove.	SD898642.
24.	Howgill, Wharfedale.	SD968672.
25.	Kilnsey Crag, Wharfedale.	SD974684.

26.	Conistone Gorge, Wharfedale.	SD983675.
27.	Sleets Gill, Littondale.	SD961695.
28.	Arncliffe Clowder, Littondale.	SD940708.
29.	Yew Cogar Scar, Cowside Beck.	SD919707.
30.	Scaleber Force.	SD841634.

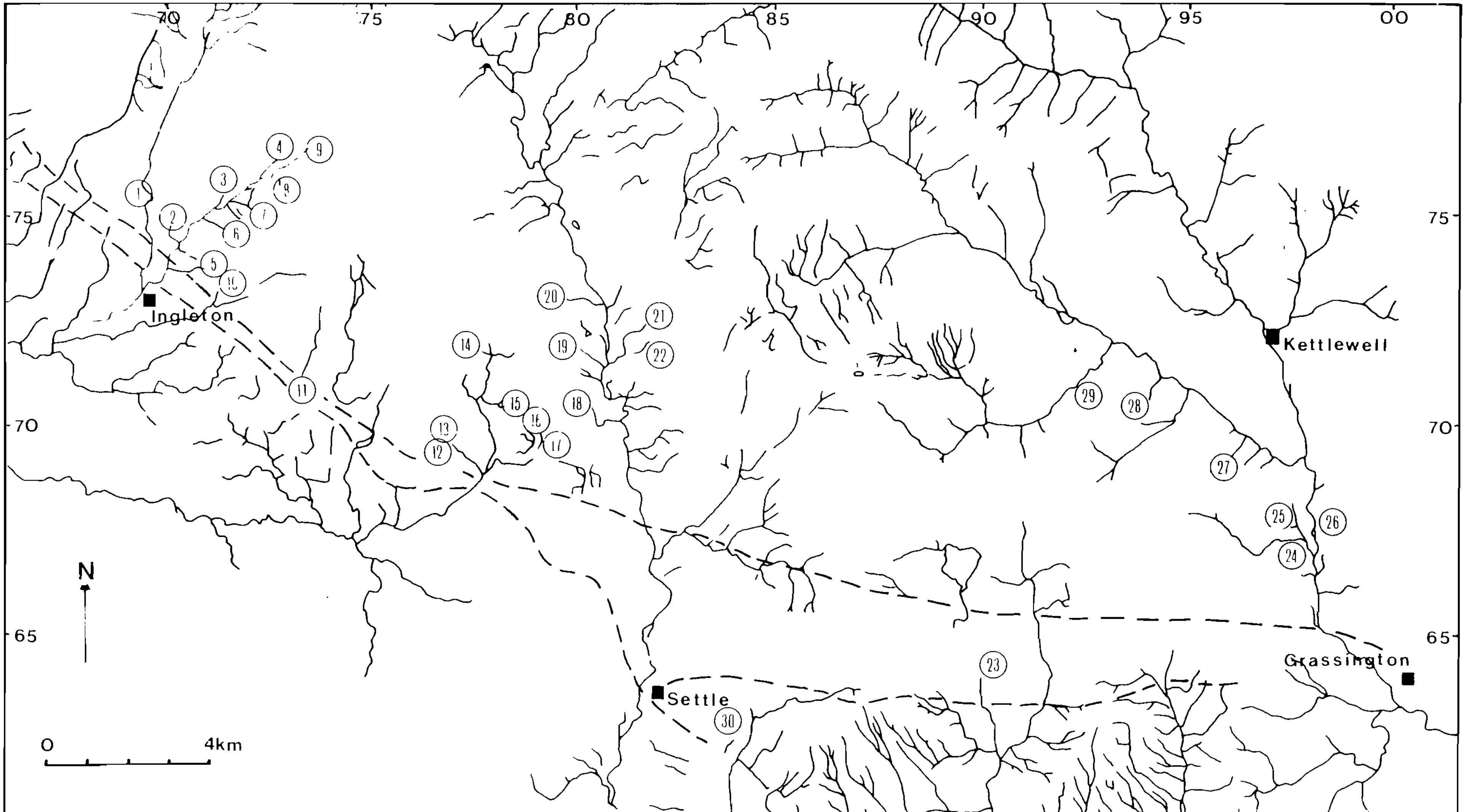
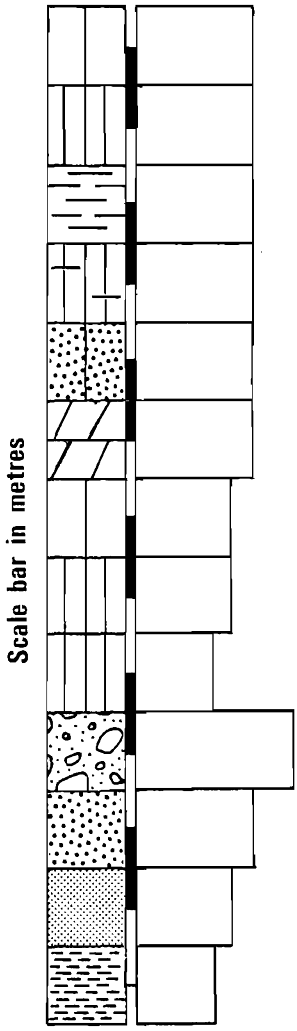


FIGURE 6.1 Location of measured sections through the Raven Ray Formation.



Mid grey calcarenite

Dark grey calcarenite

Interbedded black shale and dark - mid grey calcarenite

Dark grey calcarenite with sparse shale films

Calcareous quartz arenite

Dolomite

Mid grey calcisiltite

Dark grey calcisiltite

Dark grey calcilutite

Boulder rudite

Fine grained quartz arenite

Fine grained quartz silt

Black shale

unspecified bioclasts

bivalves

brachiopods

bryozoa

crinoids

gastropods

coated grains

intraclasts

lithoclasts

lithoclast layer or lenses

F foetid

P pyrite

R rubbly weathering

S silicified

Bioturbation

TFF Thornton Force Formation

DGF Douk Gill Formation

HL Horton Limestone

FIGURE 6.2 Key to symbols used in figured sections through the Raven Ray Formation.

Figures 6.3 to 6.11. Measured sections through the Raven Ray Formation. (The lowermost bed of the Formation is shown resting on limestones of the Thornton Force Formation or Douk Gill Formation where the contact is exposed).

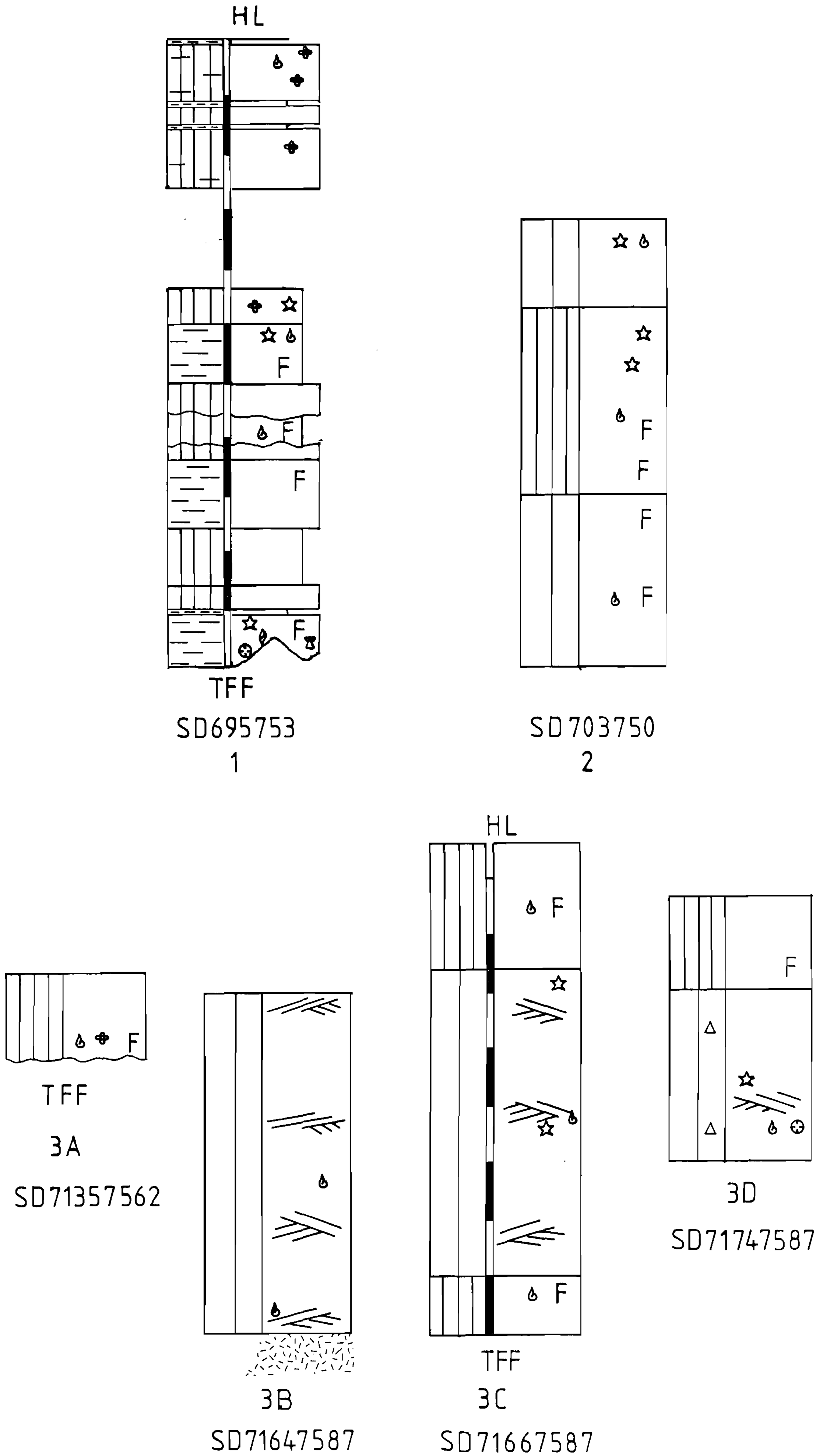

HL
TFF
SD695753
1
SD703750
2
TFF
3A
SD71357562
3B
SD71647587
HL
TFF
3C
SD71667587
3D
SD71747587

FIGURE 6.3

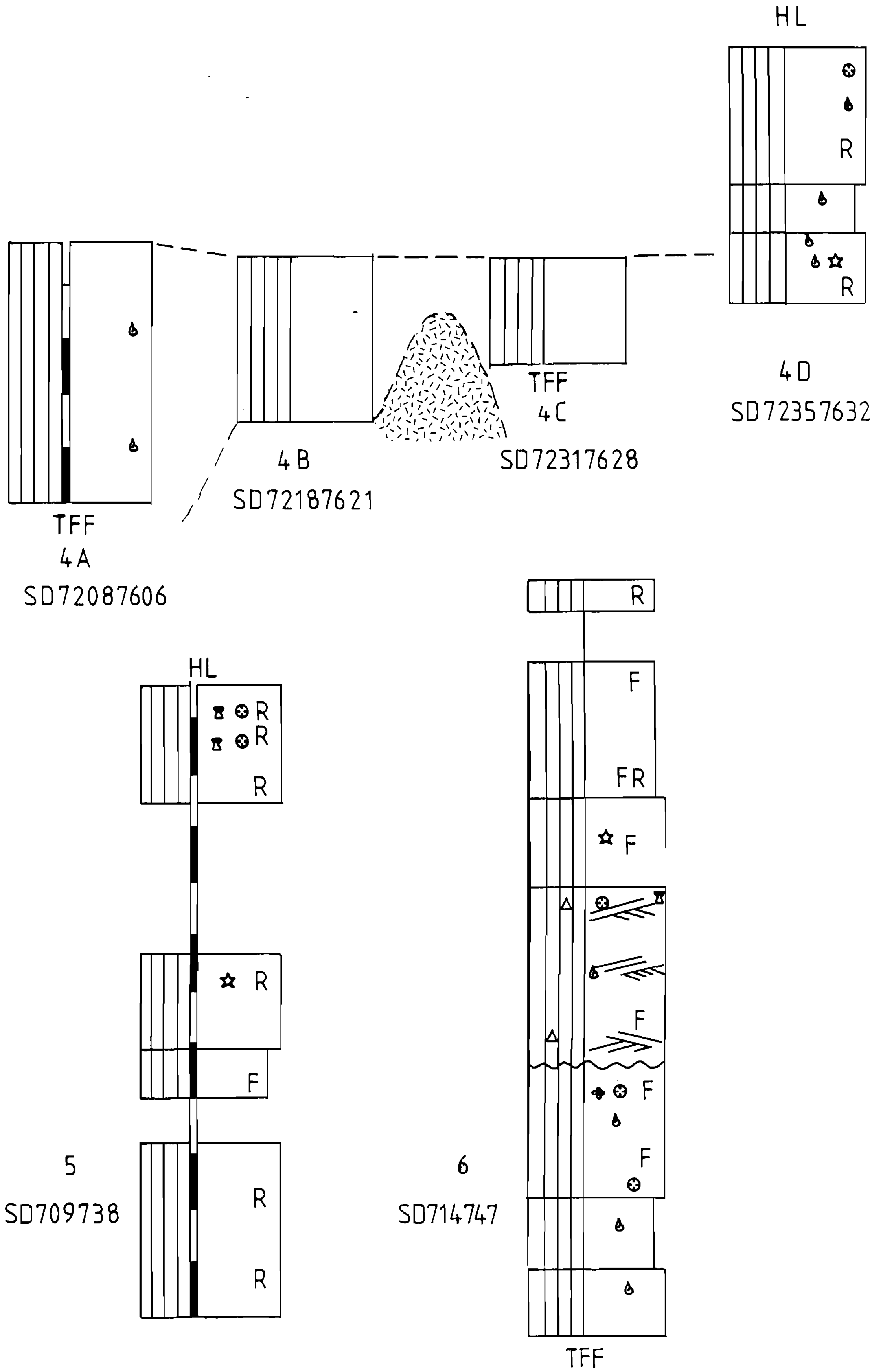

HL
R
R
4D
SD72357632
TFF
4A
SD72087606
4B
SD72187621
TFF
4C
SD72317628
R
HL
R
R
R
F
FR
F
R
F
F
F
F
R
R
5
SD709738
6
SD714747
TFF

FIGURE 6.4

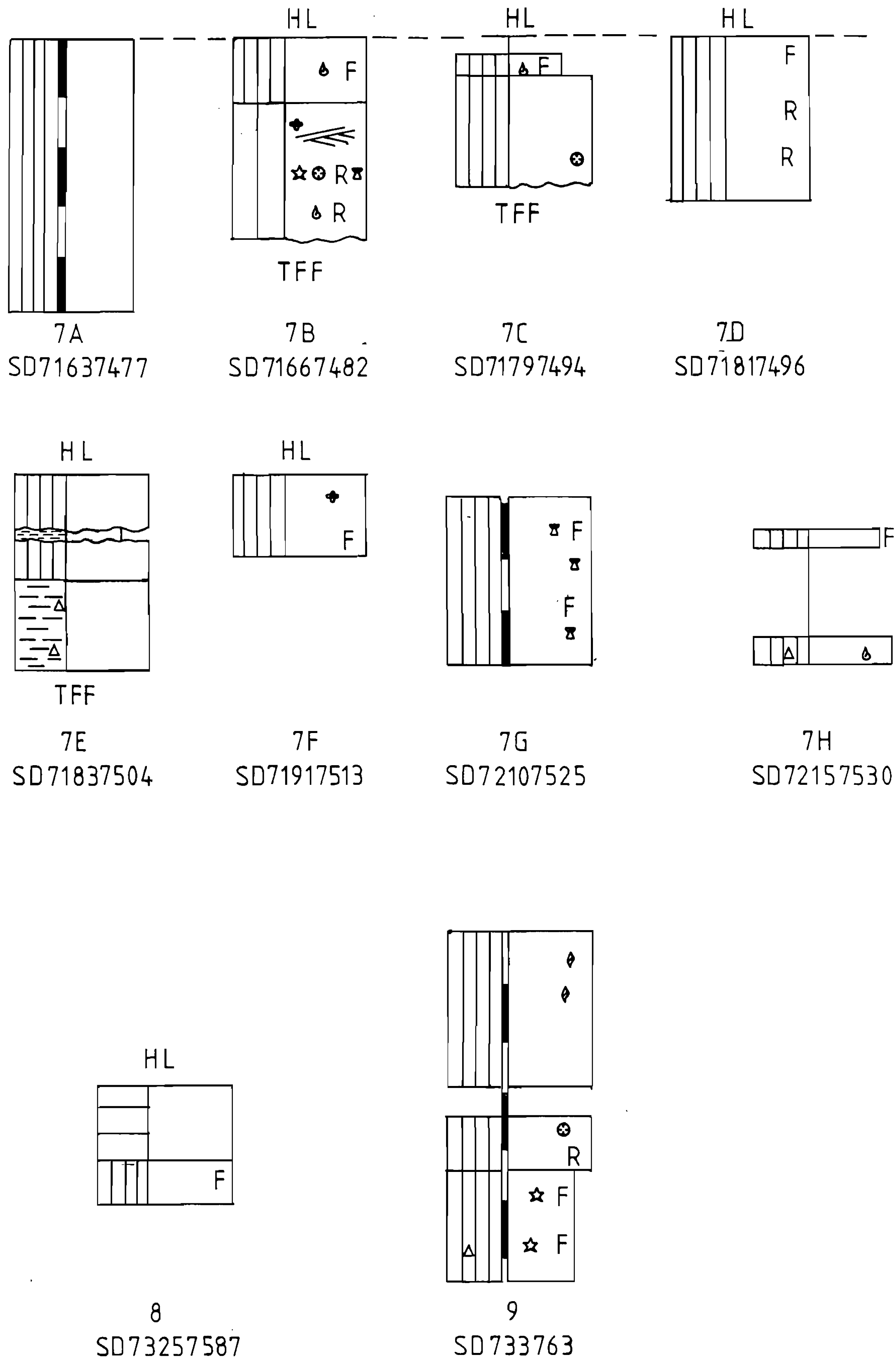

HL
HL
HL
HL
F
F
F
R
R
R
R
TFF
TFF
7A
SD71637477
7B
SD71667482
7C
SD71797494
7D
SD71817496
HL
HL
TFF
F
F
F
F
7E
SD71837504
7F
SD71917513
7G
SD72107525
7H
SD72157530
HL
F
R
F
F
8
SD73257587
9
SD733763

FIGURE 6.5

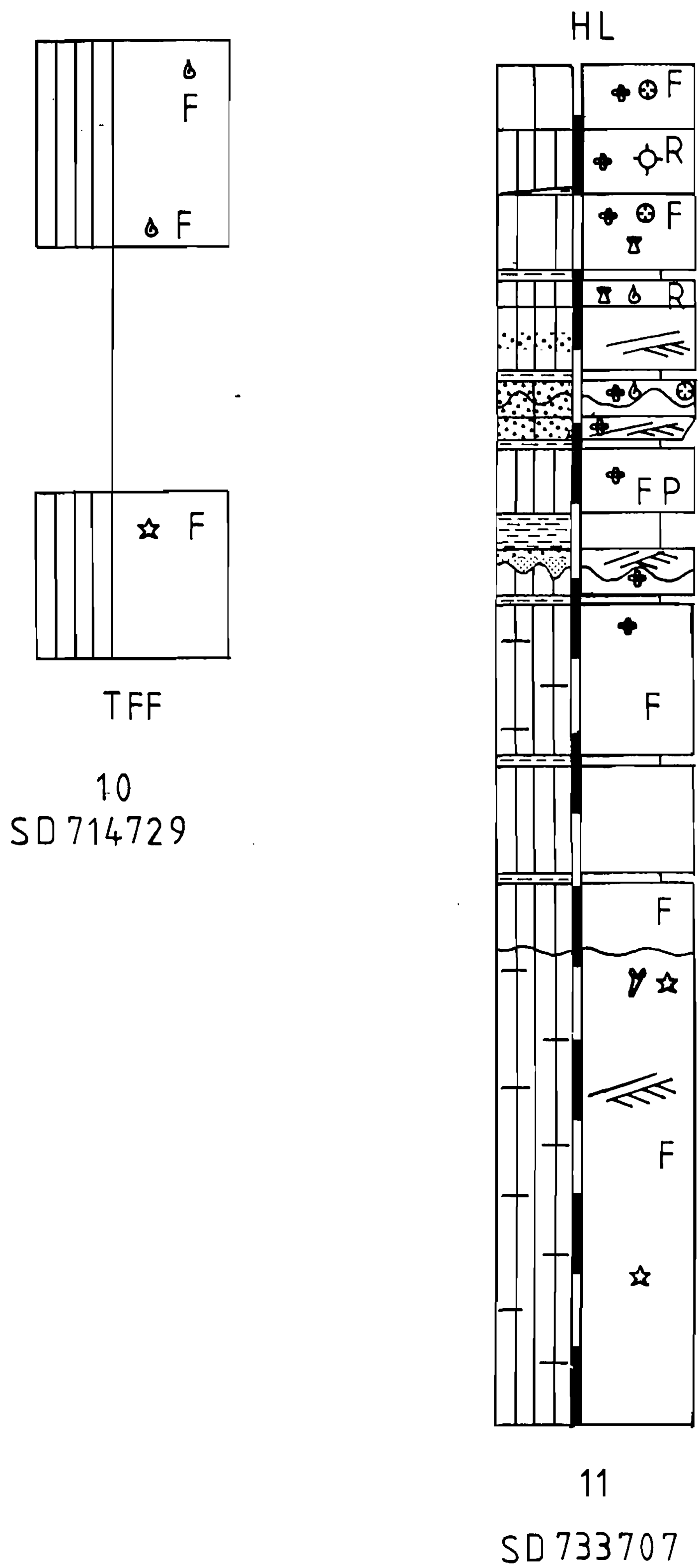
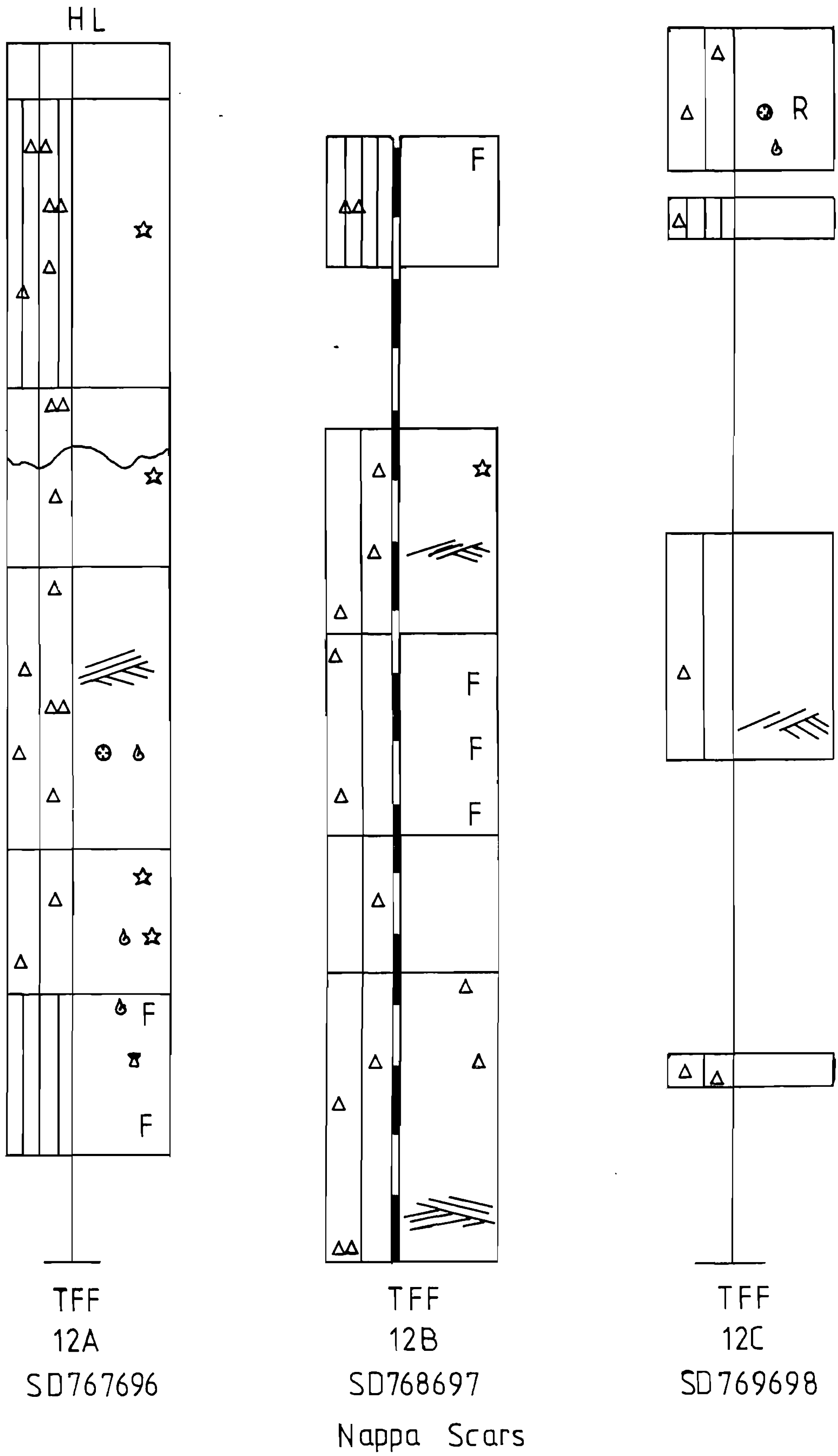


FIGURE 6.6



HL
F
R
F
F
F
F
F
TFF
12A
SD767696
TFF
12B
SD768697
TFF
12C
SD769698
Nappa Scars

FIGURE 6.7

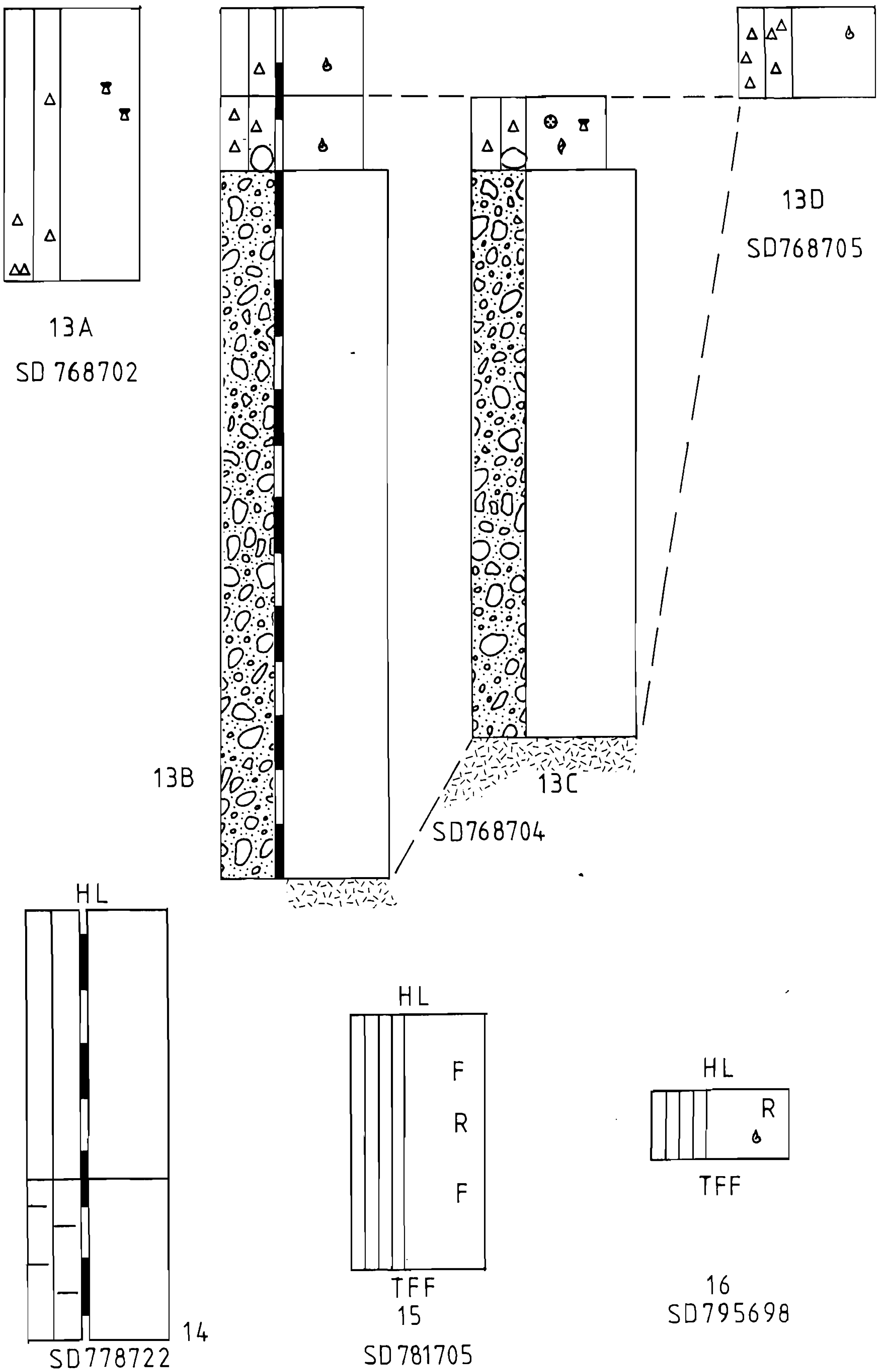

13A
SD 768702
13B
13C
SD768704
13D
SD768705
HL
14
SD778722
HL
F
R
F
TFF
15
SD 781705
HL
R
TFF
16
SD795698

FIGURE 6.8

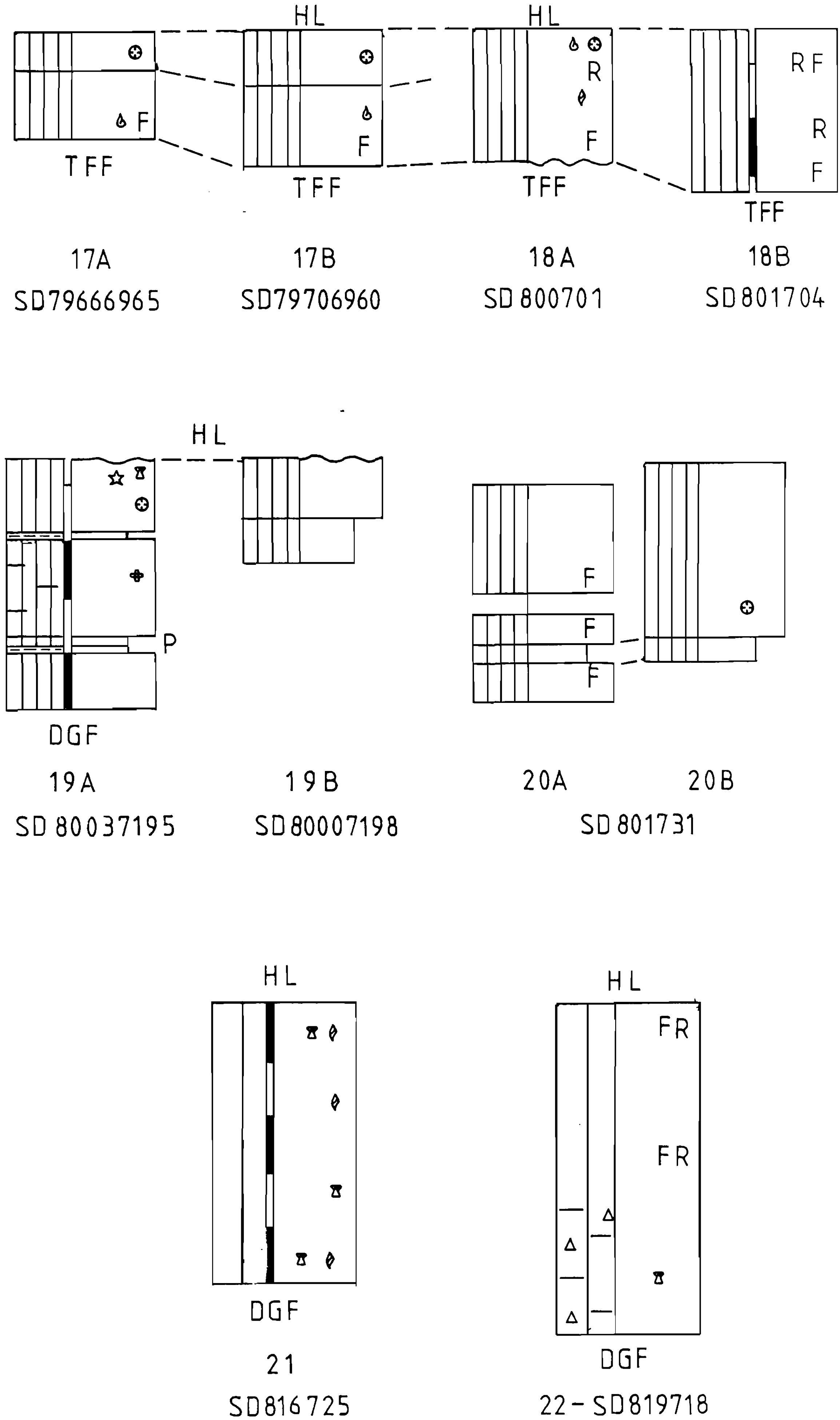

HL
HL
TFF
TFF
TFF
TFF
R
F
F
F
RF
R
F
17A
SD79666965
17B
SD79706960
18A
SD 800701
18B
SD801704
HL
P
DGF
F
F
F
19A
SD 80037195
19B
SD80007198
20A
20B
SD 801731
HL
HL
FR
FR
DGF
DGF
21
SD816725
22 - SD819718

FIGURE 6.9

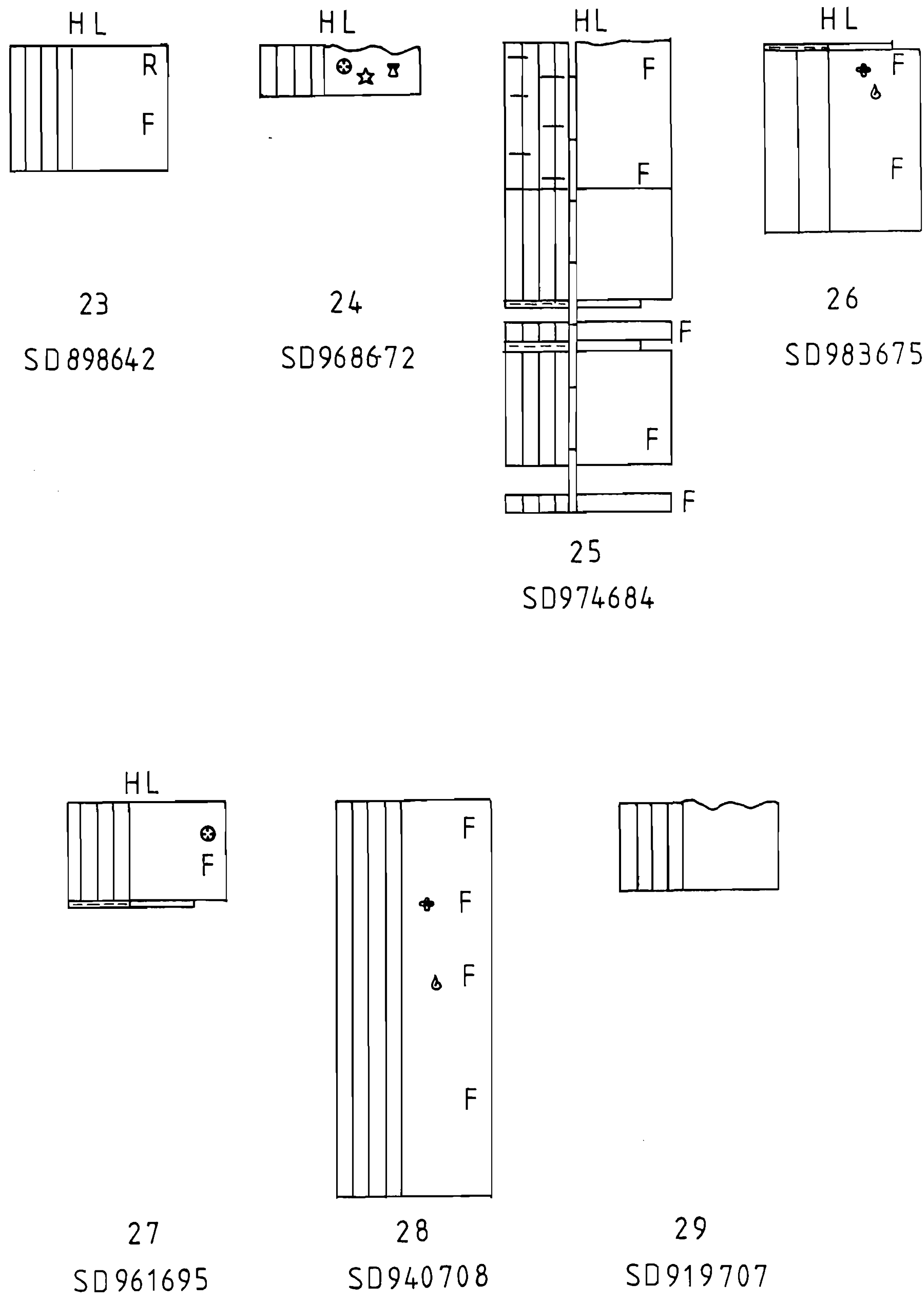

HL
R
F
23
SD898642
HL
24
SD968672
HL
F
F
F
F
F
25
SD974684
HL
F
F
26
SD983675
HL
F
27
SD961695
F
F
F
F
28
SD940708
29
SD919707

FIGURE 6.10

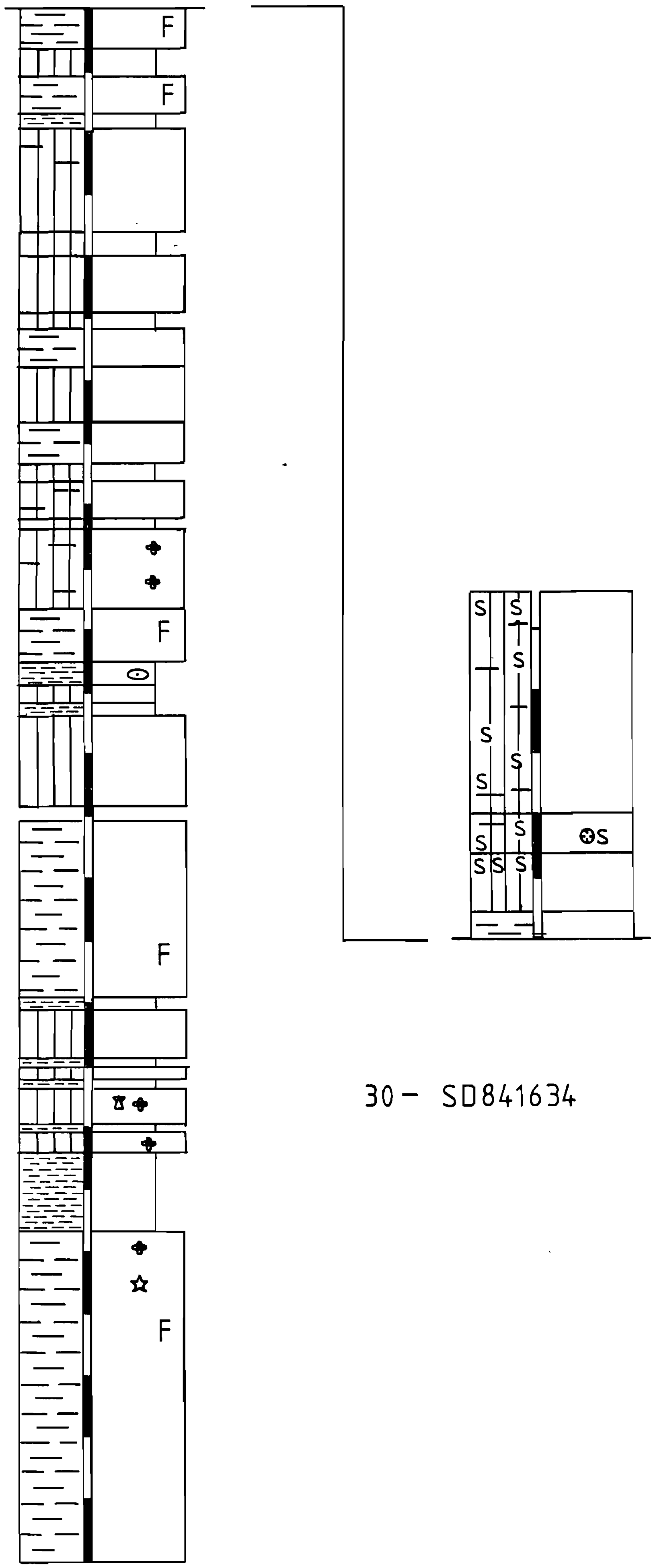


FIGURE 6.11

CHAPTER SEVEN

THE HORTON LIMESTONE

The Horton Limestone is the third formation of the Great Scar Group. For the most part it rests on the underlying Raven Ray Formation,.and is overlain by the Kingsdale Limestone. However, in Crummack Dale and possibly in Silverdale, it rests directly upon Lower Palaeozoic rocks.

The Horton Limestone was first described by Garwood & Goodyear (1924) as the Nematophyllum minus Beds, one of the most widespread horizons of the succession in west Yorkshire. It is confined to the area north of the Craven Faults except for a small exposure near Skyrethorn (SE 0762) where limestones of similar age crop out. Its greatest thickness is 230'(73m) according to Garwood & Goodyear. Lithologically the Horton Limestone is extremely uniform but can be divided into two portions on the basis of colour; a lower dark grey limestone overlain by pale grey to buff coloured limestones. The transition is abrupt but there is no change in fauna. Garwood & Goodyear attributed the dark colour of the lower beds to the presence of land in the immediate neighbourhood supplying fine detrital material. At the top of the Horton Limestone a white-weathering calcilutite, the Porcellanous Bed of Garwood & Goodyear (1924), is widespread. It was designated by them as the boundary of their S_2 and D_1 faunal zones, which were difficult to separate in any other way. They noted that the useful marker bed failed southwards and was not present south of the North Craven Fault.

Very little work was done on the Horton Limestone until Ramsbottom (1974) discussed the detailed stratigraphy of the Carboniferous Limestone in Yorkshire. Prior to this, the Horton Limestone had been mentioned briefly by Schwarzacher (1958), Doughty (1974) and Waltham (1971). The Horton Limestone was first defined by Ramsbottom (1974) as "the limestones exposed in Horton Quarry". This definition is inadequate since the quarry has been extended and now includes the calcilutite and lower Kingsdale Limestone. In palaeontological terms the Horton Limestone would have been declared nomen nudum, since it lacks any diagnosis of the characteristics of the defined subject, nor does it specify the dimensions. Moreover, the name Horton is already pre-occupied by the mid-Silurian Horton Formation, formerly the Horton Flags, having the same type-area. The conservatism so prevalent amongst British geologists renders it difficult to alter stratigraphic terminology, however antiquated or imprecise. On these grounds only, the Horton Limestone is retained. It is redefined here as the mid grey and pale grey limestones, including the calcilutite, overlying the distinctive dark grey Raven Ray Formation, and being overlain by the massively bedded, pale grey Kingsdale Limestone.

Ramsbottom (1973, 1974) proposed that the Dinantian strata of Great Britain were deposited during a series of eustatic transgressions and regressions. According to Ramsbottom, the Horton Limestone accumulated in the transgressive phase, and the calcilutite during the regressive phase, of major cycle four. In 1976, the Dinantian Working Group defined a new series of stages conforming closely with the major cycles of Ramsbottom. The Horton Limestone was deposited during the Holkerian Stage.

It could be argued that the calcilutite itself is a separate formation, being lithologically distinct from the rest of the Horton Limestone. This would complicate matters considerably, particularly as more than one calcilutite horizon has been identified. It is impossible to separate the Horton Limestone into meaningful units above and below of the lower calcilutite, therefore, for the purposes of this thesis, the calcilutites are described as part of the Horton Limestone.

Since the detailed mapping of Garwood & Goodyear (1924) the calcilutite (Porcellanous Band) has been regarded as the base of the overlying D_1 Subzone. Thus its base defines the top of the Horton Limestone. However, during the course of this study a marked erosion surface, with relief of 1-2 metres, was observed approximately 6-11 metres above the top of the upper calcilutite in both the Ingleton and Kettlewell districts. The limestones cropping out between the calcilutite and the erosion surface above are very similar lithologically to the Horton Limestone below and it is proposed to include them in the Horton Limestone.

It must be emphasised that it is the presence of the calcilutite that enables the distinction between S_2 (Holkerian) and D_1 (Asbian) limestones, especially in poorly exposed ground. However, the calcilutite does not crop out over much of the study area (Fig 7.10) and time-consuming studies are necessary to identify the boundary. Jefferson (1980) has proposed that cycles are present in the Horton Limestone, and that these, when identifiable, can be used to determine the position of the Holkerian - Asbian boundary.

The Horton Limestone has been subdivided into parts to facilitate easier description. The calcilutite is dealt with in great detail in the latter part of the chapter and is only briefly mentioned in the descriptions of the subareas (Fig 7.1).

7.1 Ribblesdale

Although Ramsbottom (1974) defines the Horton Limestone type-section as Horton Quarry, he gives no description of the rock-types or the thicknesses. Unfortunately, only parts of the succession at this locality can be described in detail because of the inaccessibility of much of the quarry face.

The contact between the Horton Limestone and the underlying Raven Ray Formation is exposed in the quarry at SD80007198, and just to the south above Gillet Brae (SD80037195) where there is relief of 0.25-0.35m on the top bed of the Raven Ray Formation. Colonies of *Lithostrotion*, in growth position and up to 1.0m across, fill these hollows and many other corals were observed throughout the lowest beds of coarsely bioclastic Horton Limestone. There is a similar relationship between the Horton Limestone and the Raven Ray Formation at Douk Gill Scar (SD816726) where coarse bioclasts and massive *Lithostrotion* occur in the lowest beds of Horton Limestone. Garwood & Goodyear (1924) commented on the frequent occurrence of Lithostrotion colonies in the lowest beds of the Nematophyllum minus Subzone.

In Horton Quarry, the type-section of the Horton Limestone, the sequence listed below was observed. Unfortunately large parts of the quarry face are inaccessible and there the thickness can only be estimated. The quarry succession described below is listed in stratigraphical sequence with the oldest beds occurring lower in the description.

	Kingsdale Limestone, well bedded, pale grey calcarenites. Thin mudstone resting on the erosion surface.
c.5.00m	Limestone, pale grey, fine grained calcarenite.
3.45-6.00m,	Limestone, wavy laminated at base, grading up into fenestral bioclastic calcilutite.
c.40.00m,	Limestone, mid grey calcarenites overlain by interbedded mid and pale grey calcarenites and then by pale grey calcarenites. Mostly medium and fine grained. A thin calcilutite occurs 11m from the top. Abrupt change in lithology.
9.25m,	Limestone, medium grained mid grey calcarenites the top 1.50m of which become fine grained. Lithostrotion, Syringopora, brachiopods and gastropods observed in more fossiliferous beds.
0.65m,	Limestone, dark grey fine grained calcarenite in single bed.
	Raven Ray Formation.

In Horton Quarry there is undulose relief of 0.25-0.40m at the top of the Raven Ray Formation. The basal Horton Limestone beds are coarsely bioclastic but with no visible corals in the lowermost two metres.

South of Horton Quarry the lower part of the Horton Limestone is poorly exposed except in Foredale Quarry (SD799705, Fig 7.3.,2) where the basal limestones overlie the Raven Ray Formation. The contact is irregular and there are 0.20-0.30m of relief.

c.20.00m,	Horton Limestone, pale grey calcarenite. The calcilutite is not exposed.
c.10.00m,	Limestone, pale grey calcarenite to the top of Foredale Quarry.
11.00m,	Limestone, poorly bedded, pale grey, medium grained calcarenite.
7.00m,	Limestone, dark grey, medium grained calcarenite with wavy bedding planes.

The consequence of the non-exposure of the calcilutite is that the top of the Horton Limestone cannot be recognised, a feature observed by Garwood & Goodyear (1924).

North of Horton Quarry the upper part of the Horton Limestone is poorly exposed along the public footpath near Beecroft Farm (SD797727). At this locality 11.05m of calcarenite and calcisiltite separate the two calcilutite horizons. The section measured is described below.

0.75m,	Limestone, pale grey calcilutite.
1.85m,	Limestone, pale grey calcisiltite.
8.30m,	Limestone, pale grey, very fine grained calcarenite, poorly and intermittently exposed.
0.60m,	Limestone, pale grey, fine grained calcarenite.
0.30m,	No exposure.
0.45m,	Limestone, pale grey calcilutite.
4.25m,	Limestone, cross-laminated, richly bioclastic, pale grey, fine grained calcarenite containing Linoprotonia and Davisiella.

The top of the Horton Limestone is exposed again near Selside (SD785764). Below South House (SD787742) there are indications of changes in lithology; above the upper calcilutite there are shaly limestones and mid to dark grey calcarenites. North of Selside (SD785764) this horizon is not exposed but new rock types are developed at the level of the low calcilutite.

2.40m,	Limestone, pale grey calcilutite. Above the remainder of the Horton Limestone is not exposed.
2.75m,	Limestone, pale grey calcarenite, coarse grained at base and fining upwards.
1.60m,	No exposure.
2.35m,	Limestone, mainly pale grey coarse grained calcarenite. The base of the lowest bed is mid grey, coarsely crinoidal foetid calcarenite where pyrite nodules occur.
0.05m,	Paper shale.
0.45m,	Finely laminated black shale which thickens to the north as the underlying bed thins.
0.80-0.30m,	Limestone, cross-laminated, dark grey calcarenite. Where the bed is thinnest slumped structures were observed.
0.40m,	Limestone, two beds of black calcilutite separated by black fine grained calcarenite.

There are no more exposures of the Horton Limestone in Ribblesdale at which measured sections could be obtained. Some mid grey limestones, probably part of the lower Horton Limestone crop out in Dub Cote Quarry (SD821717) and at Douk Gill Scar (SD816726). Garwood & Goodyear (1924) suggested that the Carboniferous succession in the adjacent valley of Silverdale commenced with the Nematophyllum minus Beds (Horton Limestone). Unfortunately the outcrop is very poor and it is impossible to verify this.

7.2 Kingsdale and Chapel-le-Dale

The valleys of Kingsdale and Chapel-le-Dale have been excavated through the Carboniferous limestone to the Lower Palaeozoic rocks at their southern ends. Unfortunately, much of the lower slopes are till-covered and the Horton Limestone is only poorly exposed.

The base of the Horton Limestone and the contact with the underlying Raven Ray Formation is exposed at Raven Ray (SD695755), Fig 7.4;5) where there is an abrupt change from thinly bedded dark grey calcarenites (biomicrites) with shale partings to more thickly bedded, shale-free, mid grey calcarenites. Only the lowermost 15m are seen.

The middle and upper parts of the Horton Limestone are exposed in the old quarries at SD691756 (Fig 7.4;6). The outcrop begins below the road. The highest exposed limestones are well bedded, dark grey weathering, coarse grained calcarenites. They are well jointed and form distinctive limestone pavements. These beds are considered part of the lower Kingsdale Limestone.

6.70m,	No exposure.
1.00m,	Limestone, pale grey, very fine grained calcarenite.
0.90m,	Limestone, two beds of pale grey calcilutite.
7.65m,	Limestone, very poorly exposed, white weathering, pale grey, very fine grained calcarenite containing whole brachiopods and rare trilobite fragments.
13.15m,	Main part of the quarry. Pale grey coarse, medium and fine grained calcarenites in beds 1.00-1.50m thick.
1.35m,	No exposure.
4.30m,	Limestone, poorly bedded, pale grey, medium grained calcarenite.
3.15m,	No exposure-road level.
2.75m,	Limestone, sparsely bioclastic, pale grey, medium grained calcarenite.
4.80m,	Limestone, mid grey, medium grained calcarenite containing corals, brachiopods and crinoids.
4.70m,	Limestone, pale grey, medium grained, laminated bioclastic calcarenites.

Below, there is no exposure between the base of this outcrop and the top of Raven Ray where the top of the Raven Ray Formation is exposed. Assuming that there is no faulting in the unexposed ground between the two outcrops, the Horton Limestone must be at least 66m thick.

Northwards in Kingsdale, the major part of the Horton Limestone is obscured by till and only the calcilutite is occasionally exposed. Waltham (1974,p33) measured a number of sections through the Horton Limestone in potholes. Below the calcilutite there are approximately 70m of Horton Limestone in Lost John's Pot (SD671786), 21m in Swinsto Hole (SD694775), 23.50m in Rowten Pot (SD698780) and 67.50m in Juniper Gulf (SD767734). The exposure is totally covered on the eastern side of Kingsdale.

Exposures improve in Chapel-le-Dale. Almost the entire thickness of the Horton Limestone, 79 metres, is exposed at Twisleton Scar End (SD708752).

-	Limestones typical of the Kingsdale Limestone.
7.55m,	No exposure.
0.25m,	Limestone, very poorly exposed white calcilutite.
12.60m,	Limestone, very poorly exposed bioclastic, pale grey calcarenite.
2.30m,	Limestone, very finely interbedded pale grey calcarenite and calcilutite.
2.80m,	Limestone, pale grey, very fine grained calcarenite containing gastropods, brachiopods, and small colonies of *Lithostrotion* and *Syringopora*.
0.75m,	Limestone, dark grey, very fine grained calcarenite.
4.10m,	Limestone, medium bedded, pale grey and medium grey calcarenite.
4.20m,	Scree.
c.28.00m,	Limestone, intermittently exposed bioclastic mid grey fine grained calcarenites in beds up to 1.50m thick. Locally intraclastic.
1.65m,	Limestone, bioclastic, dark grey, fine grained calcarenite.
10.60m,	Limestone, medium-thick bedded, fine to medium grained, slightly foetid, bioclastic mid grey calcarenites containing small coral colonies and brachiopods.

The most northerly exposure on the northwest side of Chapel-le-Dale is at Brows Pasture (SD731763) where the upper 38.20m of the Horton Limestone crop out. The sequence observed is described below.

-	Excellent exposure of lower beds of Kingsdale Limestone.
4.60m,	Limestone, poorly exposed pale grey calcarenites.
1.55m,	Limestone, pale grey, medium grained calcarenite.
4.00m,	Limestone, buff-grey fenestral calcilutite.
3.60m,	Limestone, mid-pale grey, fenestral, bioclastic calcisiltite in two beds.
7.15m,	Limestone, pale grey, coarse grained calcarenite gradually fining upwards.
1.55m,	Limestone, two beds of pale grey calcilutite separated by pale grey fine grained calcarenite.
1.20m,	No exposure.
0.40m,	Limestone, parallel laminated, pale grey, medium grained calcarenite.
1.75m,	Limestone, single bed of fine grained calcarenite - calcisiltite grading up to calcilutite at the top.
1.35m,	Limestone, dark grey calcisiltite forming a distinctive white weathering bed.
5.80m,	Limestone, mid grey, fine to medium grained calcarenite.
5.25m,	Limestone, pale grey, very fine grained calcarenite.

The base of the Horton Limestone is revealed at the head of Light Water Spring (SD732758) at the southeast side of the valley. Unfortunately the contact with the underlying Raven Ray Formation is very poorly exposed and it appears to be dolomitised. Above there are 4.60m of mid grey, slightly foetid and rubbly calcarenite. The limestones are closely jointed, coarse grained and very crinoidal. The upper 1.25m is cross-laminated to the southwest. There is no bedding, only stylolite partings at 1.10-1.60m intervals. The remainder of the Horton Limestone, except for the calcilutite, is obscured by a local thick veneer of till.

The Horton Limestone is better exposed below Raven Scar near Ten Pound Gill (SD729747), Fig 7.4;11). At this locality there are about 80 metres of Horton Limestone. Both the top and the base are exposed, but it is impossible to estimate the throw of the fault above Ten Pound Gill. No repetition of bedding was observed and there appear to be at least 24m of mid grey limestone at the base of the Formation. The succession comprises:-

5.70m,	Non-exposure to the base of dark grey weathering beds of Kingsdale Limestone.
0.60m,	Limestone, pale grey calcisiltite.
3.10m,	Limestone, pale grey calcilutite.
2.95m,	Limestone, closely jointed, pale grey, very fine grained calcarenite.
13.50m,	Till and sporadically exposed beds of pale grey calcarenite.
3.50m,	Limestone, closely jointed, pale grey calcarenite forming an extensive pavement.
3.45m,	No exposure.
3.90m,	Limestones, pale grey, crinoidal calcarenites with ferroan calcite cemented bioclasts.
2.70m,	Limestone, mid grey, fine grained calcarenite paling upwards.
0.80m,	Limestone, pale grey, fine grained, bioclastic calcarenites.
4.65m,	No exposure.
4.70m,	Limestone, pale grey, fine grained calcarenites with ferroan calcite cemented bioclasts.
4.90m,	Limestone, bioclastic, pale grey, medium grained calcarenite.
6.00m,	Limestone, mid grey, very fine grained calcarenite.
8.35m,	Limestone, mid grey, very fine grained calcarenite containing sparse large crinoids.

The remainder of the exposure, 9.90m of mid grey crinoidal, medium grained calcarenite at the base of the Formation, is separated by a small fault with an indeterminate throw. It disrupts the outcrop and there is no exposure for several of metres. The lowest limestones of the Formation are very poorly bedded and coarse grained where they overlie the Raven Ray Formation.

The succession exposed in Meal Bank Quarry (SD698735) is not typical of the Ingleton Dales. The locality is south of the North Craven Fault (Fig 7.4;12). The outcrop begins close to this fault and proceeds southwards towards the South Craven Fault. All the beds are dipping at approximately 20°/230°N and there is a maximum of 70.20m of Horton Limestone.

-	Kingsdale Limestone. There is an angular disconformity, between the Kingsdale Limestone and shale filling solution hollows in the top of the Horton Limestone, and the Horton Limestone itself, of approximately 2° (Plate 11a).
0.25-3.30m,	Solution hollow filled with shale (fireclay). It is full of pyritised rootlets (Plate 11c) and is overlain by 0.10m-0.24m of coal.
5.20-3.30m,	Limestone with solution hollows in the top bed, and thinning to the north. The pale grey, fine grained calcarenite contains pyrite and marcasite nodules at the top of the bed and is stained by their weathering products.
18.85m,	Limestone, mainly fine grained, pale grey calcarenites with layers of inverted brachiopods.
3.50m,	Limestone, pale grey, fine grained calcarenite coarsening upwards.
7.15m,	Limestone, richly bioclastic, pale grey, medium and coarse grained calcarenites containing crinoid, brachiopod and coral debris.
8.55m,	Limestone, mid grey calcarenites, paling upwards through interbedded mid and pale grey limestones into the overlying pale grey calcarenites.
26.95m,	Poorly exposed limestones from the river bank to the base of the quarry. Mid grey, medium grained, bioclastic calcarenites containing brachiopods and crinoids.

7.3 Crummack Dale

In Crummack Dale the Horton Limestone overlies the Raven Ray Formation only at the two extremities; in the mouth of the Dale above Nappa Scar in the west and White Stone Wood in the east; at the head of the Dale at Austwick Beck Head (SD776718) and further north, at a small spring (SD778722). Throughout the greater part of the Dale the Horton Limestone rests unconformably on Lower Palaeozoic rocks, of which the graywackes form steep ridges. Compaction-draping of the Horton Limestone is clearly discernible over the ridge crests. There are nearly continuous outcrops of calcilutite at the top of the Horton Limestone from SD772717 (north of Crummack Farm) to SD785716), where the thickness of the Horton Limestone varies from 32 to 48 metres. Southwards, the top is not preserved to the east of Crummack Dale or is not identified on the west side.

Above the Nappa Scar outcrops of the Thornton Force Formation and the Raven Ray Formation the Horton Limestone is intermittently exposed (SD767699). There is a lack of lithoclasts in the pale grey calcarenites and bedding is obscured by a veneer of till and the litter of Norber erratics. Progressing northwards across the smooth till slopes with erratics, occasional limestone terrace are seen, each showing a tendency to become increasingly lithoclastic in a northerly direction. Unfortunately much of the limestone is lost beneath a veneer of till and is not until nearly 1km to the north that better outcrops along the unconformity are seen.

At the western side of the Dale there is excellent exposure of the lower Horton Limestone and the unconformity between SD76687078 and SD77057140 (Fig 7.5). There appear to be a series of wedges of boulder-lithoclasts at the base of the limestone. South of this exposure the outcrop deteriorates rapidly and it is not possible to distinguish between poorly exposed graywacke boulder-lithoclasts and the Norber erratics, also graywacke boulders. At SD76687078 there are 13m of poorly exposed graywacke boulder-lithoclasts unconformably overlying the eroded, rounded tops of graywacke beds dipping at 34°/045°N. Above, the following section was measured.

5.65m,	Limestone, pale grey calcarenite with the lowermost 0.20m being very coarse grained and bioclastic.
1.00m,	No exposure.
13.00m,	Boulder rudite.
	unconformity.

The top of the limestone can be traced north to SD76687085 where 10.90m of graywacke boulders overlie dipping graywacke beds. Large, incompletely exposed boulders to 3.7x1.7x1.6m were observed with a possible maximum size of 5x4m. Above, there is no exposure for approximately 1m and then 3.85m of cross-laminated, pale grey, fine grained calcarenite. The cross-lamination is to the north, and off the rising graywacke mound. Compaction-draping over the crest of the graywacke ridge is responsible for considerable changes in the direction of dip of the Horton Limestone. Fortunately, the outcrop is extensive enough to permit correlation of the measured sections by walking out individual beds.

The top bed of limestone can be traced north from the previous locality to SD76687086 where approximately 5m of poorly exposed boulders unconformably overlie graywacke beds. The rudite is overlain by 1.70m of calcarenite with cross-lamination to the south-east, directed off, or around, the ridge. Bedding is complicated by tectonic partings.

The top bed can be traced into the next exposure at SD76687087 (Fig 7.5;13D). 2.60m of fine grained, pale grey calcarenite with cross-lamination to 150°N occur above the traceable parting. Below this are sparse poorly exposed lithoclast boulders; it was not possible to determine if they were in place. The top bed was traced north into the outcrop at SD76697091 where there are 1.70m of limestone between the top of this bed and the next traceable parting.

The upper parting can be correlated in the next exposure at SD76707093 where the following sequence was measured:

2.75m,	Limestone, variably lithoclastic, pale grey calcarenite in which the finer grained beds are cross-laminated.
2.75m,	Rudite, poorly exposed boulder-lithoclasts unconformably overlying dipping graywacke beds.

The top of the limestone can be traced to the top of the next exposure (SD76707095).

0.55m,	Limestone, pale grey, lithoclastic, wispy cross-laminated calcarenite wedging out northwards in a distance of 15m.
2.75m,	Rudite, poorly exposed boulder-lithoclasts unconformable on finely cleaved Lower Palaeozoic rocks which dip at 20°/170°N.

At SD76707097, the top of the poorly exposed boulder bed correlates with the top of the limestones described in the previous sections. There are at least 4m of boulders, excluding the 1m of till, above the ridged top of the Lower Palaeozoic rocks. The largest incompletely exposed boulders were 1.15x0.70x0.35m in size. Above the rudite there are 1.50m of fine-medium grained, pale grey calcarenite, in which ripples and cross-lamination were seen, up to the next traceable parting. Small siltstone and graywacke lithoclasts occur at some horizons.

The parting was traced north to SD76717098 where 2.15m of limestone were observed above. The limestones are coarse grained and variably lithoclastic calcarenites with the uppermost 0.20m forming a distinctive traceable rubbly layer.

The next exposure is very close to the crest of the anticline in the Lower Palaeozoic rocks (SD76737107). The unconformity is exposed and graywackes dip at 14°/153°N. They are cleaved at 88°/228°N. The poorly exposed boulder rudite is a maximum of 2.15m thick and it is overlain by 1.35m of limestone.

The rubbly layer could be traced northwards to SD76737112 (Fig 7.5;13L). The following succession is exposed.

0.85m,	Limestone, pale grey, coarse grained, lithoclastic calcarenite.
0.90m,	Limestone, pale to mid grey, medium grained calcarenite including the rubbly layer at the top.
0.40m,	No exposure.
4.50m,	Rudite, very poorly exposed graywacke boulders unconformably overlying Lower Palaeozoic rocks.

Beyond, at SD76747114 (Fig 7.5;13M) the succession is thinner below the traceable parting and the boulder rudite is now only 4m thick, with boulders averaging 2.2x0.3m. It unconformably overlies graywacke and is overlain by 0.35m of calcarenite. Above the parting the rubbly, coarse grained calcarenite contains many small Lithostrotion colonies and poorly preserved solitary corals.

The boulder rudite continues to thin over a ridge in the unconformity and at SD76757115 is only 2.90m thick. It is overlain by 1.85m of calcarenite to the traceable rubbly parting. The unconformity is irregular because of weathering and erosion of the dipping beds prior to deposition of the Carboniferous limestones, and a second ridge is exposed at SD76767115 (Fig 7.6;14A). The boulder bed here is 4.7m thick and is overlain by 1.2m of calcarenite containing numerous 6cm long vertical burrows originating at the overlying rubbly layer.

The outcrop is considerably improved at the next locality (SD76767118, Fig 7.6;15B), although, unfortunately, the unconformity is not revealed. The sequence observed is described below.

1.05m,	Limestone, pale grey calcarenites to the level of the traceable parting.
4.25m,	Rudite, boulder and cobble rudite with the top layer being winnowed graywacke boulders. The matrix between boulders was created by the smashing of larger clasts.

2.20m, Rudite, composed of graywacke boulders up to 1.65x1.60x0.65m in size.

At the next outcrop (SD76777120) the unconformity is exposed. The Horton Formation dips at 27°/072°N and is cleaved at 61°/210°N. The sequence is as follows:

1.85m, Limestone, medium grained calcarenite to the traceable parting.

1.05m, No exposure.

4.65m, Rudite, poorly exposed graywacke boulders up to >1.75x0.90x0.75m in size with patches of calcarenite matrix.

1.20m, No exposure above the rounded edges of dipping Horton Formation beds.

The next measurable section is located at SD76777122 and comprises 7.20m of limestone and rudite to the traceable parting.

1.80m, Limestone, poorly exposed calcarenite to base of the rubbly limestone bed.

1.25m, No exposure, but loose blocks of pebbly limestone with fine grained siltstone clasts 300x160mm were observed in this interval.

0.50m, Limestone, parallel laminated, fine grained calcarenite.

3.65m, Rudite, graywacke boulders in a lithoclastic calcarenite matrix. Largest boulders, 2.6x1.2m in size, immediately overlie the unconformity.

Although the unconformity is not exposed at SD76787124 (Fig 7.6;14E) the boulder rudite is thinner. It occurs as two lenses, 0.85 thick and 0.25m thick respectively, separated by 0.45m of lithoclastic, fine grained calcarenite with pockets of pebble-lithoclasts. The largest exposed boulders in the rudite are at least 0.70x0.50m. Above there are 3.90m of mainly fine and medium grained calcarenites, locally with lenses of pebble-lithoclasts and cross-lamination, to the rubbly bed. Small sops of <u>Lithostrotion basaltiforme</u> in growth position are common in the rubble bed.

Northwards the quality of the exposure deteriorates and the next measured section is located at SD76797126 (Fig 7.6;14F).

1.10m,	Limestone, coarse grained calcarenite with lithoclasts to 5mm in length.
1.00m,	Limestone, mid grey, fine-medium grained, laminated calcarenite.
0.15m,	Sandstone, brown-weathering, fine grained quartz arenite.
0.80m,	No exposure.
0.40m,	Limestone, mid grey, fine grained calcarenite containing lithoclasts to 10mm in length.

The unconformity is not exposed and there is no evidence of a boulder rudite at this locality nor at SD76807128 where a thicker carbonate sequence is exposed. This exposure is separated from the previous section by a small fault (Fig 7.6;14G). The rubbly limestone crops out on both sides of the fault allowing adequate correlation. The throw is approximately 0.50m to the south. The section observed is described below.

1.45m,	Limestone, laminated, coarse to fine grained, sparsely lithoclastic calcarenite.
0.30m,	Limestone, very bioclastic rubbly calcarenite with Lithostrotion basaltiforme in growth position.
3.25m,	Limestone, coarse to fine grained calcarenite.
0.40m,	Limestone, intermittently cross-laminated, fine grained calcarenite.
0.95m,	Limestone, coarse grained, pale grey calcarenite. The top of this bed is traced northwards into the next section.

There is poor exposure for the next 70m to the north. At SD76857129 boulders of graywacke protrude through the till veneer, and at SD76887130 boulders can be observed lying immediately below the traceable parting. The coarse grained calcarenite varies in thickness (0.20m-0.60m) as it fills the relief on the irregular top of the boulder rudite. At SD76897131, an in situ colony of branching Lithostrotion can be seen to have used a boulder at least 4.4m in length as a substrate. At SD76907132 the boulder rudite is exposed and is at least 5.75m thick. It is overlain by approximately 0.50m of coarse grained calcarenite to the traceable bedding plane.

At SD76947134, a thick succession could be measured. It comprises:-

0.75m,	Limestone, coarse grained calcarenite to the level of the traceable parting.
6.45m,	Rudite, poorly exposed boulder lithoclasts. No matrix was observed.
0.70m,	Limestone, pebbles and cobbles of siltstone occur in fine grained lithoclastic calcarenite.
0.25m,	Sandstone, pebbly quartz arenite.
0.10m,	Limestone, pebbly fine grained calcarenite.
0.25m,	Rudite, pebbles and rare cobbles to 110x90x40mm comprise a rudite with a calcarenite matrix which grades rapidly up into quartz arenite.
0.20m,	Limestone, pebbles of fine grained sandstone to 90x30mm in size occur in fine grained calcarenite.
2.15m,	Limestone, mid grey, fine grained calcarenite which is lithoclast-free. Sops of phacelloid Lithostrotion occur in the top lm.

At SD76957185, poorly exposed boulder rudite crops out immediately below fine grained calcarenite. The whole of the coarse grained calcarenite has wedged out in a distance of only 10m. The fine grained calcarenite above, 0.50m thick, is cross-laminated and lithoclastic throughout. It is overlain by a bed, 0.80m thick, of mid grey, fine grained calcarenite with sparse lithoclasts. The beds at this and the previous locality are draped over the unconformity and dip at about 15° into the rock face.

Northwards, at SD76987137 (Fig 7.6;14L) there is poor outcrop of 4.30m of graywacke boulders. After an interval of 1.50m of non-exposure there are 1.65m of coarse grained calcarenite containing Caninia debris to the traceable parting. Above, there are 0.40m of fine grained calcarenite.

The sequence of fine grained calcarenite overlying coarse grained calcarenite is not revealed at SD77017136. There are 1.30m of boulders in a crinoidal, lithoclastic calcarenite overlain by 3.10m of calcarenite, the lowest 1.20m of which are mid grey, foetid and contain silty partings. A much thicker succession is exposed at SD77027138 (Fig 7.6;14N). There are no boulder lithoclasts.

5.50m,	Limestone, coarse grained calcarenite to pronounced terrace at top of the scar.
2.50m,	Limestone, pale grey, fine grained calcarenite.
0.40m,	Limestone, medium grained calcarenite with irregular bounding surfaces. The bed probably correlates with the rubbly bed of previous sections.
5.00m,	Limestone, mostly cross-laminated, locally parallel laminated, pale grey, coarse grained calcarenite. The lowest 1m is rich in brachiopods.
0.20m,	Limestone, parallel laminated, fine grained calcarenite.
0.65m,	Limestone, pale grey, coarse grained calcarenite. The top of this bed has been used as the traceable parting in correlation of previous sections.
1.65m,	Limestone, cross-laminated, fine grained calcarenite with pyritic, quartz silt laminae.
0.50m,	Limestone, pale grey, coarse grained calcarenite with small sops of coral and lithoclasts 45x25x5mm. The top of this bed correlates with the top of the boulder rudite at SD77017138.
0.50m,	Limestone, dark grey, fine grained calcarenite.
0.25m,	Sandstone, calcareous quartz arenite with flat graywacke clasts 250x50mm in size.
3.05m,	Limestone, poorly exposed mid grey calcarenites.

The final exposure of this series on the western side of Crummack Dale is located near Crummack Farm (SD77057140, Fig 7.6;14P). There is a considerable thickness of virtually lithoclast-free limestone exposed and no rudite was observed. The thick sequence is listed below.

4.60m,	Limestone, bioclastic, coarse grained calcarenite to the top of the scar.
0.45m,	Limestone, fine grained calcarenite.
4.70m,	Limestone, coarse grained calcarenite with sparse weathered pebble and granule lithoclasts.
1.35m,	Limestone, cross-laminated, pale grey, coarse grained calcarenite containing brachiopods.
2.00m,	Limestone, pale grey calcarenite, coarse at the base but fining rapidly upwards. The top of this bed, a stylolite, correlates with the top of the calcarenite with silty partings described at SD77027138.
0.95m,	Limestone, two beds of fine grained calcarenite.
0.80m,	Limestone, coarse grained calcarenite with lenses of fine grained lithoclasts and intraclasts.
4.70m,	Limestone, mid grey, fine grained calcarenite with sparse 2mm-size graywacke lithoclasts. There is relief of 0.15m on the top surface.
1.00m,	Limestone, slightly foetid, mid grey, fine grained calcarenite with sparse graywacke lithoclasts.

The quality of the exposure deteriorates rapidly north of this outcrop and one or more faults could occur north of Crummack Farm. Except for intermittent outcrop of the calcilutite most of the Horton Limestone is obscured by till. Only in the most northwesterly region of the valley (SD778722) are approximately 15m of mid grey limestones comprising the lower part of the Horton Limestone exposed.

Two sections were measured through the Horton Limestone in northeast Crummack Dale near Moughton Whetstone Hole (Figs 7.7;15A and 15B). The most westerly was measured above Capple Bank (SD783719, Plate 10a) where there are only 32.25m of Horton Limestone to the top of the calcilutite.

0.45m,	Limestone, poorly exposed calcilutite.

4.50m,	Limestone, poorly exposed, pale grey, fine grained calcarenite.
15.70m,	Limestone, closely jointed, pale grey, coarse grained calcarenite typical of the upper part of the Horton Limestone.
9.95m,	Limestone, moderately bedded, mid grey, fine grained calcarenite.
1.05m,	Limestone, shaly and rubbly, mid grey calcarenite with partings at intervals. Spirifera is common.
0.60m,	Limestone, mid grey calcarenite.

The base of the limestones is level with the ribs of graywacke on the top of Capple Bank.

The second section through the Horton Limestone was measured south of Moughton Whetstone Hole at SD784717. The unconformity is not exposed although a small spring and much weathered graywacke debris occur at this location. The maximum thickness of Horton Limestone below the level of the calcilutite is only 48.30m At neither this locality nor SD783719 were beds above the calcilutite exposed. The measured sequence is listed below.

1.50m,	Limestone, calcilutite.
30.00m,	Limestone, pale grey calcarenites.
3.50m,	Limestone, bioclastic, pale grey, medium-coarse grained calcarenites with sparse granule lithoclasts throughout.
7.05m,	Limestone, mid grey calcarenites poorly parted at 1-1.5m intervals. The limestones at the base are very fine grained and cross-laminated from the northeast and southwest.
6.45m,	No exposure above spring. Large slabs of pebble rudite and pebbly limestone, 0.40m thick, project through the till veneer and there is no evidence of this rock-type in the scar-face.

The bedding of the limestones dips gently at 16°/360°N, off the graywacke ridge of Hunterstye, towards Moughton Whetstone Hole. The present dip probably is a combination of original depositional dip and compaction draping.

Another series of exposures was measured on the east side of Crummack Dale between the lower slopes of Hunterstye (SD78257110) and the end of Studrigg Scar (SD78107074). Above Hunterstye, between the calcilutite and the top of the Lower Palaeozoic rocks, there can be only approximately 25 metres of Horton Limestone.

As the limestone beds are traced southwards the number and thickness of the beds increases as the level of the unconformity falls. At SD78257110 (Fig 7.7;16A) the following section was measured.

4.00m,	Limestone, dark grey weathering, mid grey calcarenite.
2.50m,	Limestone, mid grey, medium grained calcarenite to pronounced stylolitic parting.
1.50m,	Limestone, mid grey, fine grained calcarenite which pales upwards as it becomes coarser grained. Sparse 2mm-size graywacke lithoclasts are present.
1.05m,	No exposure between the base of the limestone and Lower Palaeozoic rocks below.

At SD78287108 there is a greater thickness of limestone, with 2.60m of mid grey lithoclastic calcarenite occurring below the dark grey weathering limestone at the base of the previous section. There is no in situ graywacke below. A parting which occurs 0.85m below the top of the mid grey lithoclastic calcarenite can be traced southwards to SD78217105 where a further 2.50m of limestone occur below. In this way the limestones increase in thickness to the south as the level of the unconformity falls. This relationship between overlapping limestone beds and the Lower Palaeozoic rocks is demonstrated in Figure 7.7.

At SD78167098 there is a relatively thick accessible section, although unfortunately, the Lower Palaeozoic rocks are not exposed.

1.00m,	Limestone, lithoclastic, mid grey calcarenite to the prominent parting noted in sections to the north.

0.35m,	Limestone, pale brown, dolomitic, nodular calcarenite.
1.40m,	Limestone, mid grey calcarenite.
0.85m,	Limestone, mid grey calcarenite.
2.35m,	Limestone, poorly exposed, mid grey calcarenite to prominent parting which can be traced into the outcrops to the south.

The succession at SD78147096 (Fig 7.7,16G) is very similar to that described above, except that there are now 7.25m of limestone below the prominent parting described. 1.55m above the base of these limestones there is another prominent bedding parting which can be traced into Studrigg Quarry (SD78137091). The section measured at this locality is described below.

2.35m,	Limestone, mid grey calcarenite. Above this limestone the scar is inaccessible.
0.65m,	Limestone, mid grey calcarenite with irregular base. The limestone fills the relief in the underlying bed.
0.85m,	Rudite, cobble-boulder rudite with a matrix of millimetre-size lithoclasts in calcarenite.
1.35m,	Limestone, poorly exposed, mid grey calcarenite.
0.70m,	Limestone, lithoclast-free, mid grey calcarenite.
1.40m,	Limestone, mid grey, medium grained calcarenite unconformably overlying Horton Formation siltstones. The limestones are sparsely lithoclastic, containing intraclasts and coated grains. Lithoclasts between 60x30mm and 240x120mm occur in the middle and scattered on top of the bed.

At the southern end of the quarry exposure (SD78137088) the unconformity has stepped down by approximately 1.0m. It appears to be horizontal and coated with an irregular layer of boulders, the largest of which is 1.00x0.55m. There is no boulder rudite; it appears to have been only a very local feature in the quarry. However, only 20m to the south a boulder rudite crops out once again. The rudite is at least 1.50m thick and it is composed of semi-rounded graywacke clasts commonly up to 330x230x150mm in size (Plate 9c). The top of the rudite is relatively level because smaller lithoclasts and a calcarenite matrix infill the hollows between the layer clasts.

Ten metres further south (SD78127086, Fig 7.7;16K) there are 0.40m of calcarenite overlying the boulder rudite and twenty metres beyond (SD78127084) the sequence is thicker, 1.00m of calcarenite overlies 2.10m of boulder-cobble rudite. The largest boulders of graywacke and lithoclastic limestone are 1500x450mm in size. The boulder bed achieves a maximum thickness of 3.40m and extends for 45-50m along Studrigg Scar.

Below the rudite at SD78127084 there are 0.70-0.80m of mid grey, medium grained calcarenite which, in places, rests unconformably on the Horton Formation. It is a graded bed always less than 0.90m thick in which 50mm-size lithoclasts are frequent at the base but entirely absent at the top. Locally, minor relief on the unconformity is infilled with a layer of pebbles, cobbles and boulders up to 0.50m thick.

Ten metres beyond there is another small quarry (SD78127083). The section measured is described below.

4.35m,	Limestone, mid grey, fine grained calcarenite rich in gastropods.
1.95m,	Limestone, mid grey, medium grained calcarenite containing sparse weathered cobble lithoclasts in the lowermost 0.60m. Bellerophontids are common in the middle of the bed. The upper bedding surface correlates with the top of the boulder bed at SD78127084.
0.30m,	Limestone, mid grey calcarenite free of lithoclasts. A monolayer of sparse boulders fills the slight relief in the near-horizontal surface of the unconformity.

Southwards the outcrop deteriorates rapidly and the unconformity is obscured by till. However, the thickness of limestone below the base of the boulder rudite increases so that the level of the unconformity must continue to fall.

South of SD78107074, where there are 3.30m of limestone below the level of the rudite (Fig 7.7;16P), the quality of the exposure deteriorates and it became impossible to measure and correlate sections. The poor bedding partings are impersistent and much of Studrigg Scar is inaccessible.

In the vicinity of White Stone Wood (SD781705) it is possible to distinguish equivalents of the Thornton Force Formation (Chapter 4 p.74) and the Raven Ray Formation (Chapter 6 p.106). Overlying the latter there are 4.70m of slightly foetid, thinly bedded, mid-dark grey, fine grained calcarenite. The beds weather very rubbly, a feature observed of the lower beds of the Horton Limestone above Capple Bank (SD783719). Sparse granule-lithoclasts occur throughout. The top of the limestone weathers back to form an extensive platform and there is no exposure above for a considerable thickness.

Beyond this locality, much of the outcrop in White Stone Wood (SD781704-783701) is inaccessible because of the vertical nature of the scar. Also partings or stylolites are not laterally persistent making correlation extremely difficult. The lower mid grey limestones are intermittently, and often poorly, exposed around the end of Moughton above the Austwick Road as far as Moughton Nab.

7.4 Wharfedale (south) and Littondale

In this area the calcilutite is not exposed although at some localities, almost the entire thickness of the Horton Limestone crops out. Probably it does not occur. Either it was not deposited or it was locally removed before the deposition of the Kingsdale Limestone. As a result of the non-exposure or non-occurrence of this important horizon, it is difficult to distinguish the Horton Limestone from the overlying Kingsdale Limestone in poorly exposed ground.

The most southerly exposure of the Horton Limestone in this subarea is located close to the North Craven Fault at Robin Hood's Quarry (SD978654). 12.15m of mid grey, very coarse grained, bioclastic calcarenite are revealed. Coated grains were observed between 3.65m and 4.95m in association with numerous brachiopods and gastropods. In situ

Lithostrotion and Syringopora, as well as Caninia and Dibunophyllum occur in a single bed between 5.65m and 6.45m. The top of this bed is mounded. The bed between 8.60m and 9.40m from the foot of the exposure is intensely bioturbated and overlain by a thin black shale from which burrows extend down into the limestone. In the overlying bed (9.40m-10.35m) the bioclasts present are frequently chertified. It is unfortunate that this outcrop is so isolated. Pale grey calcarenites are observed high above at Haw Hill (SD976657) but the vertical separation is great.

Much of the middle and upper parts of the Horton Limestone are exposed in Conistone Gorge (SD985676). There are 56.55m of the Formation at this locality, and the Horton Limestone-Kingsdale Limestone probably occurs at some position within the 11.0 metre till-filled gap in the exposure.

12.20m,	Limestone, strongly bedded, pale grey, laminated, coarse grained calcarenite containing lenses of brachiopod and bivalve debris, probably forming part of the lower Kingsdale Limestone.
11.00m,	No exposure.
36.25m,	Limestone, thickly and poorly bedded, pale grey, coarse grained calcarenites. Closely jointed. Ferroan calcite veins common in top 8m.
5.75m,	Limestone, pale grey, medium grained calcarenite.
7.65m,	Limestone, pale grey, coarse grained calcarenite.
6.35m,	Limestone, closely jointed, bioclastic, mid grey, coarse-medium grained calcarenite containing solitary corals, crinoids and fragments of Koninckopora.
0.55m,	Limestone, single bed of dark grey, medium grained, slightly foetid calcarenite. The top of the bed is very coarse grained and bioclastic.

It is possible that the lowest bed exposed may be part of the Raven Ray Formation, although, it is more likely to be just a darker bed in the mid grey calcarenites of the lower Horton Limestone. If so, then the Horton Limestone-Raven Ray Formation contact is well below the base of the outcrop because only 6.90m of mid grey and dark grey limestone are exposed (Fig 7.8;18).

The Raven Ray Formation-Horton Limestone boundary is exposed in Howgill (SD968672) and at the base of Kilnsey Crag (SD973680). At both localities the boundary can be seen to be an erosion surface. At Howgill there is relief of only about 0.20m on the top of the Raven Ray Formation. There are 6.60m of mid grey, occasionally slightly foetid Horton Limestone above. Layers of shells and sparse small coral colonies (only 0.10-0.15m in diameter) occur in the lowest bed which is 0.30-0.50m thick. There is relief of 0.05m on the top of this bed. The remainder of the limestone exposed at this locality is thinly parted, coarse grained and crinoidal.

At Kilnsey Crag (SD973680) the major part of the Horton Limestone crops out and the contact with the Raven Ray Formation is seen. There are two small faults, both downthrowing to the south, which occur at the contact between the two Formations. The total throw is 0.65m. Both faults die out quickly in the overlying limestones. In total there are 96.30m of limestones above the prominent Raven Ray Formation-Horton Limestone contact exposed at the base of Kilnsey Crag. Unfortunately the calcilutite was not seen and the Horton Limestone-Kingsdale Limestone boundary is not identifiable.

27.50m,	Limestones, jointed, saccharoidal, pale grey calcarenites above Cool Scar.
31.85m,	Limestones, pale grey coarse grained calcarenite to top of Kilnsey Crag.
18.30m,	Limestones, mid grey, medium-fine grained calcarenites with Syringopora and overturned Lithostrotion in the uppermost 4m.
2.75m,	Limestone, pale grey-buff, coarse grained calcarenite.
11.90m,	Limestones, mid grey, medium-coarse grained calcarenite with Caninia at the base and coated grains and solitary corals in uppermost 1.35m.

3.30m,	Limestones, dark grey, medium grained calcarenite with large crinoid ossicles. The upper bedding surface has relief of 0.15m.
0.65-0.85m,	Limestone, dark grey,medium grained calcarenite with relief of 0.20m on its upper surface. The bed conformably overlies the Raven Ray Formation, and there are 0.20m of relief at the contact.

The Horton Limestone is being quarried behind Kilnsey Crag in Cool Scar Quarry (SD968677). the 105m depth of the quarry is almost entirely in poorly bedded, pale grey, intraclastic limestones. Mid grey limestones crop out at the base of the quarry but are of little economic importance. Darker limestones were temporarily exposed in a deeper quarry level which has since been filled in.

The next exposure of the lower part of the Horton Limestone is at Moss Beck (or Lower Sleets Gill, SD965690). The Raven Ray Formation is not seen and there are 14.45m of mostly mid grey limestones cropping out in the stream banks. It is unfortunate that there is no more outcrop, however, this section does show the interbedding of pale and mid grey calcarenites which is typical of the transitions from lower mid grey to upper pale grey calcarenites of the Horton Limestone. The outcrop is described below.

0.75m,	Limestone, mid grey, medium grained calcarenite.
1.75m,	No exposure.
0.65m,	Limestone, pale grey, coarse grained calcarenite.
0.60m,	Limestone, poorly exposed, mid grey calcarenite.
1.60m,	Limestone, mid grey, fine-medium grained calcarenite.
1.30m,	Limestone, pale grey, medium-coarse grained, crinoidal calcarenite containing recrystallised shells.
0.70m,	Limestone, mid grey, medium grained, crinoidal calcarenite.
0.35m,	Limestone, dark grey, fine grained calcarenite.

6.75m, Limestone, slightly foetid, mid grey calcarenites. The base of the limestone is fine grained but the top is coarse. The medium-thick beds are jointed and crinoidal.

There is more exposure of the Horton Limestone in Sleets Gill (SD961694). The section is complicated by the presence of a number of faults with indeterminate throws. It is not known whether there is any repetition of strata as a result of faulting. It is unlikely that the total thickness exposed and described (c.100m) is all Horton Limestone, however, it is not possible to distinguish between the Horton Limestone and Kingsdale Limestone in such poorly exposed ground where the calcilutite does not occur. The section measured is described below.

30.00m, Limestone, pale grey, saccharoidal calcarenite to the base of a till ridge.

16.50m, Limestone, pale grey, saccharoidal calcarenite to the level of Sleets Gill Cave (SD959693).

Fault orientated at 140°N.—Probable downthrow to south

11.50m, Limestone, pale grey saccharoidal calcarenite.

2.95m, Limestone, shattered, locally dolomitic, pale grey calcarenite.

10.00m, Limestone, pale grey-buff, saccharoidal calcarenite with crinoids.

13.45m, Limestone, mid grey, medium-fine grained crinoidal calcarenite paling upwards.

9.10m, Limestone, mid grey, coarse-very coarse grained, crinoidal calcarenite.

Fault—

1.50m, Dolomitic limestones.

Fault—

5.75m, Limestone, mid grey, fine-medium grained sparsely crinoidal calcarenite containing rare inverted sops of Syringopora.

Fault—

0.75m,	Limestone, mid grey, fine grained calcarenite conformably overlying the Raven Ray Formation immediately above Sleets Gill Bridge.

The middle and upper parts of the Horton Limestone are well exposed at Arncliffe Clowder (SD938706). The probable thickness of the Formation is 74.35m, although, the contact with the underlying Raven Ray Formation is not seen and there is a gap in the outcrop of at least 10.00m above the highest beds of the Raven Ray Formation at the base of the crag.

-	Well bedded, pale grey, cross-laminated, bioclastic calcarenites, probably of the Kingsdale Limestone.
3.95m,	Limestone, pale grey, crinoidal, medium grained calcarenite. The top weathers back forming a prominent platform, probably the Horton Limestone-Kingsdale Limestone boundary.
1.90m,	No exposure.
10.40m,	Limestone, pale grey, fine grained calcarenite.
2.05m,	Limestone, mid grey, fine grained calcarenite.
2.10m,	Limestone, pale grey, medium-fine grained calcarenite weathering back in crag face.
12.40m,	Limestone, pale grey, medium grained, saccharoidal calcarenites with the lowermost 1.0m weathering back strongly.
16.95m,	Limestone, pale grey, very coarse grained, crinoidal calcarenite.
13.80m,	Limestone, very poorly bedded, mid grey coarse grained calcarenite to a very prominent bedding parting.
6.80m,	Limestone, single bed of dark grey, medium-coarse grained calcarenite with relief of 0.05-0.10m on the top of the bed.
3.90m,	Limestone, slightly foetid, mid grey, coarse grained, crinoidal calcarenite.
c.10.00m,	No exposure between the highest beds of the Raven Ray Formation and the base of the scar.

The remaining exposure in this subarea is in the vicinity of Arncliffe at Yew Cogar Scar (SD918706). The Raven Ray Formation-Horton Limestone contact is exposed at the base of the scar dipping at 8° to the northeast; there is relief of about 0.10m on the surface. Only the lower part of the Formation was measured because of the rapid deterioration in the quality of the exposure above 28.35m.

11.00m,	Limestone, mid grey, medium grained calcarenite with sparse coarse crinoid ossicles. The outcrop deteriorates above.
14.55m,	Limestone, mid grey, medium-coarse grained calcarenite containing Caninia, Lithostrotion, crinoids and coated grains. The top is a prominent bedding plane along which a small cave (Falcon Cave) has developed.
2.30m,	Limestone, dark grey, slightly foetid, mid grey calcarenite truncated by a pronounced bedding plane.
0.50m,	Limestone, dark grey, medium grained calcarenite. There is relief of 0.10-0.15m on its upper bedding surface (Plate 8a), and it conformably overlies the Raven Ray Formation.

There is the same weathering contrast between the overlying beds of the Horton Limestone and the lowest bed of Horton Limestone at Yew Cogar Scar as at Kilnsey Crag (Plate 8b).

7.5 Wharfedale (north)

This subarea includes a single exposure in Littondale and three exposures in the vicinity of Kettlewell. The calcilutite crops out at all of these localities.

The middle and upper parts of the Horton Limestone are excellently exposed north of Arncliffe at Old Cote Low Moor (SD925726). The Raven Ray Formation does not crop out, and the total thickness of the Horton Limestone exposed at this locality is approximately 56 metres.

-	Limestone, well bedded, dark grey weathering calcarenites of the Kingsdale Limestone.

5.15m,	No exposure.
1.50m,	Limestone, pale grey, fine grained calcarenite draped over the mounded surface of the calcilutite and thin calcarenites below.
0.05m,	Limestone, a wedge of pale grey, coarse grained calcarenite.
0.10-0.15m,	Limestone, pale grey, very fine grained calcarenite.
3.05m,	Limestone, interbedded, pale grey fine grained calcarenite, calcisiltite and calcilutite.
0.35-0.50m,	Limestone, pale grey calcisiltite with relief of 0.10-0.15m on the upper bedding surface.
8.90m,	Limestone, intermittently exposed pale grey, fine grained calcarenite.
0.10m,	Limestone, pale grey calcisiltite.
1.00m,	Limestone, buff-pale grey calcilutite.
0.25m,	Limestone, pale grey calcisiltite.
9.70m,	Limestone, poorly bedded, very strongly jointed, pale grey, medium-fine grained calcarenite.
6.05m,	Limestone, sporadically exposed, mid grey, fine grained calcarenite.
5.30m,	Limestone, mid grey, fine grained calcarenite.
6.70m,	Limestone, mid grey, medium grained calcarenite.
6.25m,	Limestone, slightly foetid, mid grey, medium grained calcarenite.
1.35m,	Limestone, slightly foetid, dark grey, medium grained calcarenite at the base of the exposure.

There is sporadic good exposure of the Horton Limestone between Low Holme Barn and Knipe Wood (SD973707) in Wharfedale. Much of the lower part of the Formation crops out, although, the Raven Ray Formation-Horton Limestone contact is not seen. It is probable that the whole of the thickness described below is the Horton Limestone. If this is true then there are at least 87 metres of Horton Limestone in this part of Wharfedale. Calcilutite fragments were observed in the scree in the vicinity of Knipe Wood, but, unfortunately, none was observed in outcrop making the distinction between the Horton Limestone and Kingsdale Limestone more difficult.

18.60m,	Limestone, very poorly exposed pale grey, coarse grained calcarenite which darkens as it fines upwards.
4.65m,	No exposure.
23.65m,	Limestone, pale grey, mostly coarse grained, saccharoidal calcarenite.

Below there is no exposure for 25.85m because of a thick till veneer and the B6160 Kettlewell-Skipton road. Below the remaining 14.55m of limestone are exposed in Low Holme Barn pasture.

2.50m,	Limestone, mid grey, very coarse grained calcarenite which pales upwards.
6.05m,	Limestone, dark grey, coarse and very coarse grained calcarenites containing solitary corals in the lower part.
2.60m,	Limestone, five beds of mid grey, coarse grained calcarenite which pale upwards.
3.40m,	Limestone, five beds of dark grey, bioclastic, coarse grained calcarenite.

There is good exposure of the Horton Limestone at the western side of Wharfedale above Kettlewell at the base of Gate Cote Scar (SD966720). The section commences at the river's edge beneath Kettlewell Bridge and there are at least 75 metres of Horton Limestone intermittently exposed.

-	Limestones, dark grey weathering, thickly bedded calcarenites of the Kingsdale Limestone.
7.35m,	No exposure. The Horton Limestone-Kingsdale Limestone contact occurs in this interval.
1.25m,	Limestone, pale grey, very fine grained calcarenite and calcisiltite in two beds.
0.90m,	No exposure.
1.25m,	Limestone, two beds of pale grey calcisiltite.
2.35m,	Limestone, three beds of pale grey calcilutite.

17.75m,	No exposure.
11.95m,	Limestone, closely jointed, white-weathering, medium grained calcarenites with layers of mostly inverted brachiopods, forming a small quarry face.
8.35m,	No exposure.
13.15m,	Limestone, irregularly jointed, thickly bedded, pale grey-buff, medium grained calcarenites.
9.00m,	No exposure on either side of the B6160 road.
7.60m,	Limestone, mid grey, medium grained calcarenite with layers of gastropods and bioclasts.
1.30m,	Limestone, dark grey, medium grained calcarenite rich in crinoids.

At the north end of Gate Cote Scar (SD964724) the upper part of the Horton Limestone is better exposed. The section measures approximately 49 metres and no dark or mid grey calcarenites are seen. The contact with the overlying Kingsdale Limestone is poorly exposed but appears to be irregular and similar to that seen in Chapel-le-Dale (section 7.2, Fig 7.4, SD705755). Massive beds of dark grey weathering limestone occur above. The section through the Horton Limestone comprises:

7.80m,	Limestone, pale grey, coarse-medium grained calcarenite to the contact with the Kingsdale Limestone.
1.35m,	No exposure.
2.00m,	Limestone, white weathering, pale grey, very fine grained calcarenite-calcisiltite interbedded with calcilutite.
0.25m,	No exposure.
1.65m,	Limestone, white weathering, pale grey calcilutite.
1.50m,	Limestone, very jointed, pale grey, medium grained calcarenite.
2.95m,	No exposure.
31.50m,	Limestone, intermittently exposed, pale grey, saccharoidal calcarenites are poorly bedded and closely jointed.

7.6 The Malham Area

There are very few outcrops of the Horton Limestone in the Malham area. Most of the exposed limestone pavements are developed in the Kingsdale Limestone or limestones of the lower part of the Yoredale Group. There are exposures of poorly bedded white limestones between Silverdale and Malham and between Malham and Arncliffe. In these areas, however, the quality of the outcrop is poor, the calcilutite does not occur, and it is impossible to distinguish between the Horton Limestone and the Kingsdale Limestone. The calcilutite was described by O'Connor (1964) as being present in a quarry near Sannet Hall. No calcilutite is exposed in the quarry at the present time, nor in the surrounding outcrops and quarry debris.

Most of the face of Malham Cove (SD898641) is composed of the Horton Limestone. This limestone is the Malham Limestone of Mundy & Arthurton (1980). They indicated that the Horton Limestone and the Kingsdale Limestone could not be distinguished in this area because of the non-occurrence of the calcilutite and so introduced their new terminology. However, there is no need for the Malham Limestone since the lithostratigraphic boundary between the Horton Limestone and the Kingsdale Limestone is clearly the level at which prominent bedding becomes apparent and the cross-laminated, intraclastic, coated-grain calcarenites give way to more diversified carbonates above. This abrupt change of physical characteristics occurs 81.25m up the cove face. The famous limestone pavements are developed in the thick and well bedded, dark grey weathering Kingsdale Limestone. The Horton Limestone-Kingsdale Limestone contact occurs at the level of the lower lip of the cove (Plate 11d). The bedding plane weathers back and caves are developed along it.

5.30m,	Limestone, buff-pale grey fine grained calcarenite.
2.00m,	Limestone, pale grey fine grained calcarenite forming an overhang.
28.90m,	Limestone, pale grey medium-fine grained, saccharoidal calcarenite, to pronounced parting.

17.70m,	Limestone, pale grey-buff, coarse grained calcarenite to prominent parting which forms a ledge around the lower part of the cove.
14.60m,	Limestone, pale grey-buff, coarse grained calcarenite to strong parting.
12.75m,	Limestone, mid grey, coarse-medium grained, closely jointed calcarenite with stylolites occurring at 3m intervals. The top forms a prominent parting in the cove face.
>2.00m,	Limestone, dark grey, medium grained, medium bedded calcarenites in the stream bed at the base of the Cove.

The section through the Horton Limestone at Gordale Scar (SD914637) is inaccessible. Only the upper part of the Horton Limestone is exposed and the Horton Limestone-Kingsdale Limestone boundary occurs at the first major bedding plane approximately half way up the first buttress. The calcilutite is not present here. The limestones below this bedding plane are white weathering, very closely jointed, medium grained calcarenites typical of the Horton Limestone. There are no bedding planes, only poorly developed near-horizontal, laterally impersistent stylolites at irregular intervals. Above the bedding plane the limestone weathers darker grey and is clearly well bedded.

The remaining section in this subarea is at Great Close Scar (SD902666). Although it is the only outcrop in this subarea lying north of the North Craven Fault it still lacks the calcilutite. A few beds of pale grey limestone crop out near the top of Great Close Scar some distance above Malham Tarn and approximately 12.40m above the highest spring. Only pale grey-buff, medium-coarse grained calcarenites are exposed, subdivided by laterally impersistent stylolites at 2-3m intervals. There are three traceable bedding planes in the succession: 3.60m, 11.40m and 16.25m above the base of the outcrop. Above the upper bedding parting the limestone recedes sharply and there is an abrupt change in outcrop pattern. The 6.55m of limestone above are thickly and very well bedded, a feature characteristic of the Kingsdale Limestone. This prominent parting can be traced around Great Close Scar; it is taken as the Horton Limestone-Kingsdale Limestone boundary.

7.7 Moughton Calcilutite Member (Porcellanous Band)

A thin calcilutite occurs near the top of the Horton Limestone. It is a significant mappable horizon, readily identifiable in the field. It is variable in colour (mid grey to buff and pale grey) and in thickness (0.50m-6.00m approximately). In some areas two or more calcilutites can be identified, separated by coarser limestones. The lower calcilutite usually is the darker of two (e.g. Fig 7.16;27).

The calcilutite, or Porcellanous Band, was first reported by Garwood & Goodyear (1924) who mapped its distribution. Unfortunately the calcilutite is no longer exposed at a number of their localities today. It is apparent that Garwood & Goodyear were not aware of the presence of more than one calcilutite and it is not always clear which was mapped. They regarded the calcilutite as a convenient boundary between the S_2 and D_1 limestones of the study area, and correlated it with the Bryozoa Band of Westmorland (Garwood, 1912) which occurs at this stratigraphic level. However, over most of the study area the calcilutite is absent or not exposed and it becomes difficult to distinguish the Horton Limestone from the overlying Kingsdale Limestone.

The distribution of the calcilutite(s) is limited to the more northerly parts of the study area; though it appears to be unrelated to the Craven Fault system. Garwood & Goodyear (1924) apparently believed that the distribution of the Porcellanous Band was influenced by the North Craven Fault. In fact, it dies out some distance to the north of the Fault, with the separation increasing eastwards. The calcilutite is not present between the Craven Faults. Westwards the calcilutite can be traced by sporadic outcrop to Ribblesdale where it achieves its maximum thickness of 6.00m in Horton Quarry, though it thins to discontinuous lenses only a kilometre to the south, across Moughton. It seems to be absent in Clapdale and is reported to thin out underground in the Gaping Gill Cave system (Waltham, 1974, p34). It is present, though poorly exposed, in Chapel-le-Dale and Kingsdale and has been reported underground in these areas by Waltham, 1971. Its most northwesterly reported occurrence, now apparently concealed, is in Easegill where it consists of two beds of calcilutite separated by 0.30m of coarser grained limestone (Glover, 1974, p58). Ashmead (1974) says that the Porcellanous Bed has not been traced into the Casterton Fell area, an area stretching from the Dent Fault up Easegill. Waltham (1974) says that the caves here are restricted to a stratigraphic thickness of 145m from the Girvanella bed downwards, but his diagram (p.33) shows the Porcellanous Band in the Lost Johns section. The lower bed of calcilutite in Easegill is traceable eastwards to Ribblesdale where, in the most northerly exposure near Selside (Fig 7.16;27), it is black and associated with shales, characters resembling the outcrops in Garsdale and the Raydale and Beckermonds Scar boreholes.

The greatest thickness (6m) of the Moughton Calcilutite Member was recorded from Horton Quarry (SD79557218). The sequence comprises:-

0.50m,	Limestone, mid grey calcilutite.
0.25m,	Limestone, mid grey calcilutite overlain by a thin mudstone.
1.10m,	Limestone, pale grey calcilutite.
2.30m,	Limestone, pale-mid grey calcilutite with recrystallised bioclasts.
0.55m,	Limestone, fenestral pale-mid grey calcilutite. Bioclasts are replaced by, and fenestrae filled with, ferroan calcite.
1.05m,	Limestone, pale-mid grey calcarenite at the base fining upwards into fenestral calcilutite.

The thickness of the calcilutite is variable even within the length of the quarry exposure. At SD79547238 the calcilutite crops out but its base is not seen. However, a second lower calcilutite can be distinguished but only the uppermost 0.50m of the bed are exposed. The two calcilutites are separated by approximately 11m of pale grey calcarenite, the upper 2.50m of which are inaccessible. The upper calcilutite is at least 4.80m thick. It comprises the following:-

1.20m,	Limestone, mid grey, paling rapidly up to pale grey, mottled, locally fenestral calcilutite.

0.05m,	Mudstone.
3.10m,	Limestone, pale grey and darker grey fenestral calcilutite, calcisiltite at the base. Fenestrae and bioclasts concentrate along laminae.
0.45m,	Limestone, finely laminated calcilutite. The base of the calcilutite is not seen.

At SD79537263, the final section measured in Horton Quarry, the calcilutite is clearly much thinner. Only 3.45m are exposed. It comprises:-

-	Limestones, pale grey calcarenites.
0.85m,	Limestone, buff-mid grey fenestral calcilutite with bioclasts.
2.00m,	Limestone, very fine grained, pale grey calcisiltite, fenestral at the base only.
0.60m,	Limestone, pale grey calcilutite with numerous bivalves and gastropods.
-	Limestones, pale grey calcarenites.

The calcilutite is inaccessible over most of the length of the Horton Quarry exposure. However, it is easily distinguished by its much paler colour from the surrounding buff-grey calcarenites.

South of Horton Quarry in Ribblesdale the upper calcilutite thins rapidly to only 2.00m at SD797715. Farther south, immediately north of the Moughton Fault, it has thinned further and it is only 0.65m thick.

There is a series of excellent exposures of the calcilutite in Crummack Dale where interbedding with thin beds of calcarenite is usual. No lower calcilutite has been found.

The outcrop begins at SD78507068, where the calcilutite is only 0.05m thick. It is possible that the calcilutite occurs as a series of lenses or a very thin bed around the southern part of Moughton Scars, although the horizon remains obscured. North from SD78337130, where the calcilutite is only 0.10m thick, its position can be identified by the coral-rich horizons above the below and the cross-laminated calcarenites above. The outcrops are sparse; at SD784715 1.00m of fenestral calcilutite is visible and at SD784716 0.70m of fenestral calcilutite abruptly overlie calcarenite.

The first good exposure at the eastern side of Crummack Dale is at SD786718 where the following sequence was seen:-

-	Limestones, pale grey calcarenites.
1.50m,	Limestone, pale grey calcilutite with sparse fenestrae.
0.40m,	Limestone, low-angle, cross-laminated, pale grey calcisiltite.
0.25m,	Limestone, pale grey calcilutite.
0.05m,	Shale film.
0.35m,	Limestone, pale grey, very fine grained calcarenite-calcisiltite.
0.20-0.25m,	Limestone, pale grey calcilutite resting on irregular bedding surface.
-	Limestones, pale grey calcarenites.

North of Moughton Whetstone Hole (SD785721) a complex sequence of interdigitating calcilutite and coarser limestone was seen (Fig 7.14,4B). The succession is as follows:-

-	Limestone, pale grey calcarenite.
0.30m,	Limestone, pale grey calcilutite.
1.30m,	Limestone, pale grey, mottled calcilutite which grades up into calcisiltite.
0.35m,	Limestone, pale grey, cross-laminated calcisiltite.
0.20m,	Limestone, pale grey calcilutite.
0.30m,	Limestone, pale grey, fenestral calcilutite.
0.15-0.10m,	Limestone, pale grey calcisiltite-calcarenite.

0.15-0.20m,	Limestone, pale grey calcilutite with an irregular top, thickening to the west as the overlying calcarenite thins.

The calcilutite is next exposed above Capple Bank (SD783720). The lowermost two beds of calcilutite, separated by the calcisiltite at SD785721, appear to have become one and the sequence seen is logged below:-

-	Limestone, pale grey calcarenites.
1.40m,	Limestone, pale grey fenestral calcilutite. The contact with the overlying calcarenite is intensely bioturbated.
0.90m,	Limestone, cross-laminated, pale grey, fine grained calcarenite and a thin lens of calcilutite near its base (Fig 7.14;5A).
0.40m,	Limestone, pale grey calcilutite.
-	Limestone, pale grey calcarenite.

At SD781723 the lower calcilutite is well exposed and the lowest bed has an erosional contact with the underlying calcarenite. This bed is 0.80m thick and is overlain by 0.55m of pale grey fine grained calcarenite with an irregular top and then by two beds of pale grey calcarenite together 1.20m thick.

The succession exposed at SD77907240 is more complex and the thickness is greater (Fig 7.14;6A).

-	Limestones, pale grey calcarenites.
0.20m,	Limestone, pale grey calcilutite.
0.15m,	Limestone, mid grey calcilutite.
1.10m,	Limestone, pale grey calcilutite.
0.55m,	Limestone, laminated, pale grey, fine grained calcarenite.
1.10m,	Limestone, pale grey calcilutite.

Beyond, the calcilutite crops out at SD77887242 where the lower part is poorly exposed. Although the base is nowhere exposed, it is at least 0.35m thick. Above it are 0.65m of pale grey calcarenite and then 1.25m of pale grey calcilutite overlain by pale grey calcarenites.

A similar problem of poor exposure is encountered at SD77847246 where, although the two beds of calcilutite are seen, neither the top of the upper, no the base of the lower, are visible. The observed thicknesses are 1.00m of fenestral calcilutite overlain by 0.65m of fine grained calcarenite above which 1.25m of pale grey calcilutite occur.

The succession exposed at SD77827248 is very similar to that seen at SD77907240 (Fig 7.14;6D).

-	Limestone, pale grey calcarenite.
0.30m,	Limestone, pale grey calcilutite.
0.15m,	Limestone, mid grey calcilutite.
1.15m,	Limestone, pale grey fenestral calcilutite.
0.70m,	Limestone, pale grey, fine grained calcarenite.
0.70m,	Limestone, pale grey, fenestral calcilutite.

Only the upper bed of the calcilutite crops out at SD778725 where it comprises 1.10m of buff-pale grey, fenestral calcilutite overlain by 0.15m of mid grey calcilutite. The calcilutite is overlain and underlain by pale grey fine grained calcarenites.

The exposure deteriorates south of this locality and at SD775724 only 1.00m of calcilutite is exposed. Neither overlying nor underlying beds crop out. Beyond, exposure of the calcilutite is sporadic. At SD773719 there are two beds of calcilutite exposed. The lower calcilutite, 0.05-0.15m thick, is separated from the overlying 1.20m of calcilutite by 1.20m of pale grey calcarenite. Corals are present in the calcarenite immediately overlying the top bed of calcilutite.

The quality of the exposure deteriorates further. At SD773718 a single bed of fenestral calcilutite 1.00m thick crops out and at SD772718 the calcilutite is only 0.90m thick.

The exposure improves southwards to SD772717 where the following sequence was seen:-

-	Limestones, pale grey calcarenites containing numerous small coral colonies at the base.
0.90m,	Limestone, pale grey calcilutite, fenestral at the base.
0.10m,	Limestone, pale grey, coarse grained calcarenite.
0.60m,	Limestone, pale grey, fine grained calcarenite-calcisiltite passing upwards into calcilutite in the uppermost 0.10m.
-	Limestone, pale grey, very fine grained calcarenite.

South of the last exposure in Crummack Dale, northwest of Crummack Farm, there is an isolated exposure of the calcilutite (SD772716) where only the lowermost 0.50m of calcilutite are seen. It has not been traced south from this locality.

The calcilutite does not crop out in Clapham Bottoms, however, two beds of very much finer grained than usual, mid grey calcarenite crop out at about the right stratigraphical position along Long Lane (SD763717). It is possible that this fine grained calcarenite horizon correlates with the calcilutite. The calcilutite has been observed in the subsurface exposure of Gaping Gill Main Chamber where it played an important role in controlling the development of much of the Gaping Gill system (Glover, 1974). The calcilutite, only 0.50m thick, is locally dolomitised and conspicuous 8 metres above the Main Chamber floor. A lower less well developed calcilutite, 0-0.15m thick, is present 5 metres above the floor (Glover, 1973). It can be seen to be replaced by a coarsely crystalline shell bed 0.20m thick before it feathers out to the southeast (Glover, 1974; Waltham, 1974).

To the northwest, the calcilutite next crops out in Crina Bottom (SD721734) where its maximum thickness is approximately 1.25m. The top of the calcilutite is not exposed.

>0.80m,	Limestone, pale grey calcilutite.

0.30m,	Limestone, pale grey, medium grained calcarenite.
0.15m,	Limestone, pale grey calcisiltite fining upwards to calcilutite.

On the southeastern side of Chapel-le-Dale the calcilutite is intermittently exposed. Above White Scar Cave (SD71567414) the maximum thickness of pale grey calcilutite exposed is 2.10m. Usually the underlying beds do not crop out and no lower calcilutite is seen. Northwards the sequence is thicker and better exposed. At SD728746 the calcilutite overlies pale grey, fine grained calcarenite.

0.50m,	Limestone, calcilutite grading up into fine grained calcarenite.
1.00m,	Limestone, pale grey, bioclastic, fenestral calcilutite.
2.10m,	Limestone, pale grey calcilutite with layers of bioclasts and ferroan calcite cemented fenestrae.
-	Limestone, pale grey, fine grained calcarenite.

Farther north along Raven Scar (SD737755) only 1.40m of calcilutite are exposed. Northwards the outcrop deteriorates and the calcilutite is not easily identified.

More than one calcilutite is well exposed at the northwestern side of Chapel-le-Dale (SD73157692). The following sequence was seen:-

0.60m,	Limestone, mid grey calcilutite.
3.60m,	No exposure.
6.00m,	Limestone, bioclastic, pale grey calcarenite.
0.60-1.45m,	Limestone, mid grey calcilutite with undulose laminations and a mounded top.
0.70m,	Limestone, pale grey calcilutite with fenestrae.
1.50m,	Limestone, poorly bedded, pale grey calcilutite.
1.50m,	Limestone, pale grey calcarenite.
1.40m,	No exposure.
0.50m,	Limestone, dark grey calcisiltite.

Adjacent to the locality described above a similar sequence can be seen (SD731769) with calcilutites occurring at two different stratigraphic levels.

-	No exposure.
2.05m,	Limestone, poorly exposed pale grey calcilutite with abundant ferroan calcite fenestrae.
1.95m,	Limestone, two beds of buff-pale grey calcilutite with ferroan calcite fenestrae.
3.10m,	Limestone, pale grey, fenestral calcilutite with recrystallised ferroan calcite bioclasts.
7.10m,	Limestone, pale grey, medium-fine grained calcarenites.
0.85m,	Limestone, pale grey calcilutite grading into calcarenite at the top.
0.15-0.30m,	Limestone, mid grey calcisiltite filling the relief on the underlying bed.
0.40-0.50m,	Limestone, dark grey calcilutite.
1.20m,	No exposure.
16.15m,	Limestone, pale grey calcarenite and thin pale grey and mid grey calcisiltites.

The 0.40-0.50m thick dark grey calcilutite occurring above the thickness of calcarenites probably correlates with the dark grey calcisiltite observed at the base of the succession at SD73157692 (Fig. 7.15,15A).

To the south the outcrop is poor and the calcilutite levels are only sporadically exposed. At SD724764 the following section was measured (Fig 7.15;16).

-	No exposure.
0.15m,	Limestone, pale grey calcilutite.
12.65m,	Limestone, poorly and sporadically exposed very fine grained calcarenites.
0.40m,	Limestone, pale grey calcilutite passing upwards into calcisiltite.

0.35m,	Limestone, pale grey, fine grained calcarenite.
0.60m,	Limestone, pale grey calcilutite.
0.80m,	Limestone, pale grey, fine grained calcarenite.
0.20m,	Limestone, pale grey calcilutite.
52.05m,	Limestones, mainly pale grey calcarenites.

The calcilutite is not well exposed along the southeastern flanks of Whernside. It is poorly exposed between SD702758 and SD704753 around Twisleton Scar End. Two beds of pale grey, non-fenestral calcilutite, together 1.10m thick and occurring 6.65m below the base of the Kingsdale Limestone, were seen at SD707755. Fine grained, pale grey calcarenites and calcisiltites occur immediately above and below. The lower calcilutite horizon does not crop out.

The most western outcrops of the calcilutite in the study area are at the western side of Kingsdale (Fig 7.15; 18-21). In the most southerly of these exposures (SD69057580) two beds of pale grey calcilutite, totalling 0.90m, are exposed. At SD69247631 there is one bed of pale grey calcilutite 0.75m thick whereas at SD69287631, two beds of calcilutite are together 1.00m thick. The most northerly exposure in the Dale is at SD69777735 where two beds of pale grey calcilutite (0.50m and 1.50m thick respectively) are separated by 0.60m of pale grey, fine grained calcarenite (Fig 7.15;21). The upper thick beds of calcilutite is particularly fine grained and pale grey. The outcrop of the calcilutite and the upper part of the Horton Limestone in general are particularly poor in Kingsdale. It appears that the calcilutite generally thickens to the north in Kingsdale, but at no point is a lower calcilutite horizon seen. Waltham (1974) observed a conspicuous bed, usually about 70cm thick, of "fine, white, slightly less pure limestone occurring at the base of the D_1 zone" in Kingsdale potholes. He gives no thickness but records the presence of the calcilutite in Lost Johns Pot, Swinsto Hole, Rowten Pot and Juniper Gulf (Waltham, 1971).

East of the thickest exposure of the calcilutite in Horton Quarry, the only outcrop in east Ribblesdale is above Brackenbottom Farm (SD819725).

-	No exposure.
0.50m,	Limestone, pale grey calcilutite.
1.50m,	Limestone, pale grey calcilutite.
1.00m,	Limestone, pale grey, fine grained calcarenite.
0.05-0.15m,	Limestone, pale grey calcilutite with an irregular top coated by a thin shale.
-	Limestones, pale grey, cross-laminated, fine grained calcarenites.

This exposure is isolated by till and a lower calcilutite horizon is not seen. Glover (1974) stated that the calcilutite is not found further east than the west flank of Pen-y-ghent where two calcilutites occur three metres apart. The latter feature was not observed and the calcilutite is exposed to the east in the north of both Wharfedale and Littondale. However, it is not exposed or does not occur in the intervening ground.

There is an excellent exposure of the calcilutite horizons at Old Cote Low Moor, Littondale (SD927728).

0.10m	Limestone, pale grey, coarse grained calcarenite draped over underlying beds.
0.10-0.15m,	Limestone, pale grey calcisiltite.
0.55m,	Limestone, pale grey calcilutite with fenestrae at the base and relief of 0.25m on the top of the bed.
0.20m,	Limestone, pale grey, very fine grained calcarenite.
0.85m,	Limestone, two beds of pale grey calcilutite.
0.15m,	Limestone, pale grey, fine grained calcarenite.
0.30m,	Limestone, pale grey, fenestral calcilutite.
0.65m,	Limestone, pale grey, fine grained calcarenite.

0.05m,	Limestone, pale grey calcisiltite.
0.20-0.35m,	Limestone, pale grey, fenestral calcilutite filling the relief in the underlying bed.
0.35-0.50m,	Limestone, pale grey calcisiltite with a flat base and relief of 0.15m on top.
9.10m,	Limestone, poorly exposed fine grained, pale grey calcarenite.
0.10m,	Limestone, pale grey calcisiltite.
1.05m,	Limestone, buff-pale grey calcilutite.
0.25m,	Limestone, pale grey calcisiltite.
-	Limestone, thickly bedded, pale grey calcarenites.

The calcisiltite and coarse grained calcarenite at the top of the measured section are clearly draped over the mounded surface of the top bed of calcilutite. This bed probably was lithified prior to the deposition of the overlying beds.

There are no other exposures of the calcilutite in Littondale at which sections could be measured. It crops out poorly only at the north side of the Dale above Arncliffe. In the major part of the Dale it does not crop out or is not present. In Wharfedale there is a series of exposures west of Kettlewell between Knipe Wood (SD968715) and the northern end of Gate Cote Scar (SD962725). Immediately above Kettlewell the calcilutite is exposed at the base of Gate Cote Scar (SD966722). Three beds of calcilutite (0.75m,0.95m and 0.60m thick respectively) overlain by 1.20m of pale grey calcisiltite, crop out above approximately 70m of Horton Limestone. Unfortunately, the immediately underlying beds are not exposed. At the northern end of Gate Cote Scar (SD964724) a more complete succession is seen.

0.70m,	Limestone, fine grained, pale grey calcarenite filling the occasional irregularities on the top of the underlying bed.
1.05m,	Limestone, pale grey calcilutite.

0.30m,	Limestone, pale grey, fine grained calcarenite which grades up into calcisiltite.
0.45m,	No exposure.
1.65m,	Limestone, thick bedded, pale grey calcilutite.
-	Limestone, pale grey, medium grained calcarenite.

The calcilutite crops out at the eastern side of Wharfedale above Scar Gill House (SD978712) and near Kettlewell (SD977724). The exposure is very poor and although more than one calcilutite horizon is indicated by Wilson & Cornwell (1982), this was not observed.

North of Horton Quarry, the two calcilutite horizons are exposed near the public footpath by Beecroft Farm, Ribblesdale (SD794733). Only 0.45m of the lower calcilutite are exposed, abruptly overlying brachiopod-rich, pale grey, fine grained calcarenites. It is separated from the higher calcilutite, of which only 0.70m are exposed, by 11 metres of poorly exposed, cross-laminated, pale grey, fine ground calcarenites.

Beyond this outcrop the calcilutite is covered by a thick till veneer. It first emerges from the till at SD79207395 where it forms a limestone pavement. It is next exposed near South House (SD78907418) where there are 4.35m of calcilutite. A lower calcilutite horizon is not seen at this locality.

To the north, the next exposure in Ribblesdale is at SD78807420. The calcilutite, 3.30m thick, is incompletely exposed. It is pale grey containing sparse fenestrae at intervals. Dark and shaly limestones, not recorded elsewhere in the study area, crop out 0.70m above the top of the calcilutite. Again, the lower calcilutite horizon did not crop out.

The succession exposed immediately north of Selside (SD785763) is completely different from all other outcrops in the study area. Both upper and lower calcilutite horizons are exposed and the lower calcilutite is unusual in that it is black. The succession, listed below in stratigraphic order, is as follows:-

0.80m,	Limestone, poorly exposed, pale grey calcilutite.
1.60m,	Limestone, pale grey, fenestral calcilutite.
6.70m,	Limestone, locally foetid and pyritic, pale grey calcarenites.
0.05m,	Black paper shale.
0-0.45m,	Black, finely laminated shale which thickens as the underlying bed thins (Plate 10d).
0.80-0.30m,	Limestone, dark grey, cross-laminated, fine grained calcarenite which thins to the north. Slump structures occur in the tail of the wedge.
0.70m,	Limestone, black calcilutite.
0.95m,	Limestone, four thin beds of black, very fine grained calcarenite.
0.50m,	Limestone, top of a bed of black, fenestral calcilutite.

Unfortunately the top of the upper calcilutite horizon and the limestones above are not exposed. Consequently it is not known whether a succession similar to that at South House (SD78807420), that is shaly and black limestones, occurs above.

Finally, Garwood & Goodyear's (1924) map indicates two outcrops to the east of Selside near Low Birkwith Farm, at SD796766 and SD794722. Neither of these outcrops can be found at the present time.

7.8 Location of Measured Section Through The Horton Limestone

1	Horton Quarry, Ribblesdale	SD80007198
2	Foredale Quarry, Ribblesdale	SD799705
3	Beecroft Farm, Ribblesdale	SD797727
4	Selside, Ribblesdale	SD785764
5	Raven Ray, Kingsdale	SD695755
6	Old quarries, Kingsdale	SD691756

7	Twisleton Scar End, Chapel-le-Dale	SD708752
8	Twisleton Scars, Chapel-le-Dale	SD723764
9	Brows Pasture, Chapel-le-Dale	SD731763
10	Light Water Spring, Chapel-le-Dale	SD732758
11	Ten Pound Gill, Chapel-le-Dale	SD729747
12	Meal Bank Quarry, Chapel-le-Dale	SD698735
13	Western Crummack Dale	SD76687078-SD76757115
14	Western Crummack Dale	SD76767115-SD77057140
15	Northeast Crummack Dale	SD783719 and SD784717
16	Eastern Crummack Dale	SD78257110-SD78107074
17	Robin Hood's Quarry, Wharfedale	SD978654
18	Conistone Gorge, Wharfedale	SD985676
19	Howgill, Kilnsey, Wharfedale	SD968672
20	Kilnsey Crag, Wharfedale	SD973680
21	Moss Beck, Littondale	SD965690
22	Sleets Gill, Littondale	SD961694
23	Arncliffe Clowder, Littondale	SD938706
24	Yew Cogar Scar, Cowside Beck	SD918706
25	Old Cote Low Moor, Littondale	SD925726
26	Knipe Wood, Wharfedale	SD973707
27	Gate Cote Scar, Wharfedale	SD966720
28	North end of Gate Cote Scar, Wharfedale	SD964724
29	Malham Cove	SD898641
30	Gordale Scar	SD914637
31	Great Close Scar	SD902666

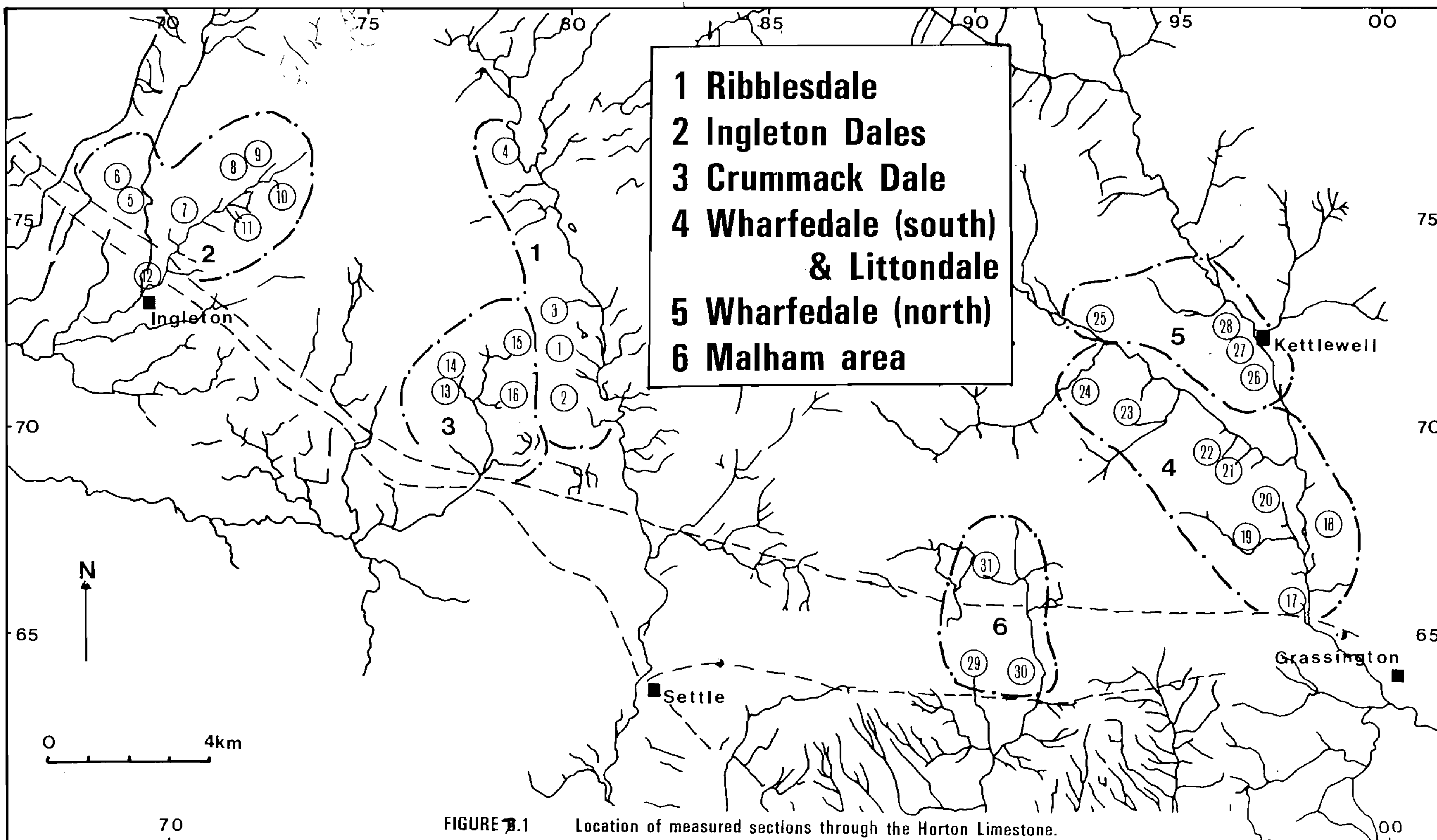
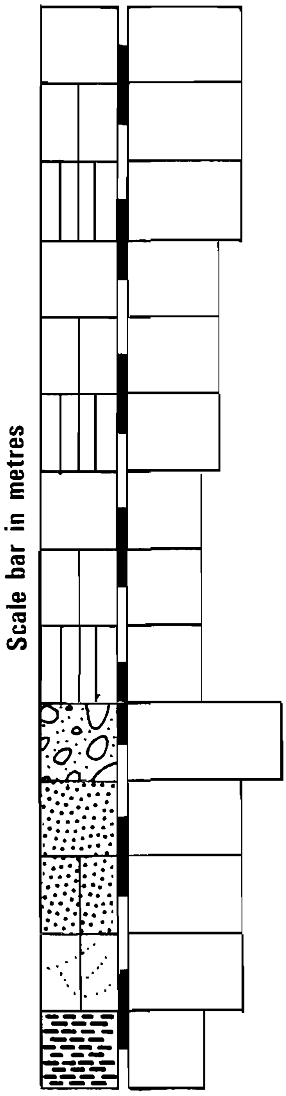


FIGURE 8.1 Location of measured sections through the Horton Limestone.

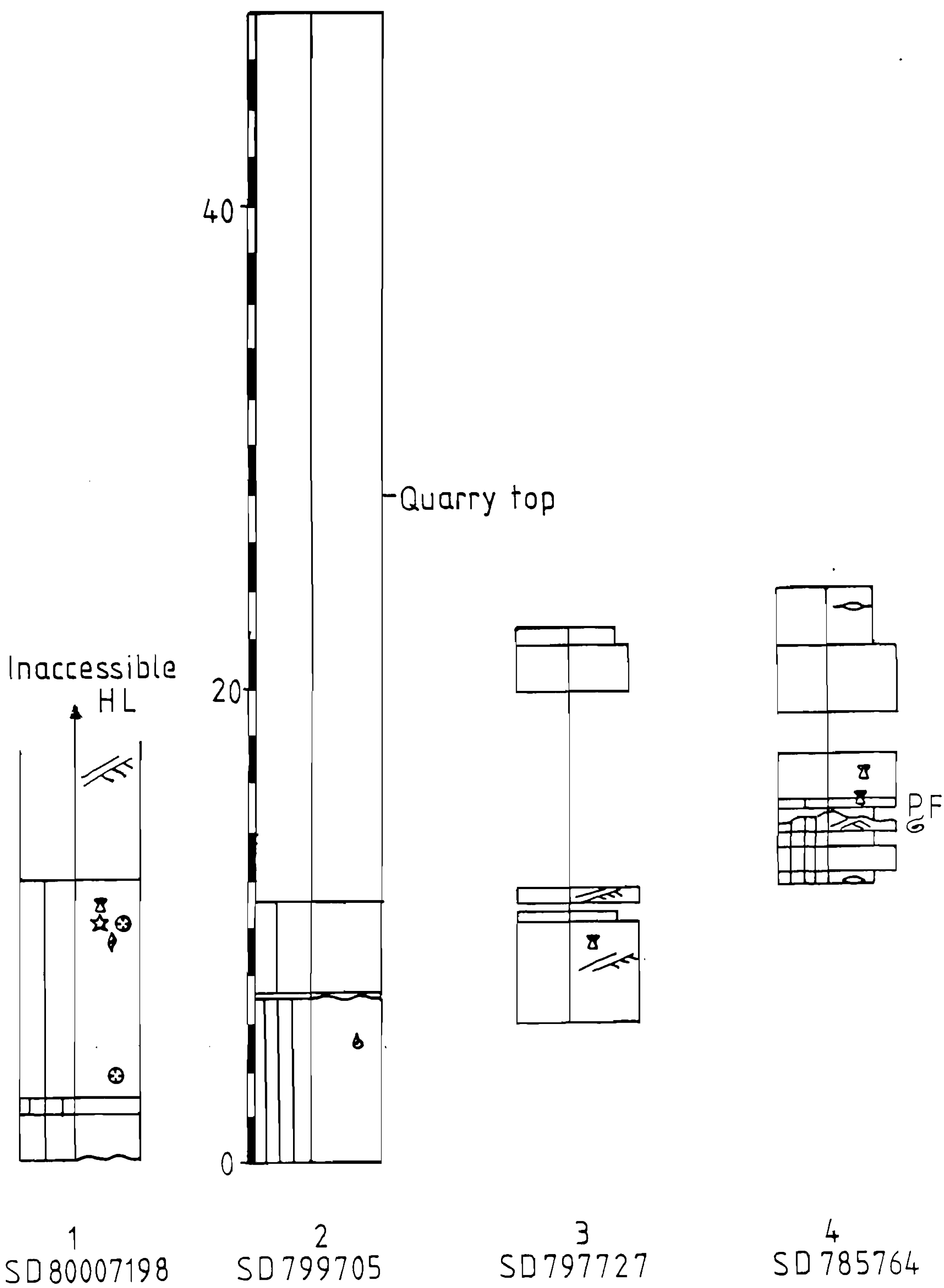


	unspecified bioclasts		birdseye fenestrae
	bivalves		slump structure
	brachiopods		bioturbation
	corals	F	foetid
☆	crinoids	P	pyrite
	gastropods	R	rubbly weathering
	coated grains	S	silicified
▲	intraclasts	RRF	Raven Ray Formation
△	lithoclasts	KL	Kingsdale Limestone

F F Faults

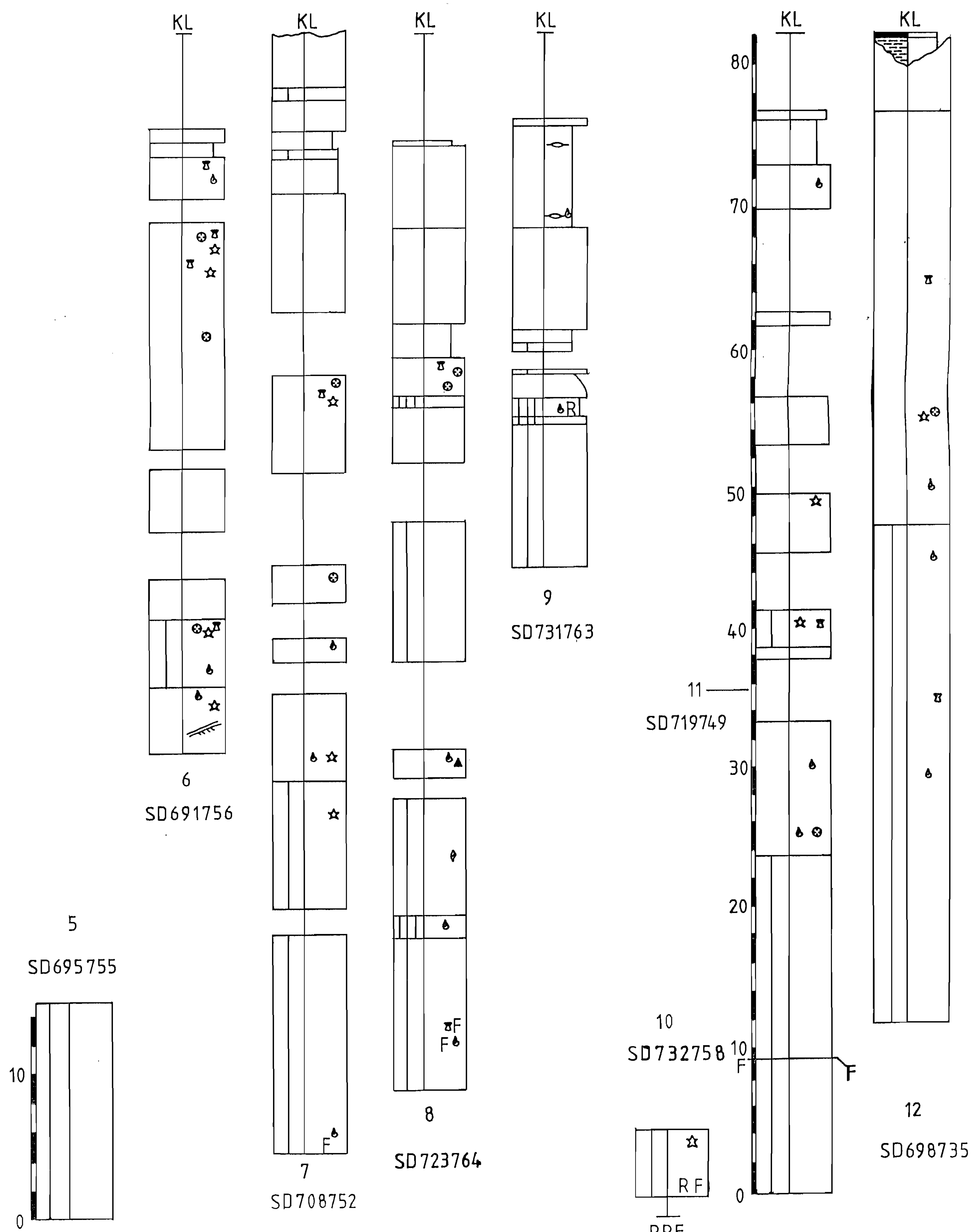
FIGURE 7.2 Key to symbols used in figured sections through the Horton Limestone.

Figures 7.3 to 7.9. Measured sections through the Horton Limestone. (The lowest bed of the formation is shown resting on limestones of the Raven Ray Formation where the contact is exposed).



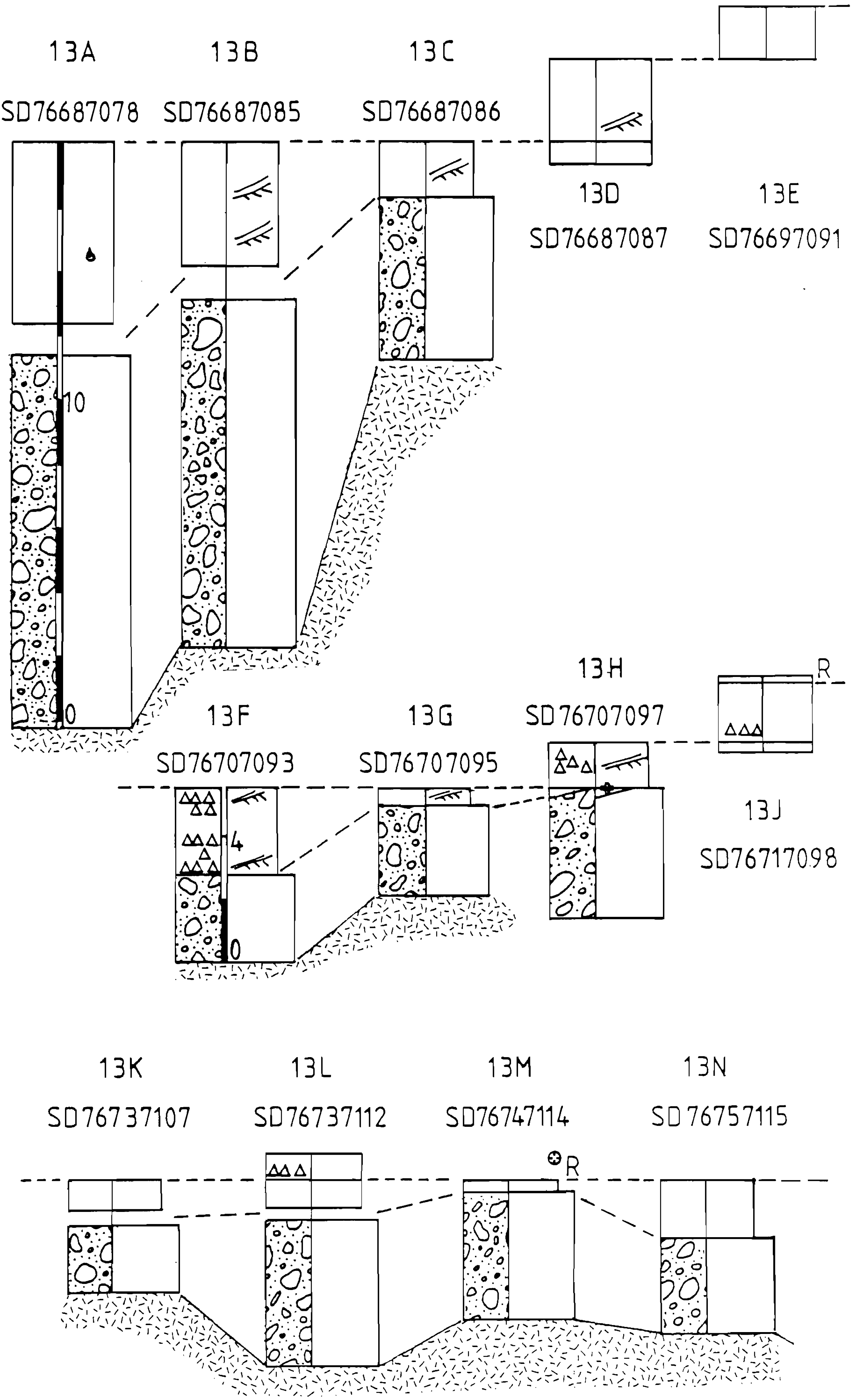
40
20
0
Quarry top
Inaccessible
HL
PF
1
SD80007198
2
SD799705
3
SD797727
4
SD785764

FIGURE 7.3



KL
KL
KL
KL
KL
KL
6
SD691756
7
SD708752
8
SD723764
9
SD731763
5
SD695755
10
0
RRF
10
SD732758
RF
RRF
11
SD719749
80
70
60
50
40
30
20
10
F
0
F
R
12
SD698735

FIGURE 7.4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13F
SD76707093
4
0
13G
SD76707095
13H
SD76707097
R
13J
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13M
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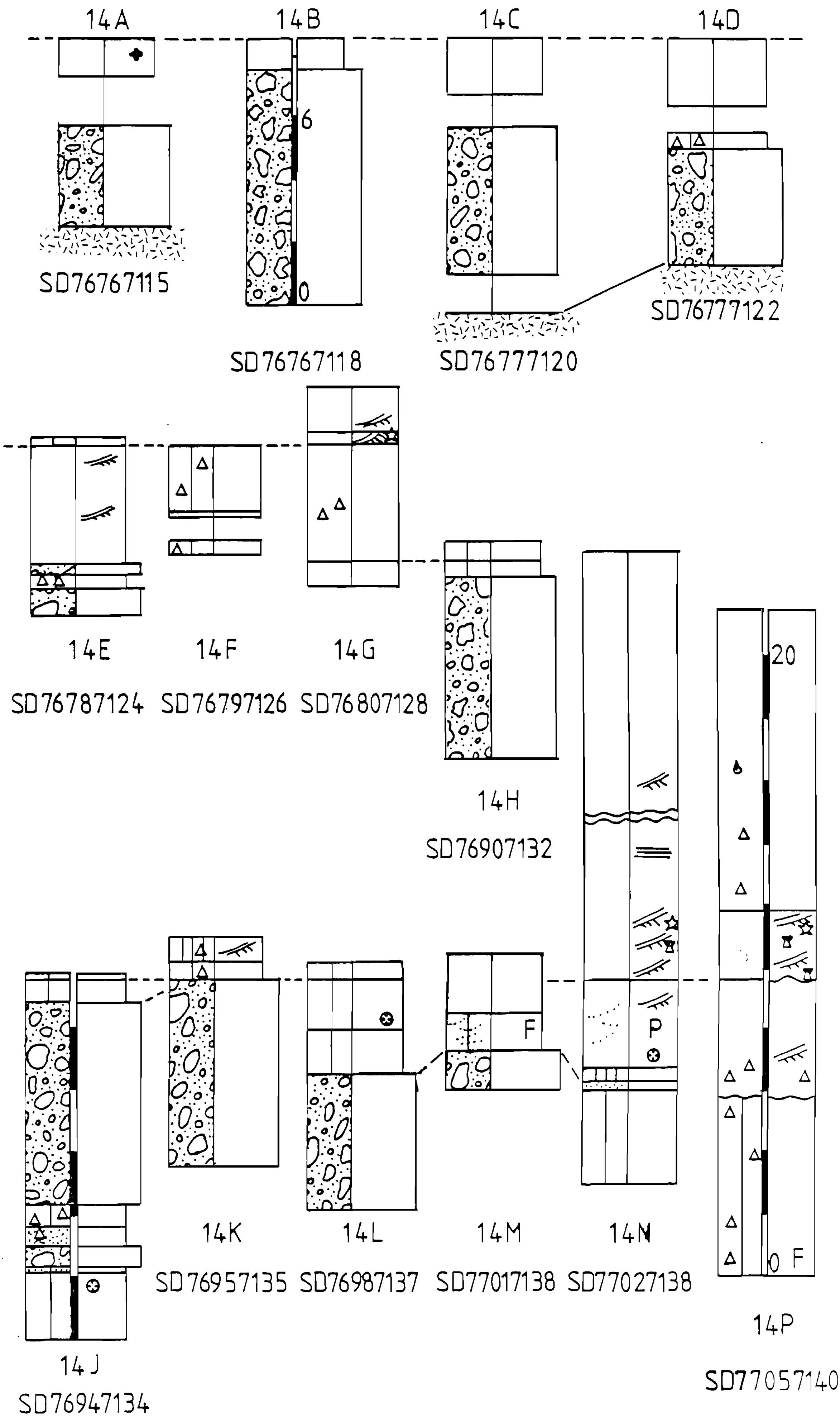
R
13N
SD76757115

FIGURE 7.5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14G
SD76807128
14H
SD76907132
20
F
P
0 F
14J
SD76947134
14K
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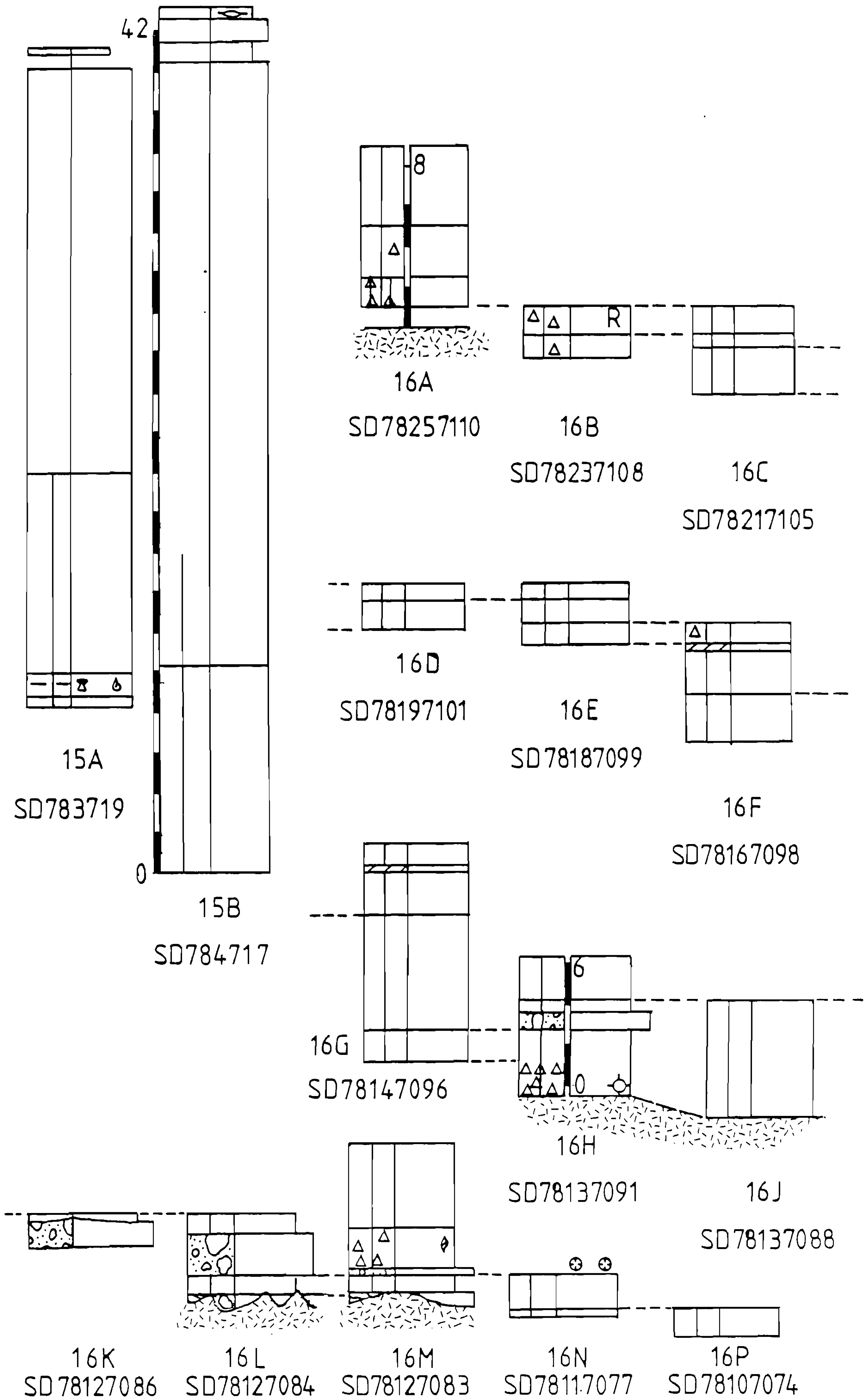
14P
SD77057140

FIGURE 7.6


42
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R
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16C
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16D
SD78197101
16E
SD78187099
16F
SD78167098
16G
SD78147096
6
0
16H
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16J
SD78137088
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16M
SD78127083
16N
SD78117077
16P
SD78107074

FIGURE B.7

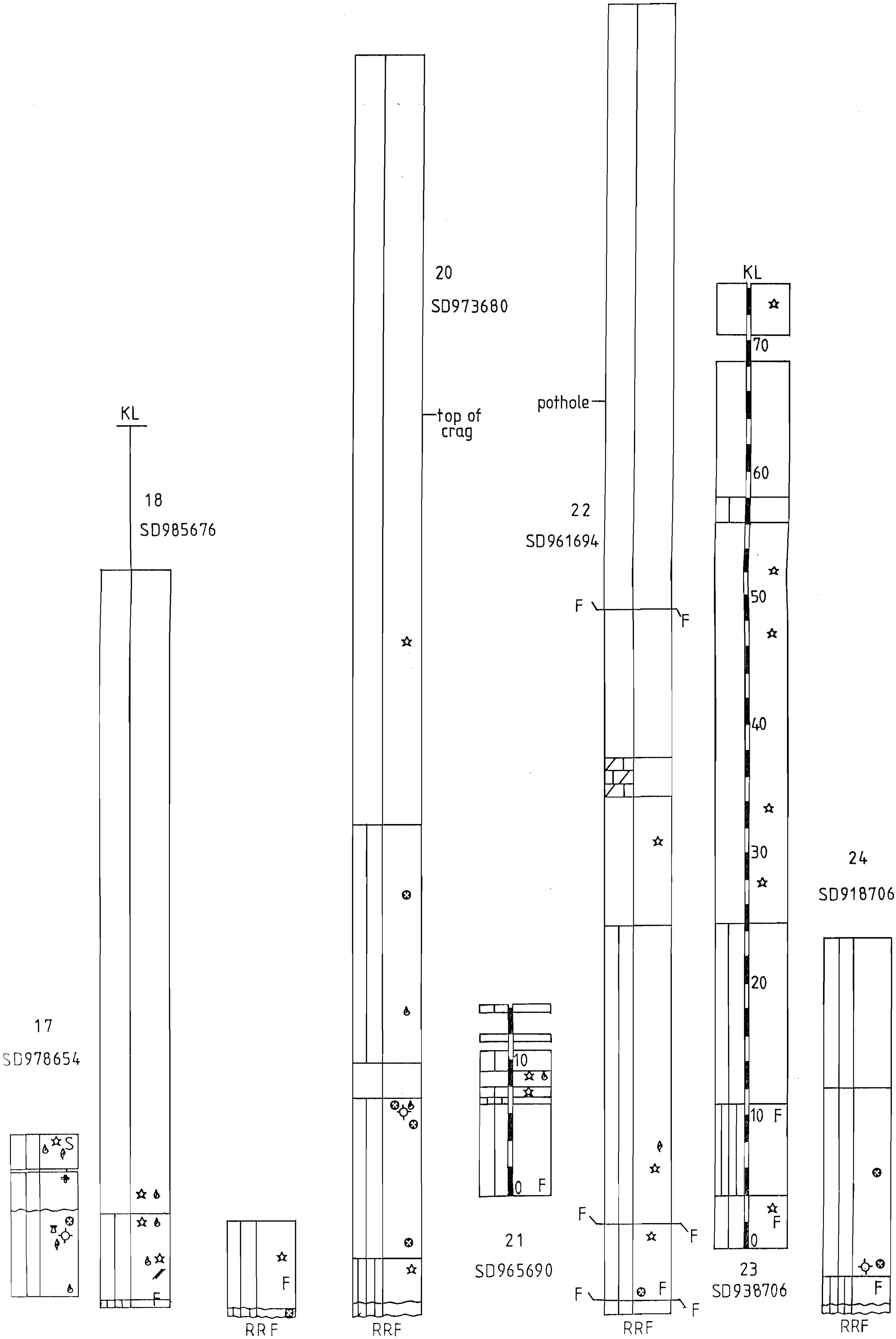
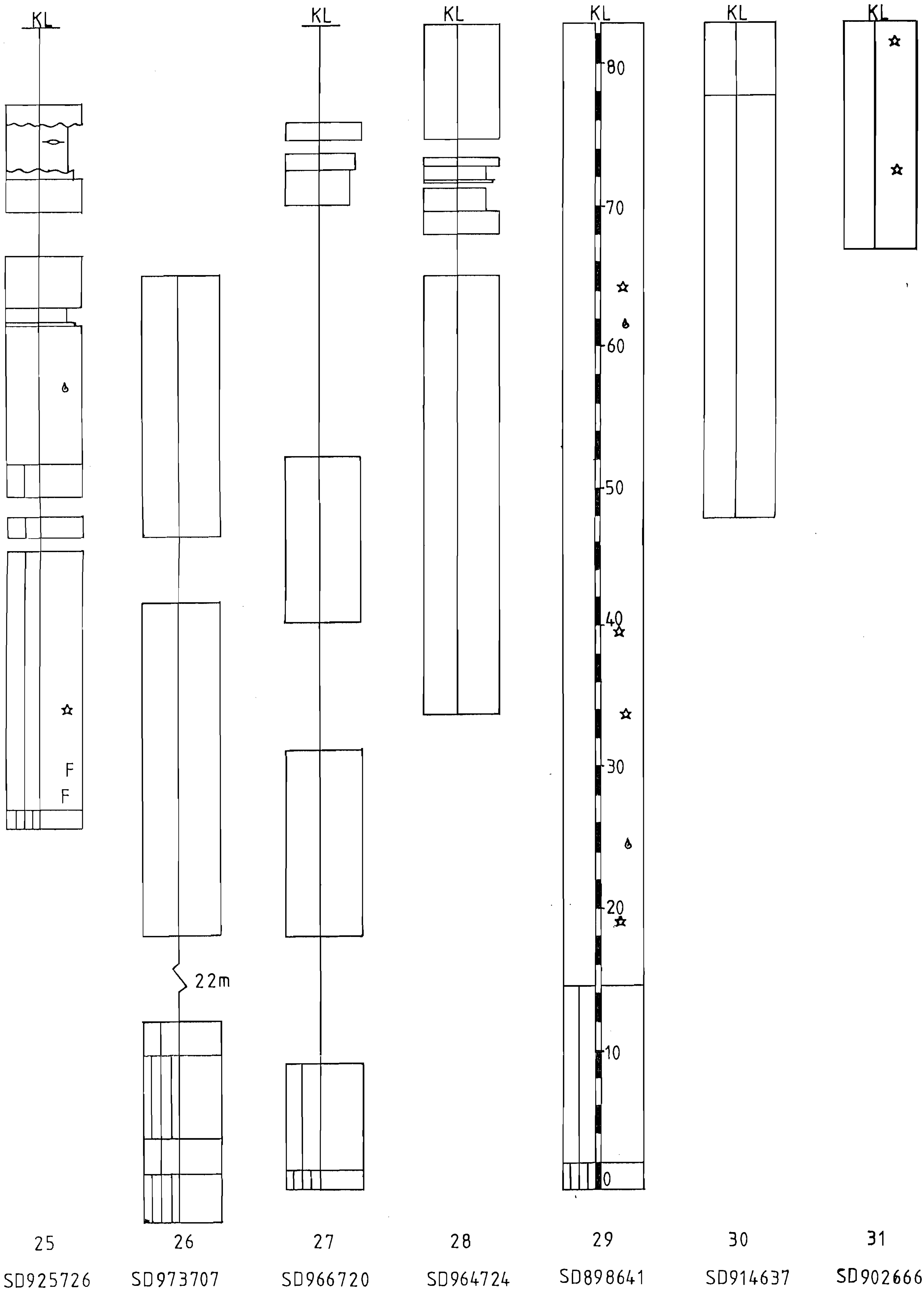

17
SD978654
S
F
KL
18
SD985676
F
RRF
20
SD973680
top of crag
RRF
21
SD965690
10
0
F
pothole
22
SD961694
F
F
F
F
F
F
F
RRF
KL
70
60
50
40
30
20
10
F
0
F
23
SD938706
24
SD918706
F
RRF

FIGURE 7.8



KL
KL
KL
KL
KL
KL
F
F
22m
80
70
60
50
40
30
20
10
0
25
SD925726
26
SD973707
27
SD966720
28
SD964724
29
SD898641
30
SD914637
31
SD902666

FIGURE 7.9

7.9 Location of Measured Sections Through The Moughton Calcilutite Member

1	Horton Quarry, Ribblesdale	SD79557218-79537263
2	South of Horton Quarry, Ribblesdale	SD796713-797715
3	Moughton Scars, east Crummack Dale	SD783713-784716
4	Moughton Scars, east Crummack Dale	SD786718-785721
5	Moughton Scars, north Crummack Dale	SD783720-781723
6	Western Crummack Dale	SD77907240-778725
7	Western Crummack Dale	SD775724
8	Western Crummack Dale	SD773719-772718
9	Western Crummack Dale	SD772717-772716
10	Long Lane, Clapdale	SD763717
11	Gaping Gill Main Chamber	SD751727
12	Crina Bottom	SD721734
13	White Scars, Chapel-le-Dale	SD71567414
14	Raven Scars, Chapel-le-Dale	SD728746
15	Brows Pasture, Chapel-le-Dale	SD73057631-73157692
16	Twisleton Scars, Chapel-le-Dale	SD724764
17	Twisleton Scar End, Chapel-le-Dale	SD706754
18	Western Kingsdale	SD69057580
19	Western Kingsdale	SD69247625-69287631
20	Western Kingsdale	SD69437665
21	Western Kingsdale	SD69777735
22	Brackenbottom Farm	SD819725
23	Old Cote Low Moor, Littondale	SD927728
24	Gate Cote Scar, Wharfedale	SD966722-964724
25	Beecroft Farm, Ribblesdale	SD794733
26	South House, Ribblesdale	SD78907418-78807420
27	Selside, Ribblesdale	SD785763

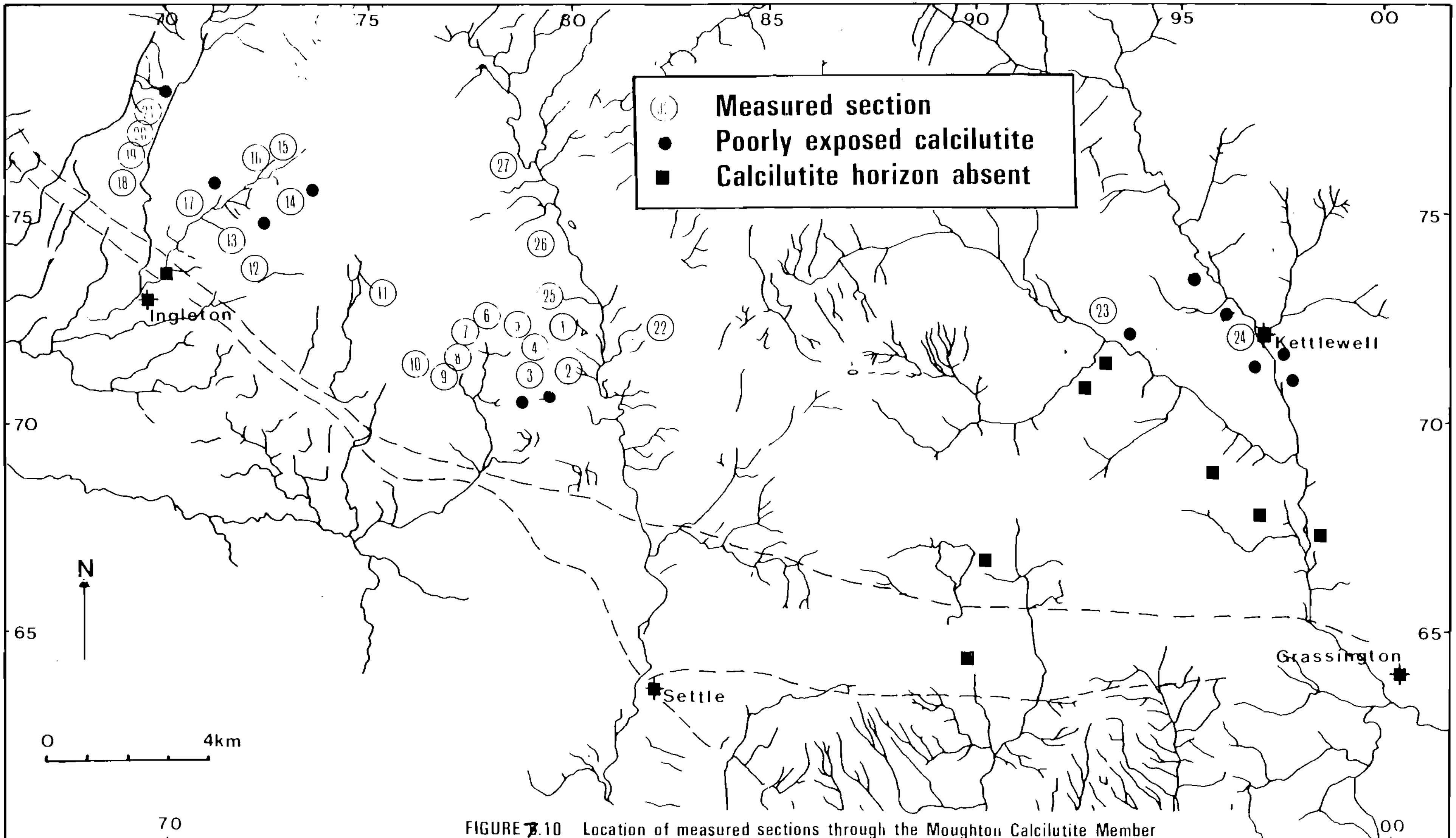
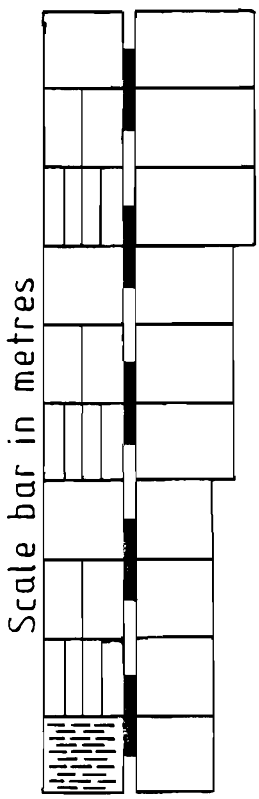


FIGURE 3.10 Location of measured sections through the Moughton Calcilutite Member



Pale grey calcarenite

Mid grey calcarenite

Dark grey calcarenite

Pale grey calcisiltite

Mid grey calcisiltite

Dark grey calcisiltite

Pale grey calcilutite

Mid grey calcilutite

Dark grey calcilutite

Shale

unspecified bioclasts

bivalves

brachiopods

corals

crinoids

gastropods

bioturbation

F foetid

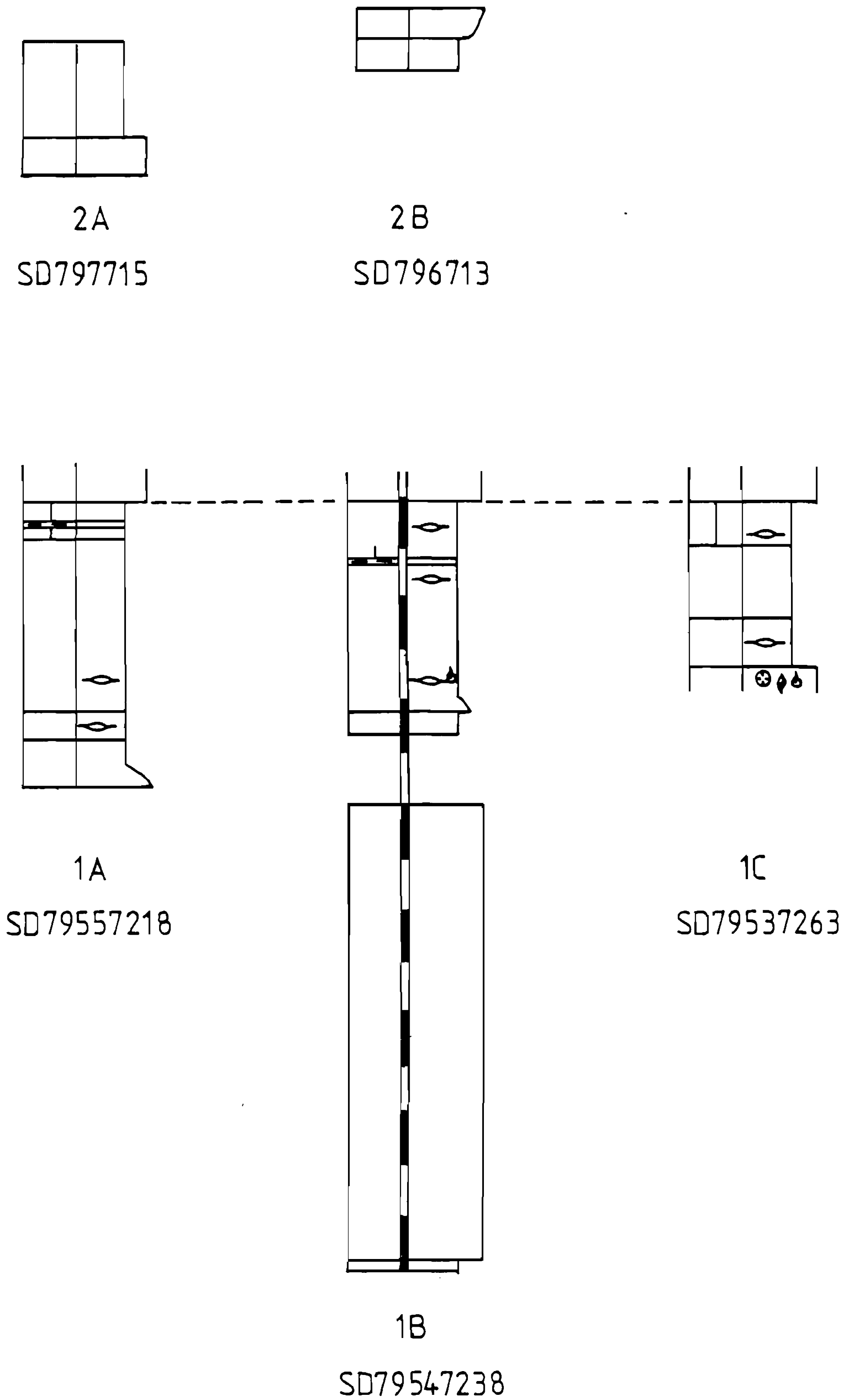
P pyrite

slump structure

birdseye fenestrae

FIGURE 3.11 Key to symbols used in figured sections through the Moughton Calcilutite Member

Figures 7.12 to 7.16. Measured sections through the Moughton Calcilutite Member. (The lowest bed of the member is shown resting on calcarenites where the contact is exposed).


2A
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2B
SD796713
1A
SD79557218
1C
SD79537263
1B
SD79547238

FIGURE 7.12

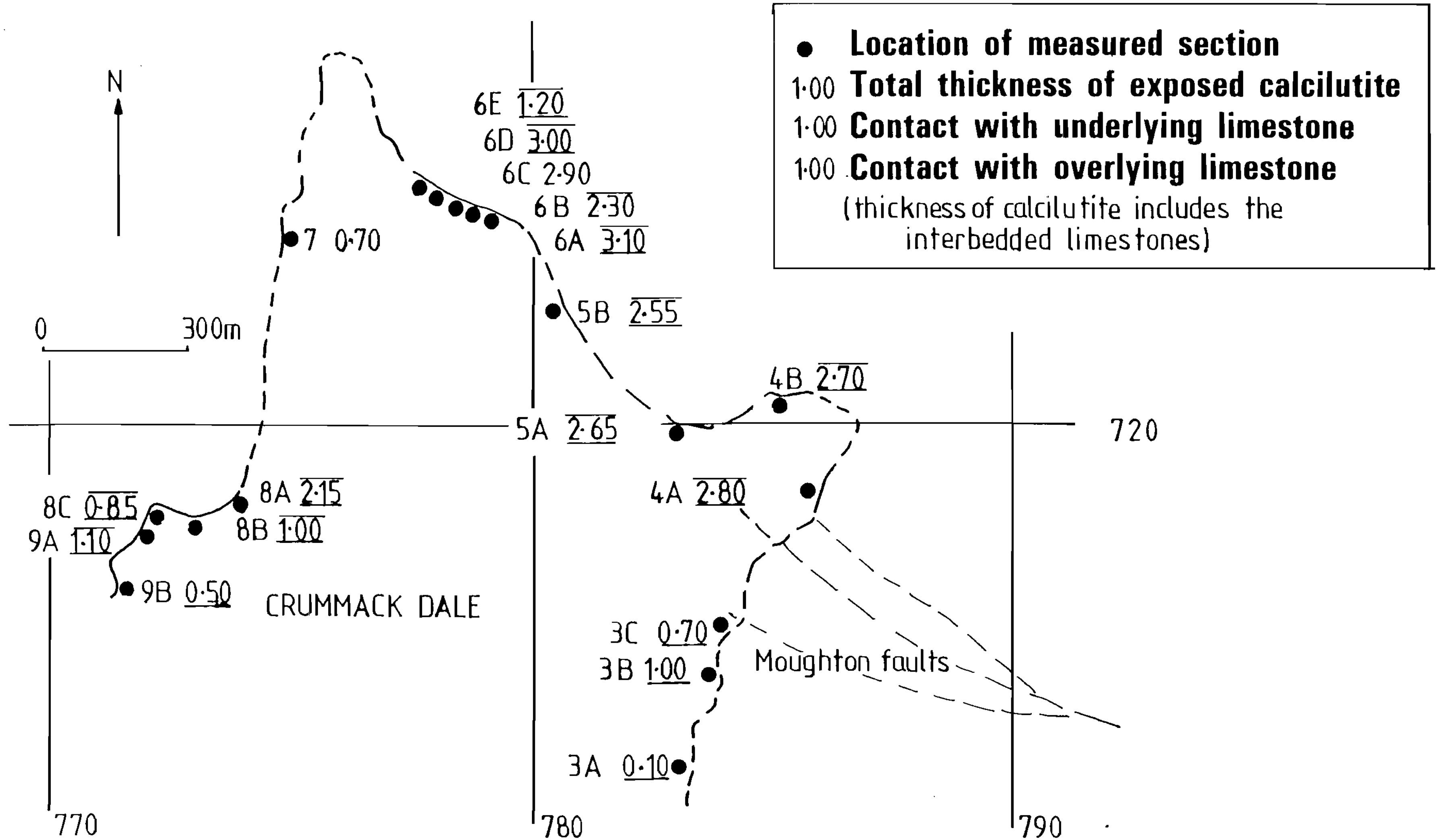
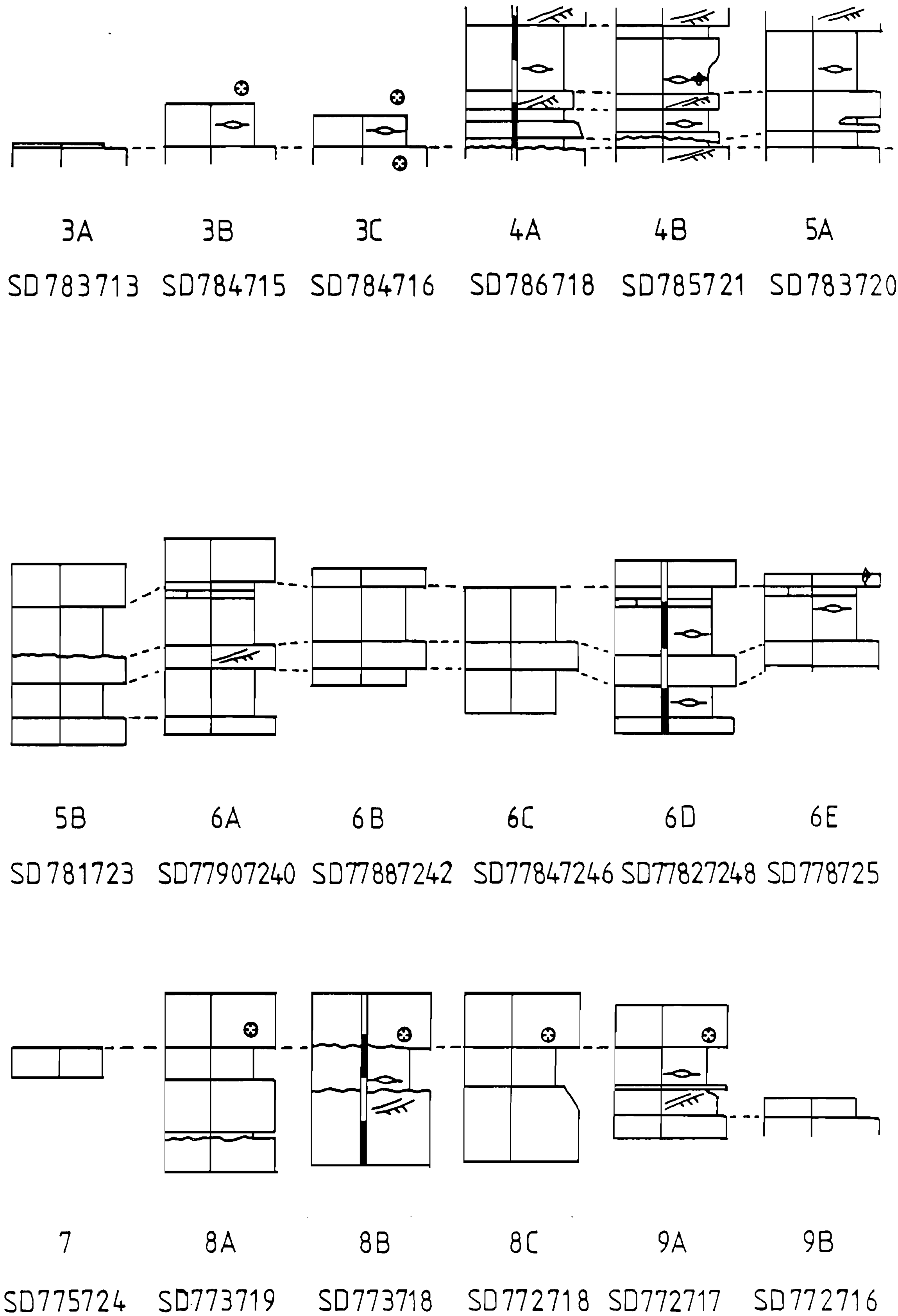


FIGURE 1.13 Location of measured sections through the Moughton Calcilutite Member in Crummack Dale showing variations in thickness (solid line is outcrop).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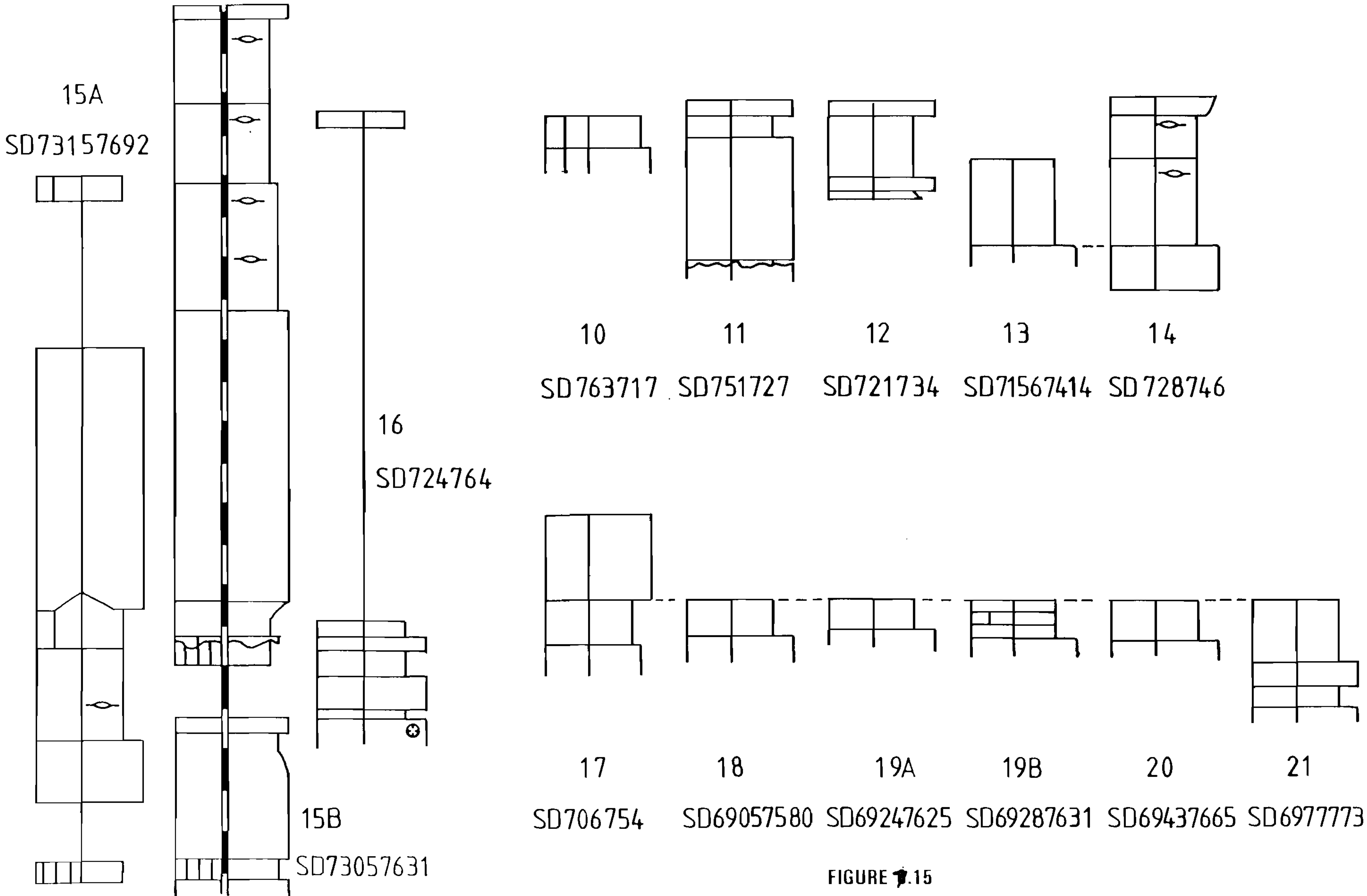
3B
SD784715
3C
SD784716
4A
SD786718
4B
SD785721
5A
SD783720
5B
SD781723
6A
SD77907240
6B
SD77887242
6C
SD77847246
6D
SD77827248
6E
SD778725
7
SD775724
8A
SD773719
8B
SD773718
8C
SD772718
9A
SD772717
9B
SD772716

FIGURE 7.14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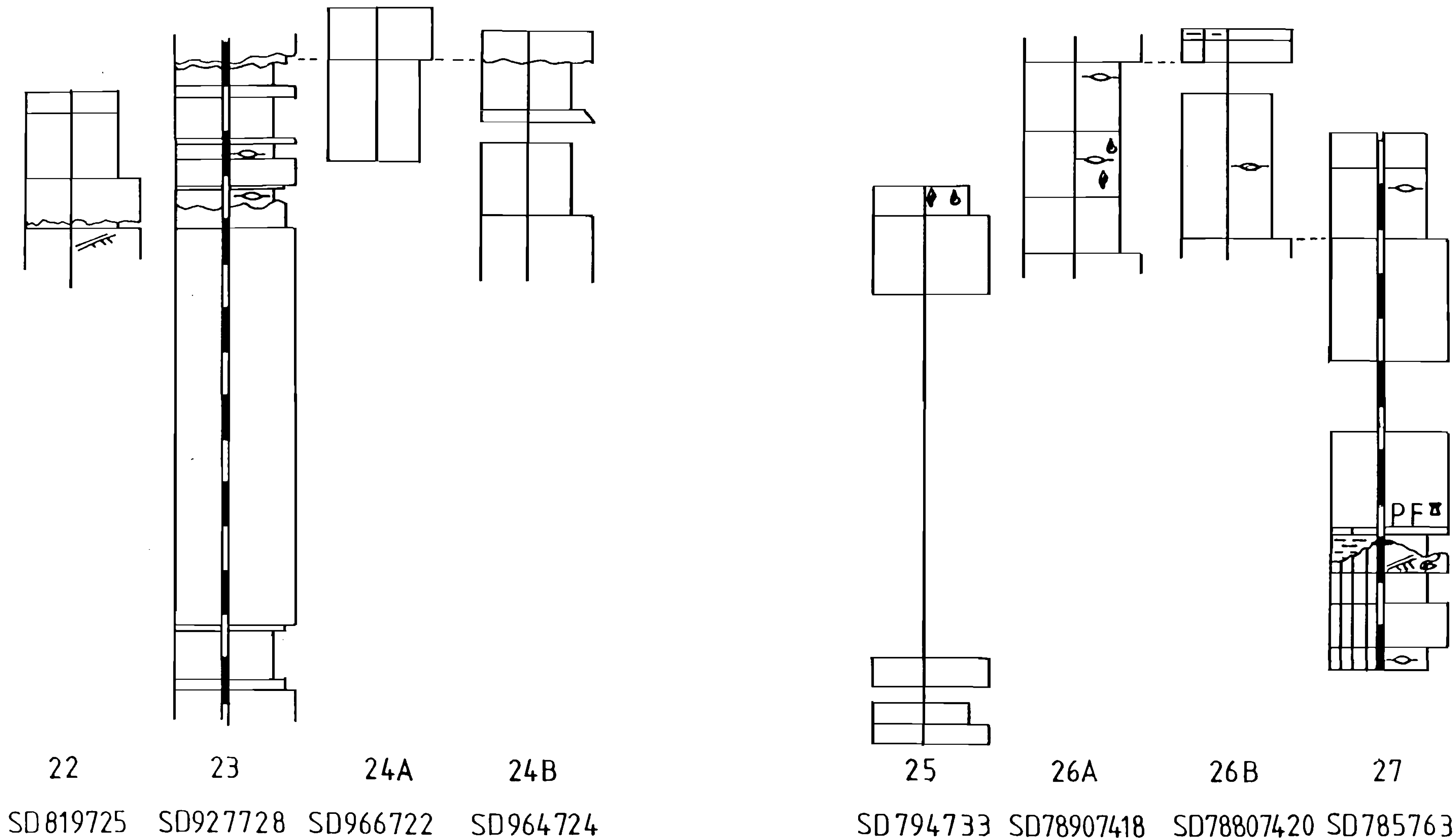
10
SD763717
11
SD751727
12
SD721734
13
SD71567414
14
SD728746
17
SD706754
18
SD69057580
19A
SD69247625
19B
SD69287631
20
SD69437665
21
SD69777735

FIGURE 7.15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23
SD927728
24A
SD966722
24B
SD964724
25
SD794733
26A
SD78907418
26B
SD78807420
27
SD785763
PF

FIGURE 3.16

CHAPTER EIGHT

SEDIMENTOLOGY AND PALAEOENVIRONMENTAL INTERPRETATION OF ROCK-TYPES IN THE THORNTON FORCE FORMATION, DOUK GILL FORMATION, RAVEN RAY FORMATION AND HORTON LIMESTONE.

The carbonate rock-types of the Great Scar Group have been described by Garwood & Goodyear (1924), Schwarzacher (1958), Doughty (1962, 1968), Jefferson (1980) and most recently by Wilson & Cornwell (1982). The few petrographic descriptions are poor and palaeoenvironmental interpretations were regarded as unimportant. However, all authors agree that pale grey, coarse grained, crinoidal limestones dominate the succession.

Virtually all types of carbonate grains, whether organic or inorganic in origin, form within the sedimentary basin as a direct product of local, specific environmental factors (Laporte, 1968; Wilson, 1975). The most abundant bioclast-former throughout the four formations of this study is undoubtedly the crinoid. Skeletal parts of other phyla are common but sporadic, and rarely dominate the crinoid concentration. Organic abundance and diversity have proved reliable despite preservational bias (Ginsburg, 1956; Newell & others, 1959; Purdy, 1963) therefore, the relative amounts of bioclasts can be taken to represent original environmental variations rather than fortuitous removal of different sorts of organisms by various diagenetic processes (Laporte, 1968). Many modern organisms, comparing closely with those in the ancient, occupy similar niches and therefore can be used to interpret the ancient environment (Wilson, 1975; Flugel, 1982).

Organisms are important environmental modifiers. Such processes as reef-building, burrowing, boring, encrusting and faecal pellet production alter the substrate. Biological erosion and comminution of carbonate rocks produces carbonate mud. Biological reworking is most common in the relatively quiet environments where organisms can burrow and shelter beneath a relatively stable substrate. In active environments, physical reworking of the substrate is too frequent to allow colonisation by organism communities. Therefore the character and distribution of communities are closely related to substrate-character (Newell & others, 1959).

Non-skeletal grains are very common, frequently occurring in greater concentrations than the associated bioclasts. Intraclasts are the dominant non-skeletal grains. They occur in abundance throughout the Thornton Force Formation and Horton Limestone and in lesser quantities in parts of the Douk Gill and Raven Ray Formations. Intraclasts show considerable size and shape variations and have many diverse origins (Bathurst, 1975; Flugel, 1982). Faecal pellets have not been identified with certainty, although pelletoids (Milliman, 1974) of similar dimensions do occur. Ooliths are a minor component of the Thornton Force and Douk Gill Formations. Most are superficial ooliths (Leighton & Pendexter, 1962), although some well developed ooliths were recognised in a part of the Douk Gill Formation.

Carbonate mud is a very important constituent of some limestones. It forms the matrix of all calcilutites and the mud-supported calcisiltites and calcarenites. The amount of mud matrix can be used as a guide to water energy and circulation (Laporte, 1968; Wilson, 1975). The micrite-to-sparite proportion becomes an index of water-agitation and energy. However, it must be remembered that a muddy sediment will result even when agitated if the mud is not transported away, and bioturbation can introduce mud into a previously clean calcarenite, leading to misinterpretation of the original environment.

The origins of lime mud are not revealed by petrographic examination. However, the sources of lime mud are the subject of an extensive literature confused by the inconsistent upper size limits for "muds".

The controversy was initiated by Agassiz (1894) who first called serious attention to lime muds west of Andros Island. Drew (1911, 1914) suggested that they were precipitated by the action of denitrifying bacteria and Black (1933) in his studies of the Great Bahama Bank, suggested that carbonate mud could be precipitated from hypersaline brines near the centre of the Bank. Cloud (1962) could account for only 25% of the mud as a product of skeletal (primarily algal) breakdown and proposed that the remaining 75% is inorganic in origin, precipitated directly from seawater with the help of denitrifying bacteria. Newell & Rigby (1957) believed that the algal population was too sparse for in situ production of all the mud. They proposed that aragonite needles could be current transported to their depositional site. Purdy (1963a and b) subdivided the lime muds of the Bahama Banks into two facies, mud and pellet mud. Unfortunately he redefined mud to incorporate all grains finer than 0.125m (3 Ø), thus including all silts and very fine sands in his mud category. This has caused considerable problems in comparing modern Bahama Banks muds with ancient micrites, whose grain size should not exceed 4μm (8 Ø). The sediments of both facies are poorly sorted and receive particles from a number of different sources, both skeletal and non-skeletal. Purdy found no evidence for direct physicochemical precipitation and proposed that algal skeletal disintegration was the major source of particles. Land (1967) observed spicules, immature ostracods and foraminifera, and granules of calcite as well as aragonite needles in muds and suggested that further investigations were necessary.

Matthews (1966), discussed the origins of lime mud off southern Belize (British Honduras). Unfortunately, he found it impossible to identify grains smaller than 20μm (5.3Ø) so that he described only the medium and coarse silts (20-62μm). To identify those grains smaller than 20μm he used X-ray diffraction to determine the carbonate minerals, postulating that this fine fraction was derived from the same biogenic sources as the identifiable grains. He noted a paucity of aragonite needles in the studied fraction and he proposed that the mud formed from a combination of transported shoal-derived detritus and in-place production of biological debris. Scholle & Kling (1972) used a scanning electron microscope to examine the <20μm mud fraction of Matthews and demonstrated that it contained a large percentage of coccoliths and aragonite needles. The breakdown of green algae is the proposed source of aragonite needles (Scholle & Kling, 1972).

The role of green algae in the production and supply of aragonite needles is supported by Lowenstam & Epstein (1957), and Stockman & others (1967). The former compared the oxygen isotope ratios of carbonate sediment with calcareous green algae and ooliths/aggregates. Their results were not entirely conclusive, demonstrating the difficulties of the application of isotope analysis. However, they did show a correlation between algae and mud, and not between ooliths/aggregates and mud, suggesting that the mud is not an inorganic precipitate but has an organic, probably algal origin. Stockman & others (1967) studied the <15μm (6.1Ø) fraction of Recent muds off southern Florida. They were able to demonstrate that disintegration of lightly calcified green algal could account for all the mud of the Inner Florida Reef Tract and a third of the mud in northeastern Florida Bay since the flooding 4,000-10,000 years ago. The authors proposed that there were other sources of lime mud, including biological and mechanical breakdown of skeletal products in the reef tracts, and suggested that the resultant debris could be transported.

Land (1970) demonstrated the role of calcareous red algae and serpulid worms in the production of lime mud off Jamaica. Unfortunately, he gave no upper size limits for the described sediments. From experimental data, Land suggested that the rate of production of lime mud ($180g/m^2$- year) is comparable with rates of accumulation of ancient platform carbonates. However, he did not propose that this significant source of Recent mud was a major source of ancient calcilutites. The poor comparison between recent lime 'muds' and ancient calcilutites (grain size <4μm) has been observed by Scholle & Kling (1972) and Stieglitz (1972).

Stieglitz (1972) used a scanning electron microscope to identify nearly all grains 15-62μm in size and some as small as 4μm. He found no evidence of inorganic precipitation; the bulk of the material was recognisable grains of organic origin. He suggested that destruction of green algae was the most important source of mud and that biological abrasion was of secondary importance. Stieglitz (1973) proposed that the disintegration of skeletons, controlled by ultrastructure, provided the needles observed in the mud. Calcareous green algae are the most important source of aragonite needles, and red algae and porcellanous foraminifera provide high-and low-magnesium calcite.They can be an important source of mud in areas of little green algal growth.

Neumann & Land (1975) continued to study the algal source of carbonate muds. They have shown that the calcareous green algae, inhabiting shallow water marine lagoons on the Great Bahama Bank, were capable of supplying more than the mass of aragonite mud (<62μm) which has accumulated in adjacent areas. However, the "mud" fraction (<62μm) of some lime muds contains 10.6-19.5% high-magnesium calcite and commonly 1-3% low-magnesium calcite (Husseine & Matthews, 1972). Clearly, there has to be more than one organic source of fine carbonate sediment contributing to these "mixed" muds. Transported abrasional products from shelf margins, red algal debris and blue-green algal tubes are suggested sources of magnesium calcite.

Finally, not all aragonite and calcite muds can be explained in terms of organic debris. These muds may be organically precipitated, but their formation is restricted to extreme temperature and elevated salinities (Milliman, 1970).

The main constituents of the carbonate rocks of the four studied formations combine in different proportions to give distinctive rock-types. These rock-types roughly fall into broad groups comparable with the facies of Ramsbottom (1973, Fig.1).

I Thickly bedded, dominantly pale grey calcarenites.

II Medium to thinly bedded, mid to dark grey, often shaly calcarenites and calcisiltites.

III Thinly bedded calcilutites and calcisiltites of variable colour.

The first group compares lithologically with Ramsbottom's pale thicker-bedded bioclastic limestone. His dark thinner-bedded bioclastic limestone probably is most closely comparable with the limestones of group II. The calcilutites and calcisiltites of group III, although they differ in colour, are lithologically similar and so have been placed together. They probably compare with Ramsbottom's calcite mudstone.

All the groups can be divided into subgroups depending upon the dominance of different grain-types. These are discussed below. Clastic and carbonaceous rock-types are common constituents of the four studied formations, particularly where they overlap the Lower Palaeozoic rocks. These rock-types vary considerably and warrant separate category status. The clastic and carbonaceous rock-types of the studied formations are treated separately using the following categories:

IV Rudites
V Arenites
VI Shales
VII Coals.

8.1 Thickly Bedded, Dominantly Pale Grey Calcarenites (I)

These limestones form the major proportion of the studied part of the Great Scar Group. Their paleness contrasts sharply with the dark colour of the thinly bedded calcarenites and calcisiltites (section 8.2.). The pale colour is due to a number of factors including the presence of abundant crinoid ossicles and sparry calcite cement, and a low organic matter content and generally sparse clastic impurities.

8.1.1. Intraclastic calcarenites (I.i)

This is the most common rock-type in the Great Scar Group, comprising the bulk of the Thornton Force Formation and the Horton Limestone. It is also locally developed in both the Douk Gill Formation and the Raven Ray Formation. As such, intraclastic calcarenites are present over most of the study area, although those of the Horton Limestone are frequently poorly exposed. They are laterally extensive; intraclastic calcarenites pass locally into marine or non-marine clastic deposits or oolitic, bioclastic or lithoclastic calcarenites (Thornton Force Formation) or into and interfinger with, featureless and fenestral calcilutites (Horton Limestone).

Although this rock-type has a wide distribution in both time and space, the bedding characteristics remain relatively uniform throughout. The limestones are well bedded, beds generally between 0.35m and 1.00m thick. Bedding surfaces are usually flat, with wavy bedding planes coated by thin shales, being most common in those limestones near the unconformity. Low-angle cross-lamination, with lamina cosets approximately 0.25m to 0.35m thick, is common. Cross-lamination is poorly defined, particularly in the Horton Limestone, except where there has been slight weathering of newly exposed rock-faces. The presence of frequent laminae of sand and granule size lithoclasts in the Thornton Force Formation emphasizes the herringbone cross-lamination in weathered faces.

Much of the carbonate grain content is unrecognisable at outcrop. Only at Nappa Scars are large calcarenite intraclasts (up to 150mm) clearly distinguished from the sparsely lithoclastic calcarenite matrix. In the field, sparse crinoid ossicles, brachiopods, gastropods and solitary or colonial corals occur, although, in many outcrops of intraclastic calcarenite no recognisable fossils are recorded. In thin section, intraclastic calcarenites are moderately well to very well sorted, fine to medium (locally coarse or very coarse) grained carbonate sands composed predominantly of intraclasts. Bioclasts and rare ooliths may also be present. Intraclasts (Folk , 1959) comprise fragments of penecontemporaneous, partially lithified sediment which have been eroded from ajoining parts of the sea floor and reconstituted to form new sediment. As such, the term includes clasts of lime mud of uncertain origin (pelletoids, approximately 0.2mm in size), grapestone (Illing, 1954) and algal-coated micrite clasts, as well as the usual mud clasts. The term pelletoid has been used for all micrite grains less than 0.2mm in size. According to Folk (1959), pellets are round or ovoid aggregates of microcrystalline calcite ooze devoid of any internal structure. In the limestones of the Great Scar Group, there are many grains with similar physical characteristics to those described by Folk, but they are frequently associated with similar, much larger grains for which a faecal origin is improbable; which are true intraclasts. Indeed, the pelletoids may be small, more rounded intraclasts.

A number of different varieties of intraclast have been observed in thin section. The most common variety is rounded grains of microcrystalline calcite between 0.08mm and 3.00mm in size. Sparse larger micrite clasts up to 15mm in length have been observed although intraclasts greater than 2mm are uncommon. Most of these micrite intraclasts preserve faint internal boundaries (pellets, pelletoids?) and lithoclasts (quartz, feldspar, graywacke, slate) and bioclasts are incorporated within many of them. Sparse micrite clasts enclose patches of sparry calcite which probably formed by replacement of pre-existing bioclasts already incorporated within the intraclast. There has been minor diagenetic alteration of the micrite of the intraclasts to microspar. Some micritic intraclasts show pinching and distortion, suggestive of plastic deformation; these intraclasts must have been only partially lithified at the time of their deposition. Grapestones (Illing, 1954) are rare and localised in their occurrence. They vary in size from 0.35mm to 10mm and have irregular boundaries. Commonly they are less than 1mm in length, being poorly formed. They appear to be composed of micritised ooliths or altered bioclasts bound together by lime mud and sparry calcite cement, and frequently they are associated with local concentrations of superficial ooliths (Leighton & Pendexter, 1962). Algal-coated intraclasts (oncolites?) are not common, occurring only in the upper part of the Thornton Force Formation. They are easily identified by their size (up to 3mm), irregular shape and poorly preserved, patchy laminated coats. Calcarenitic intraclasts are restricted to the Thornton Force Formation at Nappa Scars and the Douk Gill Formation at Douk Gill and they vary greatly in size and shape (Plates 4d, 18a, 19d,). The largest clasts are cobble size (up to 150mm) and most irregularly shaped, although the clasts show signs of abrasion. Associated with these rounded and commonly well sorted intraclasts are common fragments of echinoderms, brachiopods, molluscs and dasycladacean algae. There are sporadic occurrences of broken, abraded and well rounded bioclasts, partially mud coated, behaving in a similar manner to the micritic intraclasts. The skeletal debris, and sparse whole foraminifera, are in the same size-range as the rounded intraclasts.

The rock-type is normally composed entirely of carbonate grains; however, where intraclastic calcarenites occur not far above, or are lateral equivalents to, clastic rocks or unconformably overlie Lower Palaeozoic basement, non-carbonate material is incorporated within the sediment. This commonly takes the form of lithoclast-rich lamina cosets with the slate, graywacke and quartz clasts being approximately the same size as the rounded intraclasts and bioclasts. Locally, pebble or cobble size lithoclasts are incorporated within the sediment or stranded on bedding planes. There has been sparse, sporadic post-depositional mixing of the rock-types by burrowing organisms.

The diagenetic histories of the intraclastic calcarenites are simple; there is no lime mud in the matrix. Syntaxial overgrowths on crinoid ossicles dominate the sparry calcite cements. Many of the outer parts of the overgrowths are slightly ferroan (Lindholm & Finkelman, 1972), post-dating the first cement. Similar alternating layers of non-ferroan and ferroan calcite in overgrowths were described by Evamy & Shearman (1965). The remainder of the pore spaces are occluded by coarse blocky calcite spar. The cement is coarsest (0.85mm-15mm in diameter) in the lithoclast-bearing intrasparites (Folk, 1959;1962) whereas it is fine and dusty (crystal size as small as 0.04mm) in the fine grained intrasparites. Cementation was early, and there has been little compaction.

It is difficult to draw a boundary between calcite micrite and sparite; a boundary strictly on grain size is not satisfactory because of the different origins of the calcite. Sparry calcite can normally be identified by its clarity and coarseness in thin section, and by the physical characteristics listed by Bathurst (1975). Sparry calcite generally forms as a simple pore-filling cement precipitated in place within the sediments. The grain size of the crystals of the spar depends upon the size of the pore space and the rate of crystallisation. In the Great Scar Group, the crystal size of the sparry calcite varies between 0.04mm and 1.5mm; crystals of 2mm or more have been observed in limestones with larger pore spaces. Primary sparry calcite, a direct precipitate, must not, however, be confused with neomorphic spar which is formed by recrystallisation of finer carbonate grains or microcrystalline calcite.

There has been minor dolomitisation of the intraclastic calcarenites of the Horton Limestone in Kingsdale. Sparse, well formed dolomite rhombs (Plate 21e) have replaced parts of both the sparry cement and the micritic intraclasts.

8.1.1.1. Environment of deposition

Ramsbottom (1973) interpreted pale, thicker-bedded bioclastic limestones in terms of their relative depth of deposition in comparison to other broad limestone facies. No absolute depth limits have been proposed for this group of limestones. They formed in deeper water than the calcite mudstones and oolites which are local lateral equivalents. This has important environmental significance in interpreting the overall setting in which these limestones were deposited. There are no deeper water, dark thinner-bedded bioclastic limestones (Ramsbottom, 1973) and massive to medium bedded strata and cross-lamina cosets up to half metre thick are common features in the seaward parts of shelves and downslope from beaches where currents exist (Thomson & Thomasson, 1969; Stricklin & Smiths, 1973).

Flugel (1982) describes two types of intraclast which are common in shallow water; mudclasts created by erosion of desiccated supratidal, partially lithified micrites and calcarenite clasts formed by mechanical erosion of lithified beach rocks within the intertidal and supratidal zones. Wilson (1975) suggests two alternative mechanisms for the formation of micritic intraclasts (and pelletoids) which are so abundant in the Great Scar Group; (i) erosion of compacted carbonate mud to form clasts which on subsequent redeposition often show signs of plastic deformation and (ii) desiccation of intertidal and supratidal mud flats creating mud curl flake intraclasts. No mud flake intraclasts have been observed in the intraclastic calcarenites and supratidal conditions appear to have been restricted to the period of formation of the Moughton Calcilutite Member (section 8.3). Bathurst (1966), in his paper on micrite-coating describes pseudo-intraclasts produced by total micritisation. However, it is most probable that the abundant micritic intraclasts and pelletoids observed in the Great Scar Group were formed by periodic destruction of subtidal or lagoonal muds, prior to total lithification of the sediment. Very strong currents, such as those induced during storms, would be require to overcome the cohesive strength of the clay-size sediment. No record of a lagoonal or subtidal environment is preserved in the sedimentary sequence.

The mechanism described by Flugel (1982) for the creation of calcarenitic intraclasts is acceptable for those of the Douk Gill Formation at Douk Gill. There, calcarenitic intraclasts were observed overlying very shallow water, possibly intertidal, sediments. In such an environment, mechanical erosion of beach rock is a common feature. It is, however, more probable that the calcarenitic intraclasts observed in the Thornton Force Formation at Nappa Scars were created by the disintegration of shallow channel-fills of cross-laminated, intraclast calcarenite (Plate 4b and 4d).

Illing (1954) found the origins of grapestone problematical. He suggested that these composite grains developed by progressive aragonitic cementation of friable aggregates of calcareous silt particles and that further cementation tended in join the grains into lumps. Corrosion prevented excessive growth of the lumps and the typical bottom sediment is a well sorted medium grade sand. Controlling factors on the formation and distribution of these grapestone sands were tidal currents of cooler oceanic water and the velocity of the currents (Illing, 1954). A detailed study of the mechanism of grapestone formation was completed by Winland & Matthews (1974). The initial binding was by growth of algae and encrusting foraminifera in the substrate. Later cementation and infilling may be the result of continued growth of these organisms in the interior of the aggregates and chemical or biochemical precipitation of cement. Specific conditions are required for grapestone formation including the supply of firm grains, conditions for subtidal algal mat growth and the growth of encrusting organisms, periods of bottom mobility, and sufficient velocity and turbulence in the water to prevent the deposition of lime mud (Winland & Matthews, 1974). The grapestones of the Bahama Banks are made from altered ooliths; the identity of the grains in the Great Scar Group is masked by intense alteration; however, ooliths are a distinct possibility.

The origin of pelletoids is problematical (Milliman, 1974). Faecal pellets are deposited in modern environments by a variety of animals including polychaete worms, some crustaceans and gastropods. If pelletoids are faecal in origin, then their size is not a measure of current energy because they are friable and their original size is controlled by the animal making them. If pelletoids are faecal in origin then their presence is indicative of a low energy environment. However, if pelletoids are closely associated with rounded intraclasts then they indicate a high energy, shallow water environment, where turbulence subjected the mud aggregates to continual abrasion. Alternatively, many pelletoids are formed by recrystallisation of other particles such as skeletal grains or ooliths (Milliman, 1974). If recrystallisation is advanced, and there is no vague residual texture, then pelletoids may closely resemble pellets.

The sorting of the clean washed intraclastic calcarenites is such that skeletal debris and intraclasts are in the same size range. Thus the two grain types have behaved as hydrodynamically equivalent particles. The dominant type of skeletal grain is crinoid remains, which had high inherent porosity. These would only have behaved as having equivalent specific gravities to the intraclasts if carbonate had already been precipitated in the pores. This could not have take place if the crinoid ossicles had been supplied directly from newly dead individuals. They could only have been derived from a previously deposited carbonate sediment, and in reworking that sediment good sorting was achieved. Significantly, only grains within a limited size range were supplied; lime mud and coarser debris either were not supplied to, or were not deposited within, the area. Folk & Robles (1964) observed that the best sorted calcarenites of the Isla Perez, Yucatan, were fine to medium grained, occurring where waves were the gentlest. The nature of the sorting of the sediment reflects the variations in sorting efficiency of currents and waves. For each particle size there is an optimum strength of either waves or currents which will produce the best sorting; currents or waves either stronger or weaker than this produce poor sorting. Persistent waves or currents of optimum strength will produce the best sorting. The best sorting is seen in the fine grained to medium grained intraclastic calcarenites of the Horton Limestone and the upper part of the Thornton Force Formation. The limestones comprise well sorted and rounded, micritic intraclasts and occasional bioclasts.

The grains of the intraclastic calcarenites appear to be well rounded. However, because of the inherent roundness of ooliths and pellets, only bioclasts are good indicators of abrasion; intraclasts are relatively soft and round very quickly. It is probable that different types of bioclast, even if of the same size, round at different rates because of differences in their shell microstructure. At the same time, coarser bioclasts almost certainly round more quickly than finer ones. Significant rounding of shells takes place only on beaches exposed to surf action (Folk & Robles, 1964) where the supply of organic material is not sufficient to overwhelm the rounding processes. There is much evidence for abrasion of bioclasts in the Thornton Force Formation. Bioclasts are broken and costae have been removed from crenulate brachiopods; the broken clasts commonly have rounded terminations. Lithoclasts, common in the intrasparites close to the unconformity with underlying Lower Palaeozoic rocks, are also well rounded and sorted, frequently being in the same size range as the associated carbonate grains. The dominant grain size is 0.2mm and so compares closely with the results of Hoskins & Sundeen (1975). They showed that the grain size of the source rock does not determine the grain size of the derived sediment; the most common grain size mode of sediment derived from the Biorka Island tonalite, and the primary grain size mode of biogenic carbonate accumulating in the same area, are both at about 0.2mm. As two different sediments with different sources have the same prominent grain size mode Hoskins & Sundeen (1975) suggested that selective size sorting had occurred during transport. Grains 0.2mm in size are of the size most easily reworked. Weak currents are able to initiate movement of this grain size whilst being unable to move either finer or coarse particles which may be present.

Thus the intraclastic calcarenites of the Great Scar Group are closely comparable with the sands of Folk & Robles (1964) and Hoskins & Sundeen (1975) in that they reflect the ability of gentle currents to achieve good sorting of this particular grain size.

The depositional characteristics of the intraclastic calcarenites are similar to those of the Lily Bank sand shoal in the Bahamas as described by Hine (1977). Lily Bank is a shallow water, oolitic sand bank which has been in existence since Pleistocene times. Hine (1977) suggested that storms shape the bank whereas the normal ebb and flow of the tides merely modify its shape. Winds are subordinate to tides as agents of bank construction (Basan, 1973). Level, duration, and direction of physical energy flux (storms, tides, waves) strongly control the distribution of bank-margin facies (Hine & Neumann, 1977). Margins of contrasting orientation and thus exposure should, correspondingly, exhibit contrasting sediment facies. However, tide-dominated coast lines e.g. Lily Bank, mask the windward or leeward effects (Hine & others, 1981). Ultimately, tide-dominated margins should support large, low insular masses which would be traversed by formerly active tidal channels.

Lily Bank is cut by a series of channels transverse to the shoal, created by storm generated currents, which funnel the ebb and flood of the tide. The flat-topped areas between channels are called shields.

Since much of the ebb influence is concentrated in narrow, deep channels, most of the surface area of the sand body (the shield) is flood dominated. On Lily Bank the dominant bedform is the subtidal sand wave which is symmetrical in the shield areas and asymmetrical elsewhere. Superimposed on the sand waves are ripples and megaripples which develop and orient themselves according to the stage and direction of the tides. Minor bedforms are responsible for the sediment transport and the morphology (low-angle cross-lamination) of the larger sandwave (Hine, 1977).

Under normal (non-storm) conditions, the tidal currents are not sufficiently dominant in either the flood or ebb direction to cause wholesale movement of the entire sand body. Although sand is constantly being transported toward the shield area by flood-oriented sand waves, and the sand grains are in constant motion, responding to tidal currents and wave motions within the shield area, the shield area itself and the shoal boundary probably does not migrate (Hine, 1977). However, during major storms, the bankward flow would destroy the shield area by rapid sediment transport in the form of cuspate megaripples on sandwaves or even the plane bed, antidune phase of the upper flow regime. High velocity bankward flow would carry the sand out into the shelf lagoon (Hine, 1977). During post-storm recovery, the symmetrical sand waves would be re-established by the equal flood and ebb flow, thus forming a new shield (Fig 8.1). It has been observed that the large-scale features of sand shoals do not change over a several-year period when there are no large storms (Ball, 1967; Bathurst, 1975).

The tidal channels and the topography of the bed forms control the environment of deposition, resulting in rapid changes in depositional regime over short distances as seen in the Thornton Force Formation. Within the troughs of the symmetrical sand waves and on the floors of small channels, a low-density community of sea grasses, green algae and pellet-producing organisms exists. Colonisation and sub-sea cementing processes (including the formation of grapestones) occur late in the symmetrical sand wave buildup which creates a low physical energy environment within the trough. At the same time, well sorted

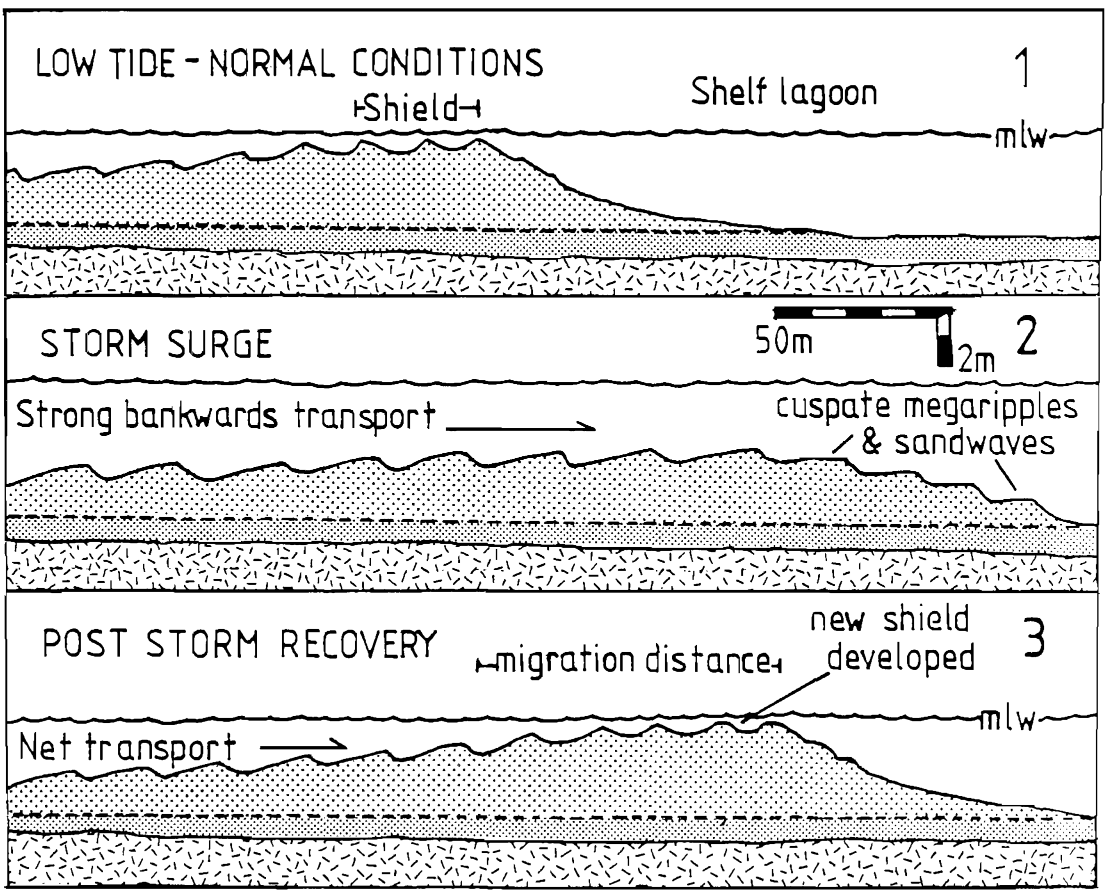


FIGURE 8.1. Inferred mechanism of sand body migration. Diagram 1 depicts normal conditions. Diagram 2 illustrates shield destruction by strong, bankward, storm generated flow. Diagram 3 shows redevelopment of the shield area in its new location farther in on the shelf lagoon floor. After Hine, 1977.

calcarenites are being deposited on the sand waves, above surge base (Hine, 1977).

Hine (1977) describes the dominant zone where aggregate grains are found as being the zone of relict bed forms. There is an adequate supply of firm grains and the bedforms are covered by sea grasses and green algae indicating that there is no sand transport by normal tidal flow (Scoffin, 1970).

The locations of Lily Bank and other comparable sand banks in the Bahamas appear to have been influenced by a rock floor high, although the major controlling factor is the influence of oceanic waves with the shelf break (Enos & Perkins, 1978). The bottom topography, through its influence on currents, controls sand body geometry, internal structure, composition and texture (Ball, 1967; Basan, 1973). Sand bodies once formed are themselves bottom topographic features that influence the character of associated sediment accumulations and may, by means of a feedback mechanism, exert some influence on their own characteristics (Ball, 1967). Antecedent topography, in the form of broad, bank-edge reentrants, has also played a key part in determining the location, size and orientation of Lily Bank shoal (Hine, 1977). Similar features probably influenced the sedimentation of the intraclastic calcarenites of the Thornton Force Formation and, to a lesser extent, the Horton Limestone.

Hine (1977) suggested that the early environment of deposition probably resembled the modern, shallow water, low energy, lagoonal lime mud dominated areas such as those of Florida Bay (Enos & Perkins, 1976) or the Bight of Abaco behind Great Abaco Island (Neumann & Land, 1975). With gradually rising sea-level, water exchange on and off the bank became more vigorous and the energy level within the bank increased, and tidal bars or linear sand ridges and a sand-wave field began to form. The sea-level continued to rise, and tidal and storm-generated flow velocities decreased as the reentrant throats increased in cross-sectional area. Consequently, the sand ridges became inactive, were colonised and eventually stabilised. Aggregate grains (grapestone), indicative of intermittent high and low energy periods (Winland & Matthews, 1974) were formed at this time. Only the shield sand waves were able to remain active.

Simultaneously, tropical storms passing through the area generated strong currents which were funnelled by any topographic low area along the length of the sand body thus forming the channels traversing the shoals. Since most storms activity provided net bankward energy flux, the sand body has responded by migrating bankward over the lagoonal sediments. Based upon the location of the bankward end of the linear sand ridges, the shoal has migrated approximately 2.5km since its inception at approximately 4,000yr BP (Hine, 1977). Similar depositional controls and a similar depositional history are proposed for the sediments of the Thornton Force Formation. There are, however, two significant differences. Firstly, Lily Bank is an oolitic sand shoal whereas the calcarenites of the Thornton Force Formation and the Horton Limestone are intraclastic. It is probable that the conditions in the depositional environment were not conducive to oolith-formation. Secondly, there are no remnants of the early stage lagoonal environment preserved in the stratigraphic record. The lagoonal sediments appear to have been totally destroyed by periodic storm events, and incorporated, as abundant intraclasts, within the shoal sediments.

An alternative analogue (in terrigenous sand) is provided by Clifton & others (1971), since there can be no doubt that these sediments, in part, impinge on a coastline. They describe the sedimentary structures typical of a non-barred high energy coastline. This could account for the channel-fills of calcarenite and their reworking into large intraclasts, particularly by undermining during reworking. A muddy, cliffed coastline (to account for the mudflow deposits, section 8.4, p222) would preclude the possibility of extensive tidal lagoons, though minor ones could exist in the lee of rocky headlands.

8.1.2. Oolitic calcarenites (I.ii)

This rock-type has a very limited distribution. Ooliths have been observed in the Thornton Force Formation in Kingsdale and Chapel-le-Dale, and in the Douk Gill Formation and Horton Limestone of parts of Ribblesdale (Plate 19). Rare altered and micrite coated ooliths were observed in the Raven Ray Formation of Chapel-le-Dale.

The bedding characteristics of the oolitic calcarenites are very similar to those of the intraclastic calcarenites; individual beds are rarely thicker than 1.00m and comprise 0.25m to 0.35m thick low-angle cross-lamina cosets. The oolitic calcarenite beds occur in the lower part of each formation and grade laterally into, and are intercalated with, intraclastic calcarenites. Oolitic calcarenite rarely comprises move than two beds thickness at each field exposure.

Most of the ooliths observed are not true ooliths; they are superficial ooliths (Leighton & Pendexter, 1962) or grains in which the thickness of accretionary coating is less than the radius of the nucleus. The minimum oolith size is approximately 0.25mm, consistent with that observed by Bathurst (1975). The largest ooliths are approximately 0.7mm in size. Superficial ooliths lack the sphericity of true ooliths because their shape is governed by that of the nucleus. Most superficial ooliths have only one or two coats resulting in subrounded, frequently elongate, grains.

Oolitic coatings occur around many grain types in the Great Scar Group. The most common nuclei are rounded micritic intraclasts, bioclasts and occasional detrital quartz grains. Intraclastic and endothyrid foraminifera nuclei often show thicker and more oolitic coating; these nuclei are well rounded and roll easily.

Oolitic grains usually comprise about 45% of the rock and rarely up to 75% of the rock. As such the calcarenites, which are usually dominated by well rounded, well sorted intraclasts, are oointrasparites (Folk, 1962) and poorly washed oointrasparites. Their diagenetic histories are relatively simple; cementation was early and there has been little compaction of grains. The earliest cement was an isopachous fringe occurring on all grains except echinoderm fragments which developed syntaxial overgrowths. Final pore-filling was with blocky sparry calcite. In the finer grained oointrasparites the pore spaces were smaller and filled with slightly dusty sparite cement.

Oolitic grains have been altered during diagenesis. Neomorphism of micrite to microspar is ubiquitous to the intraclastic nuclei and many of the oolitic coats have been partially micritised by attack of boring algae. Usually, the distinctive, well rounded outlines and faint traces of oolitic coats remain. Diagenesis of the ooliths of the Douk Gill Formation is more complex. The true and superficial ooliths have been replaced by ferroan calcite, possibly indicating an original magnesian calcite composition. Replacement by ferroan calcite was in situ in a reducing environment rich in ferrous iron (Richter & Fuchtbaüer, 1978; Richter, 1980).

8.1.2.1. Environment of deposition

The origin of ooliths, distinguished by their possession of an outer coat or cortex of concentrically laminated cryptocrystalline calcite within which a nucleus can be recognised, is still problematical. Many authors have suggested that they are direct products of organic activity or that their growth is necessarily dependent on this (Bathurst, 1975). Newell & others (1960) proposed that algae present deep in the cortex had acted as a cohesive in the accumulation of aragonitic debris whereas Vaughan (1914) suggested that marine ooliths formed in aragonitic muds as a direct result of the vital activities of denitrifying bacteria. Inorganic precipitation has been proposed as a suitable mechanism for oolith-growth provided specific conditions were met. Illing (1954) and Newell & others (1960) suggested that inorganic precipitation from a supersaturated colloidal suspension could take place in conditions of elevated temperature, an abundant supply of calcium carbonate, a good source of nuclei and agitation, as long as topographic and hydraulic controls were sufficient to keep the ooliths in their growth-promoting environment. The common upper size limit of ooliths is 1mm. Carozzi (1960) suggested that at 1mm ooliths had reached their upper size limit and were too big to be moved by local currents.

Bathurst (1967a) observed that ooliths from Bimini and west Andros had much thinner oolitic coats than those of Browns Cay (largest marine ooliths). Bathurst (1967a) proposed that there is a correlation between agitation and growth rate; the more a grain moves the faster it will grow, i.e. the rate of growth is proportional to the amount of time spent by the oolith in motion. Good sorting can partially be attributed to this process (Bathurst 1968). Small ooliths rapidly become larger because they are the most mobile and, therefore, spend more time in motion than the larger grains. The growth of larger ooliths is slower because, as they grow, they spend a progressively smaller proportion of time in motion. One other factor determining the upper size limit must be the time at which the ooliths are finally buried. The more rapid their accumulation, the quicker their burial and the smaller the grain size.

There is a further hydrodynamic problem. Tiny grains are not able to reside on oolith shoals as their cessation velocities are too low. If such grains were introduced they would be immediately winnowed out (Richter, 1983). It has been suggested that ooliths begin to grow in deeper water and move towards the crest of the shoal as they become larger. Newell & others (1960) observed that the proportion of coated grains increased towards the crests of Browns Cay and, at the same time, the number of lamellae on the nuclei increased. Consequently, newer, smaller ooliths must have been growing in the deeper, less turbulent water, below the 2m depth at which Newell & others (1960) found a sudden decrease in the proportion of coated grains. At some point the rate of gain by oolitic growth will equal the rate of loss by abrasion, thus fixing a maximum grain size. This maximum size will be controlled largely by the intensity of turbulence of the shoal; however, it is a considerable paradox that turbulence can simultaneously assist the growth of ooliths (by encouraging motion) and limit their growth by abrasion (Richter, 1983).

The oolith/aggregate assemblage is essentially restricted to chlorozoan areas (Lees, 1975) and is inhibited by minimum temperatures below 15°C. However, salinity and temperature may compensate each other because the chlorozoan association is inhibited at high temperatures if the salinity falls below approximately 31‰ and yet it develops at relatively low temperature where salinity is sufficiently high (Richter, 1983).

The ooliths observed in the Great Scar Group are superficial ooliths (Leighton & Pendexter, 1962) occurring at very few localities. Rarely do they form the dominant carbonate grain of these calcarenites. However, they are useful palaeoenvironmental indicators. Their presence implies that conditions suitable for oolith-generation existed within the Dinantian environment, that is supersaturation of the surrounding seawater, supply of suitable nuclei, agitation of the grains, maintenance of the growth-promoting environment (Weyl, 1967) and water depths of less than 5 metres. Hard peloids and polygenetic grains of micrite commonly form at depths less than 10m (Ginsburg & James, 1974).

Superficial ooliths may not have been able to develop into true ooliths because of one or more of a number of reasons. It is probable that conditions suitable for oolith-growth were only locally developed or that such conditions did not persist for long. The oolitic calcarenites occur in the lower parts of the various formations, deposited in the early transgressive phase; further transgression could have resulted in an environment too deep for oolith-generation. Alternatively , it is possible that the ooliths were introduced from a more favourable environment by currents or waves. Imbrie & Purdy (1963) considered that ooliths comprising less than 90% of the grains of a sample were not deposited at the site of their formation. The number of ooliths decreases rapidly away from that site. It seems probable that the ooliths observed in the Great Scar Group were derived from more favourable environment, of which no sediments have been preserved, and washed into the intraclastic calcarenites by storm surges. Finally, superficial ooliths will result if, not long after their formation, the grains were buried by intraclastic shoal sediments.

Considering the mobile sand body model proposed for the intraclastic calcarenites, there is very little sand transport from one sand wave to another on the shield area of the sand body (Hine, 1977) during non-storm conditions. Consequently there is probably insufficient grain agitation, the water depth may be too great or the surface may be too quickly colonised by thin films of subtidal algat mat (Bathurst, 1967b), to generate ooliths over the whole of the shield area. New oolitic grains, formed in more favourable environments, could only be introduced during storm events, implying the existence of oolith shoals farther offshore, up the onshore storm tracks.

8.1.3. Bioclastic calcarenites (I.iii)

This rock-type is not common in the Great Scar Group. It is locally developed at the base of the limestone sequence where limestones succeed coarse clastic deposits or unconformably overlie Lower Palaeozoic rocks. The rock-type is best seen in the Thornton Force Formation and Raven Ray Formation of Chapel-le-Dale.

Bedding characteristics are similar to those of the intraclastic calcarenites (section 8.1.1.), although cross-lamination is not so clearly defined. The medium to thick beds generally have flat bounding surfaces which are occasionally coated by thin shales. The grain size of the rock-type is extremely variable from bioclasts almost cobble-sized to very fine sand.

Crinoid ossicles and brachiopods are ubiquitous and small, reworked colonial corals are frequently seen. Also commonly present, but seen only in thin sections, are foraminifera, green algae, molluscs and sporadic fenestrate bryozoans. Sparse bioclasts of red algae also occur. Many of the bioclasts are heavily altered, having thick micrite envelopes. By analogy, the presence of abundant, broken and abraded, thick shelled brachiopods and coarse crinoid ossicles is indicative of deposition in an agitated, normal marine environment (Heckel, 1972). Brachiopods probably occupied all marine ecological niches but were most abundant in shallow continental seas (Horowitz & Potter, 1971) and crinoids, although now inhabiting deeper environments than in the past, required firm substrates, clear, shallow water and good circulation.

Corals and bryozoans are strictly marine, although some may tolerate wider salinities. Corals, being sessile and suspension feeders, require a good circulation and a lack of turbidity. Most colonial corals are hermatypic, possessing symbiotic unicellular algae in their tissues. Consequently they are restricted to the photic zone and require warm tropical waters. Bryozoans are not common in the Great Scar Group, but they do occur, with occasional corals, in fragmental form. They require a firm substrate for attachment and will encrust other organisms such as crinoid ossicles (Plate 17f) if no other firm substrate is available (Heckel, 1972). Being suspension feeders, bryozoans also require clear, slightly agitated seawater and grow best in areas of slow deposition.

Molluscan debris, ostracods and foraminifera are not indicative of any particular depositional environments. Molluscs and ostracods have colonised most aquatic environments and foraminifera, because of their size (commonly 0.2mm), shape and buoyancy, are easily reworked from their original environment.

In contrast to the above, dasycladacean algae are indicative of very specific environmental conditions (Ginsburg & others, 1971). Dasycladacean algae, present throughout the pale grey calcarenites of the studied part of the Great Scar Group, are erect, articulated segmented forms with radiating pores which produce calcispheres or fruiting bodies (Wilson, 1975). At present, modern forms are restricted to shallow, warm, tropical waters with salinities up to 50-60‰ (Wilson, 1975). They are most abundant, forming "meadows", in slightly agitated, protected environments just below wave base or in lagoons to a depth of

5m. Dasycladacean algae can occur to a depth of 90m where the waters are very clear. Other calcified algae are rare in the Great Scar Group, although Garwoodia and Solenopora have been identified (Wood, 1941a).

The distribution of modern green algae, including Dasycladaceae, enables them to be used as indicators of warm, quiet, shallow water regions near the coast or in lagoons. Consequently, the presence of fragments of the elongate cylindrical thallus of the dasycladacean alga Koninckopora (similar to the modern Bornetella, Wood, 1941b) in bioclastic and intraclastic calcarenites is indicative of deposition in a shallow subtidal environment either below wave base or sheltered from tidal and wave activity. This conflicts with the interpretation of the coarse grain size, fragmental and abraded nature of the bioclasts and of the cross-lamination as indicators of a turbulent environment. Since many of the green algal fragments are enclosed within micritic intraclasts or are heavily micritised, they clearly entered the turbulent environment as bioclasts or intraclasts derived from a muddy environment in which the sedimentation rate was slow. These clasts are considered to be reworked remnants of lagoonal sediments destroyed by periodic high energy events and overwhelmed by calcarenitic shoal sands (p.188).

Micritic crusts with a clotted algal fabric (Plate 16) are found cementing intraclasts and bioclasts. These crusts, patchily developed near the top of the Thornton Force Formation, are easily identified in thin section by their colour density and lamination. The crusts are considered to represent patchy cementation of less-active parts of the calcarenitic shoal sands by a thin film of shallow subtidal blue-green algal mat (Dravis, 1979). Patterns of cementation (hardground formation) apparently result from the interaction of tidal bar surface topography, local hydrology and stabilization of the surface by algal mats (Dravis, 1979).

Micritised bioclastic grains or cortoids (Flugel, 1982) are abundant in the bioclastic calcarenites and intraclastic calcarenites. Micrite envelopes coat many bioclast types, particularly echinoderms and punctate brachiopods. The irregular nature of the coats indicates that the layers are not adherent mud but probably result from infilling of algal borings. A number of mechanisms have been proposed for the formation of micrite envelopes. The most commonly accepted mechanism is micritisation (Bathurst, 1966; cryptocrystallisation, Milliman, 1974), whereby micro-organisms attack and bore surfaces of bioclasts, especially in tidal zones, the tiny voids are infilled by (bacterially precipitated?) micrite after the death of the organisms. If the process is able to continue over a long period, a micritic replacement structure arises which is centripetally rather than centrifugally orientated (Flugel, 1982). Boring organisms include some forms of bacteria, photosynthetic cyanophytes, eukaryotic green and red algae, as well as heterotrophic fungi (Bathurst, 1966; Friedman & others, 1971; Rooney & Perkins, 1972). In thin section there usually is an irregular boundary between the bored bioclast and the micrite envelope. The complete process of micritisation consists of loosening the surface, abrading and rounding the particles and later formation of micritic pelletoids (Illing, 1954; Purdy, 1968; Kendall & Skipwith, 1969).

Micritisation, as described above, is probably temperature-dependent. According to Gunatilaka (1976) no cortoids originate from carbonate particles bored by thallophytes in cooler seas (Ireland). This is due to the fact that the micrite in the microborings does not originate by way of bacterial metabolic processes but rather as a cement dependent on (higher) water temperatures and the supersaturation of calcium carbonate.

Several alternative mechanisms for the formation of micritised bioclasts have been proposed. Loreau (1970) suggested that micrite envelopes of anhedral nannocrystals, induced by organic films, form on the surface of particles. Selective dissolution of fragments of organic shells due to the different solubilities of aragonite and magnesium calcite, leading to the formation of residual micrite has been suggested by Alexandersson (1972) and Winland (1968).

The formation of "constructive" micrite envelopes has been suggested by Kobluk & Risk (1977). The intergrowth of externally calcified filamentous algae on the surface of carbonate particles leads to the formation of micrite envelopes which protect the particle from being destroyed. These "constructive" micrite envelopes are not easily distinguished from the "destructive" micrite envelopes described by Bathurst (1966). An important control on the development of constructive envelopes is the degree of agitation of the sediment substrate. Constructive envelopes, as well as destructive envelopes, will probably not form in agitated conditions (Alexandersson, 1972; Kobluk & Kahle, 1978).

The final mechanism proposed is decomposition of indigenous organic matter and simultaneous replacement by micrite of both the original organic matter and the clay-sized carbonate particles (Purdy, 1968; Burgess, 1979). This would explain partially micritised grains in which the original fabric is still visible.

Having observed that various abundances of micritised bioclasts appear at different water depths, some researchers (Perkins & Halsey, 1971; Rooney & Perkins, 1972; Swinchatt, 1969) have used micritic carbonate bioclasts as palaeobathymetric indicators of water depth, usually postulating their formation in water depths of less than 15-20m. Friedman & others (1971) pointed out the dangers inherent in such an interpretation. The sources of error are many. Boring organisms are not restricted to algae dependent upon light and hence depth. Also included within this group are fungi which are independent of light. At the same time, many endolithic algae demonstrate an adaption to reduced light supply in deeper oceanic regions (Golubić & others, 1975). Other factors of significance include agitation of the water preventing colonisation by endolithic algae, the fact that cortoids can be transported, and the alternative non-micritisation methods of creating micritised bioclasts.

The application of microborings as bathymetric indicators generally hinges on depth zonations recognised from modern endoliths and the persistence of similar forms through geologic time. A clear distinction between photosynthetic microborers and endolithic marine fungi as well as the recognition of types restricted to the deep sea environment is necessary to yield valuable criteria for palaeobathymetric interpretation of ancient carbonates.

8.1.4. Lithoclastic calcarenites (I.iv)

This rock-type is common near the base of the Great Scar Group where limestones succeed clastic deposits or unconformably overlie Lower Palaeozoic rocks. Lithoclastic calcarenites, occurring at the base of the limestone sequence, are distributed throughout Kingsdale, Chapel-le-Dale, Crummack Dale, Ribblesdale and Silverdale. The rock-type is not seen farther east where the unconformity is not exposed, and much younger Dinantian rocks are seen at surface.

The rock-type has similar bedding characteristics to those already described for the intraclastic calcarenite (Section 8.1.1.). The beds are similar in thickness and again display low-angle cross-lamination, enhanced by the presence of lithoclasts. The rock-type consists of a similar biotic assemblage to that described for the bioclastic calcarenites (section 8.1.3.), and sparse to abundant, subangular to well rounded, sand, pebble, cobble or boulder-sized lithoclasts. The lithoclasts, resistant to weathering and erosion, are clearly distinguishable in the field.

In the lithoclastic calcarenites of the Great Scar Group lithoclasts comprise a smaller percentage of the rock than do the allochems, however, they provide vital information about the geography and geology of the study area at the time of their deposition. Five types of lithoclast have been identified throughout the lithoclastic biointrasparites (Folk, 1962); they are listed below:-

1. Large well rounded clasts, greater than 2mm in size, comprising angular quartz grains 0.3mm in size.

2. Subangular to rounded polycrystalline quartz grains 1-2mm in size. The quartz crystals show strong preferred orientation and sutured intercrystalline boundaries.

3. Angular to subangular monocrystalline quartz grains 0.5-1.5mm in size, suggesting little abrasion.

4. Elongate, well rounded, fine grained lithoclasts 0.5-2mm in length, with a strong preferred orientation, composed of quartz silt and clay minerals.

5. Rounded chloritic clasts 0.25-3.0mm in size containing angular, fragmental quartz crystals.

The clasts are obviously derived from the Lower Palaeozoic rocks in the immediate neighbourhood. Chloritic clasts are derived from slightly metamorphosed Lower Ordovician rocks, the other lithic clasts comprise constituents of the Silurian sediments and the quartz grains derive from veins present throughout the Lower Palaeozoic sequence. Lithoclasts derived from Ordovician slates and shales are sparse and, because of their fine grain size, occur only in the vicinity of their source rocks.

Commonly the lithoclasts occur as laminae within the calcarenites, alternating with allochem-rich laminae. The lithoclasts tend to be the same size as the intraclasts occurring in the same laminae, suggesting that they behaved as hydraulic size equivalents. Generally, the lithoclasts are well sorted and well rounded, indicating deposition after considerable transport and abrasion in an agitated environment. This is supported by the presence of abundant broken, abraded and well rounded bioclasts, the presence of sparry calcite cement, and the low-angle cross-lamination. The carbonate and non-carbonate grains are commonly about 0.2mm in size, the size of clasts most easily reworked.

In all exposures there is a distinct trend of decreasing grain size and frequency of lithoclasts up the sequence. Superimposed on this trend are sporadic occurrences of coarser lithoclasts, frequently stranded in hollows on bed tops. The upward decrease in the grain size and number of lithoclasts could result from:-

1. The gradual burial of ridges of Lower Palaeozoic rock under carbonate sand, coupled with the erosional reduction of ridges, so that clasts produced would be smaller and fewer.

2. Current directions changing so that progressively smaller clasts were introduced into the area.

3. Current velocities diminishing so that progressively smaller clasts were introduced into the area.

As the cross-lamina coset thickness of the lithoclastic calcarenites is the same as in the overlying very sparsely lithoclastic, intraclastic calcarenites, remaining constant at 20-30cm, it is probable that there was consistent wave action and wave depth. Consequently, the decrease in grain size and number of lithoclasts up the sequence is attributed to burial of the Lower Palaeozoic rock ridges. The presence of fine grained lithoclasts high above the unconformity at any one locality is indicative of exposure and erosion elsewhere in the study area.

The sporadic occurrence of large rounded lithoclasts (pebbles, cobbles and even boulders), stranded on bedding surfaces in lithoclastic or bioclastic calcarenite, is attributed to local intense wave action (storm surges) and changes in current direction which introduced lithoclasts from exposed ridges some distance away. Well exposed occurrences in Crummack Dale indicate a maximum travel-distance of a few hundred metres from the source ridges.

8.2. Medium to Thinly Bedded, Often Shaly, Mid to Dark Grey Calcarenites and Calcisiltites (II)

The rock types are common in the Great Scar Group. Almost the whole of the Raven Ray Formation consists of medium and thinly bedded, foetid, mid and dark grey calcarenites. They are also locally developed in the Thornton Force Formation particularly at the southeastern side of Chapel-le-Dale, at Mill Scar Lash and at Stainforth Foss. The rock-type is poorly developed at the base of the Horton Limestone in Wharfedale and Littondale and locally within the Moughton Calcilutite Member in northern Wharfedale.

Although this group of rock-types could probably be divided into smaller groups on the basis of the faunal content, the Raven Ray Formation is so poorly exposed that little information is available and the rock-types are described collectively.

8.2.1. Physical features of the mid to dark grey calcarenites and calcisiltites

The mid to dark grey calcarenites and calcisiltites are foetid, organic-rich lime muds containing large, but variable amounts, of bioclasts. They are mostly packed biomicrites (>50% bioclasts) and sparse biomicrites (10-50% bioclasts) (Folk, 1962). These categories are equivalent to the packstones and wackestones of Dunham (1962). Locally, bioclastic micrites (<10% bioclasts) are also present. Calcareous shales are common in the most argillaceous and organic-rich intervals.

This group is characterised by the dark colour, foetid smell and the medium to thin wavy beds. They form the major part of the Raven Ray Formation over a considerable area of the Askigg Block. This formation is superbly exposed in its type-locality at Raven Ray, Kingsdale, but crops out poorly elsewhere in the study area. Generally, the rock-type tends to form a poor terrace frequently obscured by till or by scree from the overlying Horton Limestone. A few quarries, such as at Newby Cote (SD733707), afford good exposures.

The mid to dark grey calcarenites and calcisiltites of the Raven Ray Formation generally overlie the clean-washed, pale grey calcarenites of the Thornton Force Formation, or thin shales of the Douk Gill Formation with disconformity. However, where the topographic relief on the pre-Carboniferous unconformity exceeds the thickness of the Thornton Force Formation, the beds unconformably overlie Lower Palaeozoic rocks. In Crummack Dale, where the relief is even greater, the beds of Raven Ray Formation become lithoclastic, paler and eventually wedge out against the rising unconformity. At Twisleton Scars, as the underlying Thornton Force Formation thins and wedges out, the foetid, dark grey calcarenites and calcisiltites of the Raven Ray Formation can clearly be seen to pass into paler grey, coarse grained, lithoclastic, cross-laminated calcarenites which unconformably overlie the Lower Palaeozoic rocks. This feature is less well developed at the opposite side of Chapel-le-Dale.

The foetid, mid to dark grey calcarenites and calcisiltites comprising the major part of the Raven Ray Formation also pass vertically into coarser, cleaner washed, mid grey calcarenites. Shales become less common and the beds thicken. The top beds of the Formation are disconformably overlain by mid and pale grey, non-foetid, thick beds of the Horton Limestone in the east of the study area; the contact is apparently conformable in the Raven Ray and Newby Cote Quarry sections.

In the Thornton Force Formation foetid, mid and dark grey calcarenites and calcisiltites are restricted to a few localities where the rock-type is poorly exposed. The beds appear to pass laterally into the more typical clean-washed calcarenites. Foetid mid and dark grey, slightly argillaceous calcarenites are seen at the base of the Horton Limestone in Wharfedale and Littondale. They disconformably overlie similar very argillaceous beds of the Raven Ray Formation and pass rapidly up into non-foetid, thickly bedded, shale-free, mid grey and pale grey calcarenites typical of the Horton Limestone. The only other occurrences of foetid, argillaceous, dark grey calcarenites in the Horton Limestone are in Ribblesdale; argillaceous limestones overlie the upper calcilutite horizon of the Moughton Calcilutite Member at South House, and at Selside black, argillaceous limestones are seen between the two calcilutite horizons exposed, the lower of which is black. The first bed of black calcarenite, overlying the calcilutite, is clearly slumped in its thinner part and cross-laminated elsewhere, suggesting its derivation from the north. Unfortunately there is no exposure to the north to confirm this.

The mid and dark grey calcarenites and calcisiltites are medium and thin bedded, with undulose shale partings particularly in the lower part of the sequence. A solitary example of a wedging bed occurs in the Raven Ray Formation at Gillet Brae. Large horizontal, meandering burrows are common on bed tops and the beds are intensely bioturbated throughout. The beds contain a sparse fauna of corals, brachiopods, bryozoa and bivalves. The fauna rarely occurs in life position and much of the coral is debris. Small colonial corals, mostly Syringopora in life position, are occasionally present in this rock-type. The colonies are generally less than 20cms in diameter. Solitary corals, generally on their sides, are also present. Other phyla represented in these dark calcarenites and calcisiltites have been identified from thin section analysis. Small crinoid ossicles are common and molluscs, ostracods and foraminifera are frequently present. Much of the fine skeletal debris is of brachiopod or molluscan origin, with some fenestrate bryozoa. Foraminifera are moderately abundant, frequently dominating the microfauna. Archaediscids and endothyrids occur together with the turretted foraminifer Tetrataxis. Ostracods, although sparse, are often preserved with their valves overlapping. There are no preserved algal structures, but the common presence of bored and micritised bioclasts suggests that endolithic algae and fungi were abundant. Pelletoids, intraclasts and heavily micritised ooliths occur only sparsely.

The mid and dark grey calcarenites and calcisiltites are predominantly packed biomicrites and sparse biomicrites (Folk, 1962) and, as such, have relatively simple diagenetic histories. Carbonate cements are apparent only in cavities. The majority of primary and secondary pores have been completely occluded by non-ferroan calcite cements. Locally, a slightly ferroan calcite cement (Lindholm & Finkelman, 1972) succeeds the first cement and occupies the centres of some of the larger pores, especially filling the most inaccessible pores, such as in foraminiferal chambers, which did not receive the earlier cement. Locally, as at Mill Scar Lash, bioclasts have been replaced by ferroan calcite, only brachiopods are preserved as non-ferroan calcite. It has been suggested (Richter & Fuchtbaüer, 1978) that those skeletons with original structures now preserved by replacement with ferroan calcite were originally composed of high-magnesium calcite. Richter & Fuchtbauer further suggested that those skeletons originally composed of low-magnesium calcite, for example brachiopods, are never replaced by ferroan calcite. The replacement is dependent upon the availability of ferrous iron. Generally, the dark grey and black calcarenites and calcisiltites have a dominant non-ferroan calcite cement and all available ferrous iron was included in pyrite disseminated throughout the micrite matrix. In Newby Cote Quarry a few of the beds contain large concentrations of pyrite framboids in the body chambers of ostracods, gastropods and many foraminifera. Pyrite crystals have also formed in some bioclasts such as brachiopods and echinoderms.

Pyrite in sediment is almost always associated with organic matter (Berner, 1970). Pure carbonate sediments are generally low in iron content and require an external source of iron. The pyrite concentrations are usually fairly low and iron could have been locally supplied by the pigments (colour bands) on shells. Where pyrite is locally abundant, it occurs in limestone beds intimately associated with shales. Other carbonate sediments in the Raven Ray Formation could have been equally rich in organic matter and sulphide ion, but no ferrous iron was readily available. In the Raven Ray Formation, body chambers of shells and rotting crinoids provided sites for sulphate-reducing bacteria to produce the sulphide ion.

Recent work on modern estuaries (Murray & others, 1978) indicates that there is usually an active mud layer about 9cm thick in which interchange with the overlying water occurs and no pyrite forms. Pyritization sets in immediately below this and seems to be more limited by sulphate-availability than iron; though the sediments concerned are terrigenous muds.

Commonly there has been patchy recrystallisation of the micrite matrix to microspar (Folk,1965). With gradual reduction of crystal size microspar passes into micrite. Non-ferroan calcite generally forms most of the microspar, although some crystals have ferroan calcite cores. The growth of microspar has pushed many of the inclusions of organic matter and clay aside. Occasionally, authigenic quartz crustals are present in the matrix.

8.2.1.1. Environment of deposition

Ramsbottom (1973) interpreted dark, thinner-bedded, bioclastic limestones in terms of their relative depth of deposition in comparison to other broad limestone facies. No absolute depth limits have been proposed for this group of limestones but they are assumed to have formed in deeper water than the pale, thicker-bedded limestones. The rock-types are similar in description to the "shelf facies-open circulation" SMF-9 bioclastic wackestone or micrite and SMF-10 coated and worn bioclasts in micrite (packstones-wackestones) of Wilson, (1975).

The rock-type which occupied the shelf edge is unknown, but it is probable that a belt of shallower water existed there with the dark calcarenites and calcisiltites forming in a slightly deeper, protected shelf lagoon.

There is a general lack of information regarding the depth of deposition of such dark calcarenites and calcisiltites. The bedding features (medium and thin bedding with shaly intervals, wavy bedding and flat lens-shaped beds) and bioturbation are typical of both shelf margin and shelf lagoon limestones (Pettijohn & Potter, 1964; Shinn, 1968; Flugel, 1982).

It is important to stress the relative nature of these depositional environments. The ultimate control is the fetch of the water body in which waves are being generated; according to oceanographers, fetch is significant up to 1000km, beyond which gravitational forces limited the further growth of waves (King, 1975). Every wave system breaks into solitary waves as soon as significant bottom friction occurs. The depth for this is surge-depth, the depth at which oscillatory and intermittent bottom-movement of sand/coarse silt changes to inshore drift. The consequent sedimentary structures change from symmetrical ripples to asymmetrical ripples. On high energy coasts the zone inshore of surge-depth is hundreds of metres wide and develops zones of sedimentary structures (Clifton & others, 1971). With lessening energy, these zones reduce in width until the offshore zone of symmetrical ripples lies directly at the foot of the shoreface (D. Moore, pers. comm., observations at various localities in the Mediterranean between France and Turkey).

In the case of the Great Scar Group, the fetch would have been initially determined by the width of the Craven Basin (in the downwind direction) and this would have produced the highest energy coastal environments on the Askrigg Block by friction against shelf edge shoals or against the rocky coastline. Once this primary wave system had been obliterated, secondary waves could be generated in the water bodies occupying the Askrigg Block, where the fetch would be much less, from a few hundred metres in coastal lagoons to 50km or more. However, fetch-amplification of waves is counteracted by water-depth; it is doubtful that the secondary waves on the Askrigg Block were ever able to achieve their theoretical height.

Only in Chapel-le-Dale is there any direct evidence as to water depth. It appears that where the Raven Ray Formation was deposited over ridges of Lower Palaeozoic rocks, conditions were sufficiently shallow to result in the accumulation of cross-laminated, coarse grained, crinoidal calcarenites. This deposition occurred above surge-base, allowing sorting and winnowing of the sediment.

The presence of colonial corals in this rock-type is significant; they developed clearly in response to the environment. Modern corals are strictly marine, being able to tolerate salinities between 27‰ and 40‰, possibly as high as 48‰. Most corals prefer salinities in the range of 34-36‰ (Heckel, 1972) and clear water. In the dark calcarenites and calcisiltites the coral colonies are small, being much smaller in size than the same species are known to be capable of developing. It is probable that the depositional conditions of these beds were such as to inhibit the growth of larger colonies. A high rate of sedimentation would have created problems for larger sessile organisms, and large brachiopods are notably absent. Alternatively, their absence could be due to the lack of an adequate food supply, presence of currents, or their requiring a firm substrate. Davies (1980) has observed large numbers of Gigantoproductus in the Gayle Limestone of the Yoredale Group. There appears to be little evidence of their requiring a firm support to avoid sinking in the soft mud, and partial burial in sediment would have anchored the mature specimens.

There have been several attempts to relate the presence of boring algae in ancient sediments to depths of water. It was suggested by Swinchatt (1969) that the presence of abundant algal borings indicated deposition at a depth of less than 40 metres, and probably less than 20 metres if there had been no sediment reworking. However, other boring organisms such as fungi and sponges (Perkins & Halsey, 1971; Rooney & Perkins, 1972; Edwards & Perkins, 1974) are present to much greater depths. Boring of skeletal grains by various organisms generally decreases with increasing depth. It has generally been accepted that abundant borings in Recent sediments indicate depths of less than 25m (Riding, 1975).

If the Raven Ray Formation lagoonal environment is compared with the carbonate lagoon/shoal complex of Belize (Matthews, 1966) a number of similarities can be seen. Matthews describes a very rapid disappearance of sand-sized debris away from the shoals, even in tidal channels of varying size. It seems probable that there was an onshelf tidal flow, similar to that described by Scholle & Kling (1972), although there is little evidence of channel deposits in the Raven Ray Formation. These flows must have dispersed into smaller channels to distribute normal salinity seawater along and behind the barrier-shoals. The sparsity of crinoid debris in the dark calcarenites and calcisiltites (in comparison with the pale, thick bedded calcarenites) can be explained by such a situation, although crinoids would have been abundant along the shelf edge. However, even though these currents would also have distributed rotting dead crinoids as a food supply, other unfavourable conditions prevailed which inhibited the growth of large faunas.

The abundant micrite matrix of the dark calcarenites and calcisiltites suggests that deposition took place below surge-base. However, deposition was sufficiently close to surge-base for agitation, winnowing and sorting of the sediments deposited over small ridges of Lower Palaeozoic rocks. Tyler (1969) described similar changes of lithology. He suggested that slight variations in elevation of the sedimentary interface (in this case the level of the unconformity) were sufficient to determine the degree of winnowing and sorting of the sediment, and to create lenticular bodies of calcarenite (biosparite). Except for sedimentation over the ridges, the waves operative over the shelf during deposition of the Raven Ray Formation dark calcarenites and calcisiltites failed to sort the grains or winnow out the lime mud.

Although they represent only a small proportion of the thickness of the Great Scar Group studied, the mid and dark grey calcarenites and calcisiltites of the Raven Ray Formation are a widespread rock-type. The beds represent a period when relatively uniform conditions were established over much of the Askrigg Block.

The depositional conditions of the dark calcarenites and calcisiltites of the Thornton Force Formation and Horton Limestone are more difficult to establish because of their poor and sporadic exposure.

In the Thornton Force Formation the rock-type probably formed in shallow subtidal areas protected by carbonate shoals and/or pre-Carboniferous ridges from the winnowing and sorting action of tidal currents and waves (i.e. in similar conditions to the 'shelf facies-open circulation' SMF-10 microfacies of Wilson, 1975).

The dark limestones associated with the calcilutite horizons of the Moughton Calcilutite Member occur only at two exposures in Ribblesdale. At neither of these localities is the whole of the sequence seen and, consequently, it is not possible to identify the depositional conditions, except that the source of the argillaceous, organic-rich carbonate appears to have been to the north. Dark grey calcarenites, calcisiltites and calcilutites, associated with thin shales, are common at approximately the same stratigraphic position in the Beckermonds Scar and Raydale Boreholes (Wilson & Cornwell, 1982).

8.3. Thinly Bedded Calcilutites and Calcisiltites of Variable Colour (III)

These rock-types are less common in the Great Scar Group than any of those previously described. Although thin, there is an extensive areal distribution with calcilutites occurring in the Douk Gill Formation and the upper part of most of the Horton Limestone. It is the presence of thin bedded calcilutites, as well as sandstones and red rudites, in the Douk Gill Formation which distinguish it from its probable time-equivalent, the Thornton Force Formation. The calcilutites of the Horton Limestone, although thin and variably exposed, appear to be restricted to a specific horizon and have been designated member status: the Moughton Calcilutite Member, which has been designated as the Holkerian-Asbian Stage boundary (Ramsbottom, 1974; George & others, 1976).

Although the calcilutites can be subdivided on the basis of colour (dark grey to black, and pale grey to buff) this feature has not been used because similar depositional and diagenetic features are present in both of these groups. The dark grey to black calcilutites are foetid and so coloured because they are rich in organic matter and contain small quantities of fine grained terrigenous material. The calcilutites are mainly bioclastic micrites (1-10% bioclasts) with a few sparse biomicritic (10-50% bioclasts, but always having a mud framework) (Folk, 1962). These categories are equivalent to the lime mudstones and lime wackestones of Dunham (1962). The calcilutites have been divided into two groups on the basis of distinctive physical features seen in the field.

7.3.1. Fenestral calcilutites (III.i)

Fenestral calcilutites, although not easily distinguished in the field, are common in the thicker parts of the Moughton Calcilutite Member and are poorly developed in the Douk Gill Formation at Douk Gill. As such, fenestrae are developed both in pale to mid grey calcilutites and also, less commonly, in dark grey to black calcilutites. Thin to medium beds of fenestral calcilutite are interbedded with featureless calcilutite beds and thin, low-angle cross-laminated, fine grained calcarenites and calcisiltites. Usually the bedding contacts are sharp and planar (Plates 12b, 12c), although draping of thin calcarenite beds over mounded surfaces is seen occasionally. In a few cases, beds are bioturbated into one another. Many of the primary bedding contacts have been modified by subsequent pressure solution and the formation of stylolites (Plate 10c). A thin shale occurs on top of the fenestral calcilutite in Horton Quarry.

Fenestrae are best developed in the pale grey to buff and locally mid grey calcilutites of the Moughton Calcilutite Member. The Member is widely exposed throughout the study area (Chapter 7) but fenestrae are well developed only in the upper, thicker, more persistent calcilutite horizon. This horizon commonly crops out through the scree, forming a small scar. It is easily recognised, even at some distance, by its distinctive white weathering patina. Fenestrae, filled with internal sediment and/or various phases of cement, are well exposed in Horton Quarry. North, south, east and west of this locality the upper calcilutite horizon thins and the fenestrae present are neither as abundant nor as large. Most fenestrae are filled with sparry calcite but in parts of Chapel-le-Dale, at Horton Quarry and at Old Cote Low Moor where fenestral calcilutites are thicker, bioclasts have been replaced by, and fenestrae filled with, orange-weathering carbonate.

With the exception of fenestrae, the majority of calcilutites are devoid of sedimentary structures. Desiccation cracks have been described by Garwood & Goodyear (1924) and Sedgwick (1983a) and wavy and irregular laminations were observed at the base of the upper calcilutite horizon in Horton Quarry and in parts of Crummack Dale. Mottling and bioturbation features are sporadically preserved. The bioclastic micrites and sparse biomicrites contain only sparse macrofossils, usually gastropods with occasional bivalves or brachiopods. In thin section there is a low diversity assemblage comprising common ostracods and endothyrid foraminifera and abundant calcispheres.

In hand specimen, a number of different types of fenestra can be recognized. They appear to grade into one another suggesting that the mechanisms of their formation are related:-

1. Abundant, near-spherical or ovoid, spar-filled cavities less than 1mm in size, with mottled and bleached micrite rims.

2. Near-vertical to inclined, spar-filled tubular fenestrae, up to 20mm long with circular cross-sections 2-4mm in diameter.

3. Isolated irregularly shaped fenestrae occurring near the tops of beds. The fenestrae, 10-15mm in length, contain partial infills of geopetal sediment as well as sparry cement.

4. Patchily developed, near-horizontal, irregular, laminoid fenestrae between 10mm and 50mm in size. These fenestrae, only well developed at Horton Quarry, have a complex history of void filling involving more than one generation of sediment.

The fenestrae vary greatly in their size, shape and abundance as can be seen in Plate 12. Small, near-spherical, spar-filled fenestrae are usually the most abundant and may be the only type developed at many localities. Larger and more complex fenestrae are best developed in the thicker sequence of calcilutite as at, and in the vicinity of, Horton Quarry.

This rock-type displays the most varied diagenetic history of all the carbonates in the study area. There has been extensive leaching of aragonitic allochems and voids, both primary and secondary, have been filled with calcite which is locally ferroan.

Numerous fenestrae cross-cut the depositional fabric and have been filled with various cements and geopetal sediments. The fenestral calcilutites from Horton Quarry display two phases of fenestra-development with the second larger, complex fenestrae cross-cutting and incorporating the earlier sparry calcite-filled voids. Most fenestrae are small and are occluded by non-ferroan sparry calcite cement. Only the larger, second phase fenestrae, which appear to have some connection with each other, are partially filled by non-ferroan calcite silt. These larger voids normally have a final fill of ferroan calcite. Ferroan calcite cements are common as final void-fills in large irregular secondary fenestrae at isolated localities in Chapel-le-Dale, Old Cote Low Moor and Horton Quarry.

It seems that each area has its own individual diagenetic sequence of events. The most complex history of cavity-fill is seen in samples from Horton Quarry. The complex,large, irregularly shaped, laminoid fenestrae have an early geopetal cavity-fill of calcite cement, followed by an isopachous, bladed dolomite cement. The final void-fill is variably ferroan blocky calcite.

Patchy recrystallisation of micrite to microspar (Folk, 1965) is a common feature of these calcilutites. The microspar usually passes, by gradual reduction of crystal size, into micrite. Non-ferroan calcite forms most of the microspar, although some crystals have ferroan calcite cores.

8.3.1.1. Environment of deposition

Ramsbotton (1973) interpreted calcite mudstones in terms of their relative depth of deposition in comparison to other broad limestone facies. No absolute depths have been proposed for this group of limestones. They formed in shallower water than the pale, thicker-bedded limestones. This has important environmental significance in interpreting the overall setting in which calcilutites were deposited. The calcilutites never occur near the shelf edge, which was an area of continuous deposition of pale, thicker bedded, crinoidal calcarenites. Therefore a protective belt of shallow water calcarenites existed along and near to the shelf edge with the calcilutites forming in a slightly deeper area in their lee. To provide adequate sheltering for the Moughton Calcilutite Member, the protective shoal must have formed a ridge; a modern analogue would be the Goodwin Sands off Dover, with the deeper area called the Downs being the analogue of the micrite lagoon. Part of the Goodwin Sands, sometimes called Jamaica Land, emerges at low tide. The rock-type is similar to the restricted marine shelf lagoons, protected environment SMF-21 microfacies of Wilson (1975).

The lack of information relating to such calcilutites means that knowledge of their depositional environment is confined to careful interpretation of their faunal content and the fenestrae. The low faunal diversity is indicative of a high stress environment (Laporte, 1975). The dominance of ostracods and calcispheres is clearly a response to this environment. No truly marine forms such as corals or echinoderms (Heckel, 1972) are present, probably having been inhibited by abnormal salinity or a high sedimentation rate. The only marine forms present are tolerant of a wide range of environmental conditions and cannot themselves be used to define the nature of the depositional environment.

Much literature has been published concerning the nature, origin and preservation of fenestrae. Ham (1954) termed the voids birdseyes and Folk (1959) described fenestral rocks as dismicrite. Tebbutt & others (1965) suggested that all such voids, including the loferites of

Fischer (1964), should be termed fenestrae. At the same time they (Tebbutt & others, 1965) proposed that fenestrae could be used as reliable indicators of supratidal conditions. Shinn (1968,1983a) and Grover & Read (1978) have suggested that fenestral fabrics are frequently preserved in ancient limestones because they are formed in an active diagenetic environment with early lithification and rapid cementation.

There has been much discussion as to the origin of these structures. Illing (1959) proposed that fenestrae were formed by the growth of supratidal evaporites in lime mud. Shinn (1968) recognised two types of fenestrae; planar isolated vugs which were formed by shrinkage during subaerial exposure of the sediments, and isolated bubble-like vugs which he attributed to the formation of gas bubbles during decay. It has been suggested by more recent authors (Read, 1975); Zamarreno, 1975; Flugel, 1982) that fenestrae are the result of one or more of the following processes; shrinkage, expansion, gas bubble formation during decay, air escape during flooding or wrinkling of algal mats. All mechanisms require the periodic existence of subaerial conditions, suggesting that deposition took place on tidal flats. Indeed, Read (1975; was able to recognise three types of fenestrae, two of which are intimately related to two different morphological forms of algal mat. Read's third form, also recognised by Cressman & Noger (1976), comprises sub-vertical, tubular fenestrae probably formed by burrowing or the growth of rootlets. Consequently, this form of fenestra is not a reliable indicator of supratidal conditions, and Shinn (1983a) suggested that some other term should be used to describe these voids. Halley (1975) and Mountjoy (1975) independently stated that it is important to realise that fenestral fabrics alone are not diagnostic of an intertidal or supratidal environment. However, their occurrence within some intervals associated with either definite subaerial features or above subtidal facies clearly indicates that they represent sediments deposited within a few feet of sea-level (Shinn, 1983b).

The recognition of the tidal flat facies in ancient rocks was made possible only recently because of the various studies of modern carbonate tidal flats, especially those of Florida, Bahamas, Persian Gulf and western Australia. These studies have outlined criteria for the recognition of supratidal/intertidal deposits in the geologic record and thus provide an important "environmental datum" to which other, less recognised carbonate facies may be environmentally correlated (Laporte, 1968). In the past tidal flats developed at margins of broad, shallow epicontinental seas. Comparable seas and therefore, sea marginal flats are presently non-existent; hence, to learn from modern sediments we have to depend upon the closest analogues available (Friedman & others, 1973).

The accumulation of carbonate muds and thin sands in these environments depends upon local, often rapid, changes in sea water agitation due to storms, unusual tides, or the formation or removal of small, yet effective, barriers to water movement (Laporte, 1971). Tracing of individual peritidal units across an outcrop often is difficult as they pinch out or are cut out by the overlying bed. Heterogeneity of rock-types seems typical of tidal flat deposits. The deposits are recording the rapid and frequent change of the depositional regime (Lucia, 1972). Consequently, although the facies strike of the tidal flat deposits as a whole follows the shoreline of the basin, the strike of the facies variations within may be quite variable and complex. Migration of islands, shifting of tidal channels or prograding of carbonate mud flats are all the result of complicated local patterns of deposition which bear no consistent or predictable relationship with the major topographic or hydrographic features of the basin itself (Laporte, 1971).

If the fenestrae in the Carboniferous calcilutites are the result of any of the processes decribed above, and as such features, if developed, are compacted in the intertidal and subtidal environments (Shinn, 1983a; Shinn & Robbin, 1983), then periods of subaerial exposure are indicated with deposition having occurred on the tidal flat. These conditions may have developed only locally as fenestral calcilutites appear to pass laterally, and frequently vertically, into featureless calcilutites (microfacies SMF-23 of Wilson, 1975). The thin, lens and wedge-shaped bodies of pale grey, fine grained, cross-laminated calcarenite or calcisiltite intercalated between beds of calcilutite in the Moughton Calcilutite Member probably represent tidal channels (microfacies SMF-24 of Wilson, 1975). During the Carboniferous Period, because of the presence of large epeiric seas, it is generally assumed that the tidal range was small. Consequently, tidal channels developed on the wide tidal flat would have only low relief.

It is proposed by many authors (Read, 1975; Shinn, 1968) that the fenestrae are intimately related with stromatolitic algae. No such structures were observed in the field but they have been recorded by Sedg wick (1983a) from Crummack Dale. The small, near-spherical fenestrae appear similar to descriptions of vugs created by gas escape (Shinn, 1968) during the decay of algal mats. Associated with these fenestrae are clotted micritic textures seen only in thin section. Wolf (1965) describes similar features suggesting that the clotted micrite resulted from early diagenetic alteration of algal components. The mechanism involved destruction of algal tissue by bacteria and the crumbling, and subsequent lithification as micrite, of the calcareous material. If algae were present in this rock-type, and there is evidence of oncolites in the featureless calcilutite, then they would have taken the thrombolite form of Aitken (1967). This is the term proposed for non-laminated cryptalgal bodies characterised by a clotted fabric.

Finally, there is other evidence which supports the proposition of subaerial exposure of parts of the calcilutites. Subaerial conditions are also suggested by the presence of sub-vertical tubular fenestrae which could have originated as a result of plant growth and two further types of fenestrae with more complex histories of filling. The simpler of these two types appears to occur not far below the top of beds with pronounced erosive tops. Frequently, the fenestrae are linked to the bed surface and the geopetal sediment fill probably is a vadose silt. The more complex, large, laminoid fenestrae which are particularly well formed at Horton Quarry, developed at a later date as they cross-cut all depositional and diagenetic fabrics, frequently incorporating earlier fenestrae. These large, complex, fenestrae appear to be laterally and vertically linked. They are partially filled by a geopetal calcite silt. The first cement is an isopachous rim of bladed dolomite suggesting precipitation within pores from a hypersaline brine. Pore fluid chemistry changed dramatically as the final fill frequently is blocky ferroan calcite. Absence of sulphur and reducing conditions (Evamy & Shearman 1969), are required for its precipitation. Both of these conditions would pertain in a freshwater phreatic lens, which could only develop below an emergent sediment surface.

Further evidence for subaerial exposure is gained from examination of the bedding contacts. The surfaces formed by early lithification and desiccation were enhanced by local subaerial solution and scour during the next marine transgression, locally creating scalloped and mounded surfaces. Coalescence of scalloped surfaces in more seaward locations formed the planar contacts commonly seen. In rare subtidal areas where the carbonate sediment was not lithified early, onlapping marine beds were deposited conformably upon tidal deposits and the contacts were intensely bioturbated (Read & Grover, 1977).

8.3.2. <u>Featureless calcilutites</u> (III.ii)

Featureless calcilutites are by far the most common form seen in the field. They occur in the Douk Gill Formation and within all the calcilutite horizons of the Moughton Calcilutite Member. These calcilutites, varying in colour from pale grey to black, are thinly bedded and laterally discontinuous. They are interbedded with cross-laminated, fine grained calcarenites and calcisiltites and frequently pass laterally or upwards into fenestral calcilutites. Bedding contacts are commonly sharp and erosional; locally, overlying calcarenites are bioturbated into the top of the calcilutite. The calcilutites generally are poorly exposed; there are only four outcrops of the Douk Gill Formation and the lower calcilutite horizons of the Moughton Calcilutite Member are only locally developed and frequently obscured by a thick cover of till. The calcilutite horizons are rarely scar-formers.

In the field the calcilutites display very few depositional features. Rarely, wavy or parallel lamination can be seen but usually the calcilutites are uniform and featureless. Occasional isolated fossils (gastropods, bivalves or brachiopods) can be seen. Petrographic examination reveals that much of the fine skeletal material is of ostracod and gastropod origin. Foraminifera and ostracods are moderately common although near-spherical calcispheres usually dominate the biota. Frequently, a vertical sequence of bioclast assemblages can be determined. At the base of the featureless calcilutites there usually is a relatively diverse assemblage of foraminifera, gastropods, bivalves, ostracods and calcispheres. Upwards, molluscs, then foraminifera and finally ostracods, become less frequent, resulting in a bioclastic micrite consisting almost entirely of calcispheres. It is in this final rock-type that small euhedral crystals of authigenic quartz become common. Coated grains, oncolites, with indeterminate micritic nuclei, have been identified in thin sections of the featureless calcilutite from the upper calcilutite horizon of the Moughton Calcilutite Member in Horton Quarry. None are visible in outcrop. They vary in size from 0.2mm to a maximum of 5.5mm. The size of the smaller oncolites is dictated by their nuclei, whereas the largest oncolites are essentially unrelated to nucleus-size and appear to be complex compound grains. There is no apparent sorting. Oncolite nuclei include intraclasts of biomicrite, micritised bioclasts and unidentifiable grains. The coatings generally have no preserved algal remains, although borings through the nuclei are probably of algal origin.

The featureless calcilutites are predominantly bioclastic micrites (Folk, 1962) and as such have relatively simple diagenetic histories. The carbonate cements are most apparent in cavities, rather than in unaltered micrite. Non-ferroan calcite dominates the cements, completely filling many cavities, both primary and secondary. Occasionally, a slightly ferroan cement (Lindholm & Finkelman, 1972) succeeds the first and occupies the centres of larger cavities, especially the most inaccessible cavities such as inner foraminiferal chambers, which did not receive the first cement.

Patchy recrystallisation of micrite to microspar (Folk, 1965) is a common feature of these calcilutites. The microspar often passes, by gradual reduction of crystal size, into micrite. Non-ferroan calcite forms most of the microspar although, locally, some of the crystals have ferroan calcite cores. This feature is most common in the Douk Gill Formation. The growth of microspar in the black to dark grey calcilutites has pushed aside inclusions of clay or organic matter in the lime mud. The top of the Douk Gill Formation is unusual in that ferroan dolomite microspar has replaced the original micrite. The abundance of ferroan carbonate in this bed is responsible for the patchy orange weathering of this bed.

8.3.2.1. Environment of deposition

These calcilutites probably formed in similar depositional conditions to those of the fenestral calcilutites which were discussed in the previous section. However, the lack of fenestrae and of the associated vadose silts or phreatic cements suggest that the sediments were unlikely to have been exposed to subaerial conditions. Indeed, if these features had been developed in an intertidal or subtidal environment, they would have been destroyed by compaction during burial because of the lack of early lithification (Shinn, 1968;1983a; Shinn & Robbin, 1983). It is envisaged that, as these sediments overlie normal shallow marine sediments and are overlain by the intertidal-supratidal fenestral deposits, they were deposited in a subtidal lagoonal environment. Even at its most diverse there is a restricted biota implying that deposition took place in high-stress environment (Laporte, 1975). The foraminifera appear to be limited to one form of endothyrid and gastropods, bivalves and brachiopods are usually rare, possibly allochthonous. Only calcispheres are present in abundance, occurring in the most restricted, possibly lower intertidal flat environment. Their origin is problematical. It has been suggested that they are produced by dasycladacean algae (Wilson, 1975; Wray, 1977). Recent dasycladacean algae inhabit various restricted environments including lagoons and protected reef or tidal flats (Valet, 1979). It appears that the fossil assemblage became gradually less diverse with increasingly restricted conditions in the lagoon as the tidal flat conditions were approached. The rock-type is similar to the SMF-23 microfacies described by Wilson (1975) as being deposited in saline or evaporative tidal ponds.

Cross-laminated, fine grained calcarenites occur less commonly between beds of featureless calcilutite than within a fenestral calcilutite sequence. In the Moughton Calcilutite Member these calcarenites are still lens and wedge-shaped and within the lagoonal-low intertidal environment envisaged can be interpreted as small tidal channels. Within the Douk Gill Formation the sands are parallel laminated as well as cross-laminated and are frequently bioturbated into the underlying calcilutite. In the lagoonal-tidal flat environment envisaged, they probably represent storm sheet sand deposits introduced during intermittent high energy events.

The key to the depositional conditions which prevailed may be provided by the oncolites observed in the Moughton Calcilutite Member of Horton Quarry (microfacies SMF-22 of Wilson, 1975). The environmental significance of oncolites is the subject of a large literature. Those of the Moughton Calcilutite Member are stacked spheroids (SS) according to the classification of Logan & others (1964). Although the oncoids are poorly preserved, individual laminae appear not to be continuous around the nuclei, showing that the oncolites were not continuously agitated. Oncolites appear to be a morphological and ecological adaption of crust building communities to soft sediment substrates and/or low energy environments where a rock or shell fragment constitutes the necessary initial hard substrate for the encrusting community to settle (Monty, 1972). Logan & others (1964) compared oncolites with the soft algal biscuits described by Ginsburg (1960), and concluded that SS structures were generally indicative of permanently submerged shoal areas or areas low in the intertidal zone. Buchanan & others (1972) extended the range of oncolite formation and occurrence to well into the subtidal zone. Similar conclusions were drawn by Leeder (1975) who considered that oncolites of the Lower Border Group were formed in high energy, low intertidal to subtidal environments where they were subjected to low velocity tidal currents. However, Wilson

(1975) noted that a micrite matrix is not consistent with an original depositional environment of algal nodules which needed moving water to overturn them at intervals. Monty (1972) doubted that the soft algal biscuits of Ginsburg (1960) were analogues for lithified calcareous oncolites now found in pre-Cretaceous rocks, suggesting that freshwater algal balls are a better analogue. He believed that similar colonies of algae formerly occupied the marine environment but have since been out-competed by red algae. Only red algae form hard algal nodules (Wilson, 1975). Recent freshwater oncolites generally grow in quiet environments of streams (Monty, 1972); they do not form in constantly agitated waters as envisaged for most ancient oncolites. Monty has suggested two main settings for the growth of oncolites; sheltered and quiet backreef or lagoonal waters, or flats abandoned by a regressive sea or invaded by a transgressive sea. The first, lagoonal setting, appears the most appropriate when the depositional environments of the overlying and underlying sediments are taken into consideration. The oncolites were probably firm to hard during growth with the precipitation of calcium carbonate dominating over the trapping of loose sediment. If the Moughton Calcilutite Member oncolites are most comparable to modern, hard, freshwater algal biscuits as described by Monty (1972) then they probably formed in quiet conditions. Wilson (1975) suggests that oncolites are found at the edges of shallow ponds or channels. The lime mud matrix is supporting evidence for a quiet environment; currents powerful enough to disturb oncolites were rare and although the oncolites were moved they were rarely abraded or sorted. Conditions for oncolite formation must have been very local and short-lived because oncolites have been discovered only in Horton Quarry. Alternatively, as the oncolite bed is thin, and not recognisable in the field, it could have been missed during sampling.

Various attempts have been made to relate the presence of algae in ancient sediments to water depth. The algal calcilutites of the Moughton Calcilutite Member were apparently deposited in fairly shallow water but there is no indication of absolute water depth. Monty (1977) further discusses the tendency for many ancient stromatolites to be regarded as intertidal in origin, and again stressed the subtidal origin of many modern stromatolites and oncolites.

These featureless calcilutites have been interpreted, mainly by consideration of their relationships with overlying and underlying deposits, as lagoonal-tidal flat sediments. The calcilutites of the Douk Gill Formation were restricted to a topographic hollow where ridges of Lower Palaeozoic rock provided shelter from waves and tidal currents. Small shoals of carbonate sand probably formed at entrances to the lagoon, further restricting the effects of winds and tides and allowing lagoonal deposits to accumulate. High rates of sedimentation ultimately resulted in the infilling of the lagoon to above low tide level. Periodically, storms overwhelmed the barriers introducing firstly clastic and later carbonate sheet sands which commonly were bioturbated into the lagoon-tidal flat sediments.

The featureless calcilutites of the Moughton Calcilutite Member are again considered to represent lagoonal-intertidal deposits. It is known that these deposits thin and eventually lens-out into medium grained, cross-laminated calcarenites to the south. These calcarenites probably formed barrier shoals on or near the shelf edge allowing the establishment of a lagoon in the shallow protected environment. The calcilutite deposits are intermittently developed, suggesting that the barrier shoals were occasionally overwhelmed and calcarenites were deposited over the lagoon. On re-establishment of the barrier shoals, the lagoon was able to reform. This sequence of events appears to have happened at least twice throughout the study area, with the youngest calcilutite being the thickest and having the greatest areal distribution.

8.4 Rudites (IV)

Rudites are present at the base of the Great Scar Group in Kingsdale, Chapel-le-Dale, Crummack Dale and Ribblesdale. These deposits are confined mainly to the Thornton Force Formation and Douk Gill Formation, although they do occur in the Raven Ray Formation of

Ribblesdale and the Horton Limestone of Crummack Dale. Frequently, the deposits are thin, less than two metres, but thicker and more extensive deposits occur in Crummack Dale. The majority of rudaceous deposits unconformably overlie the Lower Palaeozoic rocks, filling hollows of varying size, or they may occur a few metres above.

Rudites of the Great Scar Group can be divided into two groups dependent upon the type of matrix present:

IV.i Rudites with clastic arenite- or lutite-size matrix.
IV.ii Rudites with calcarenite matrix.

8.4.1 Rudites with clastic matrix (IV.i)

This group of rudaceous deposits have a clastic arenite or lutite-sized matrix which supports larger pebble, cobble and occasionally boulder-sized lithoclasts. Thin cobble rudites with such a matrix occur at or near the base of the Thornton Force Formation at the northwestern side of Chapel-le-Dale. Most of the deposits occur in hollows in the unconformity and overlie Ordovician slate and graywacke. The old quarry outcrop at SD71287556 is unusual in that the rudite overlies a green-brown mudstone which passes down into the underlying slate. Commonly the rudite is abruptly overlain by quartz litharenite but at Dry Gill (SD71907593) the rudite grades gradually upwards through quartz litharenite with pebble layers into silty shale with sparse coarse sand lenses.

In Crummack Dale a bimictic boulder rudite bed 1.5m thick, is exposed in the north buttress of Nappa Scars (SD76926976), part of the Thornton Force Formation. The rudite is typical of this group in that it is ungraded, containing subangular lithoclasts of varying size up to 2.0x2.0x0.4m, all of unweathered flaggy arenites of the Silurian Horton Formation. However, it is unusual in that it has an abrupt, near-vertical contact with a rudite whose matrix is calcarenite and whose clasts are well rounded graywacke boulders from the Silurian

Austwick Formation. This vertical boundary is enhanced by differential weathering.

At Austwick Beck Head (SD776718) a thin rudite occurs at the base of the Thornton Force Formation unconformably overlying Lower Palaeozoic rocks. It wedges out rapidly to the southwest.

Mud-supported rudites are present at the base of the Douk Gill Formation in Ribblesdale. More than one thin bed of rudite separated by shales and sandstones are seen at Gillet Brae (SD800719). Similar but much thicker rudites are exposed at Dub Cote Gill (SD819718) where the lowermost rudites comprise red stained slate and graywacke clasts in a red shaly matrix although most of the sequence consists of green and brown alternating wedging beds of boulder-cobble rudite with a fine sand matrix and cobble-pebble rudite with a very fine sand-shale matrix. The whole sequence generally fines upwards and all large clasts are rounded.

There are extensive, but generally poorly exposed, boulder rudites at the base of the Horton Limestone where it overlaps Lower Palaeozoic rocks in Crummack Dale. Mostly, they have calcarenite matrixes, rudites with lithic matrix occurring at only two isolated localities.

8.4.1.1 Environment of deposition

The lack of hydraulic sorting and the absence of marine fossils in these matrix-supported rudites indicates that they were deposited by subaerial gravity flows. The unstratified and unsorted deposits are typical of debris flow deposits (Pettijohn, 1957; Bluck, 1964; Walker, 1975; Turner, 1980). The flows are too viscous to separate clay and sand particles from cobbles and pebbles (Bluck, 1967a).

Walker (1975) subdivided rudites into matrix-supported and clast-supported types, stating that the former (paraconglomerates with greater than 15% matrix of Pettijohn, 1957) formed as a result of debris flows, slumps and subaqueous flows. The latter type was not recognised and there is no evidence of a marine environment of deposition.

A debris flow is a type of gravity flow in which the large grains are supported by a matrix of interstitial fluid and fine sediment which has a finite yield strength (Middleton & Hampton, 1973). The maximum pebble size gives an approximation of the minimum competence of the gravel-transporting medium (Steel, 1974). Grains are supported by strength and buoyancy rather than by turbulence, upward escape of fluid or dispersive pressure (Gascoyne, 1978). Usually debris flow are not erosive suggesting that transport is by laminar flow (Johnson, 1970; Steel, 1974). Flows are normally initiated on slopes steeper than 30° and the bed thickness is the result of a single act of sedimentation. Flow ceases abruptly when the interstitial water is lost, when the flow becomes too thin and extended, or when there is not sufficient slope (Hooke, 1967).

The matrix-supported rudites observed at Austwick Beck Head and Gillet Brae probably resulted from solitary debris flow events initiated on the surrounding steep graywacke "hills". The polymictic deposits reflect the complexity of the source rocks in the vicinity of each locality. The Austwick Beck Head deposit demonstrates the rapid change in thickness associated with the termination of such deposits.

A similar mechanism is proposed for the formation of the bimictic rudite bed at Nappa Scars. It is considered that at the moment of deposition, the main mass of the rudite must have been travelling almost horizontally over the surface of the lithoclastic calcarenites; Sedgwick (1983) estimated at least 200m of horizontal travel. No graywacke boulders were seen in the lithoclastic calcarenites, although such boulders do occur, patchily, close to the unconformity in Crummack Dale. It is proposed that the graywacke boulders and their calcarenite matrix were entrained close to the contemporaneous contact of lithoclastic calcarenite and Austwick Formation outcrops and were then carried the 200 metres or so without mixing (Sedgwick, 1983; Moore, pers. comm.).

The scenario for this deposit involves a south to southwest facing cliff of graywackes whose dip would be into the cliff-face, thus giving stability and supporting a remnant of the overlying Horton Formation.

Given that the crest of the unconformity in this area lies some 140m higher than at Nappa Scars, where the lithoclastic calcarenites were being deposited in very shallow water, most of this cliff must have been subaerial and on the cliff-top, subject to subaerial weathering. The very limited amount of deep weathering visible in the Horton Formation clasts requires that they were derived from below the soil profile. It has been proposed (Moore, pers. comm.) that local cliff-collapse, possibly induced by storms, resulted in the removal of the graywackes from the cliff-face and consequently caused failure of the much weaker Horton Formation (Fig. 8.2). The loosened mass came down the cliff as a high density debris flow and reached such a velocity that, on hitting the beach at the cliff-foot, it ploughed into the boulder-strewn lithoclastic calcarenite and "bull-dozed" some of it in front of the flow until its momentum ceased about 200 metres from the cliff-foot. High tide and storm waves could have aided the flow by lubricating its underside.

The deposits of Chapel-le-Dale have a complex origin. They are very thin and preserved only in gentle hollows eroded in the Lower Palaeozoic rocks. Tellam (1977) suggested that the regolith from higher parts of the pre-Carboniferous land surface slumped and was redeposited and preserved in hollows. There must have been sufficient relief on the subdued pre-Carboniferous land surface to trigger slumping of the regolith in the region. At Dale Barn Spring, mass-wasting and soil creep resulted in the reorganisation of the deposit so that elongate grains became aligned parallel to the slope (Gascoyne, 1978). The movement also removed the existing, probably thin, soil from the surface, exposing and overturning the weathered slate beds. At the old quarry the slumped deposits are preserved above an ancient soil profile (Tellam, 1977). It is possible that the fine grained clayey soil, preserved in this hollow, was a sufficient lubricant to form a slide plane over which the slumped material flowed, thus enabling the soil to be preserved. There appears to have been selective slumping of the regolith at Dry Gill which left the soil profile virtually intact (Tellam, 1977).

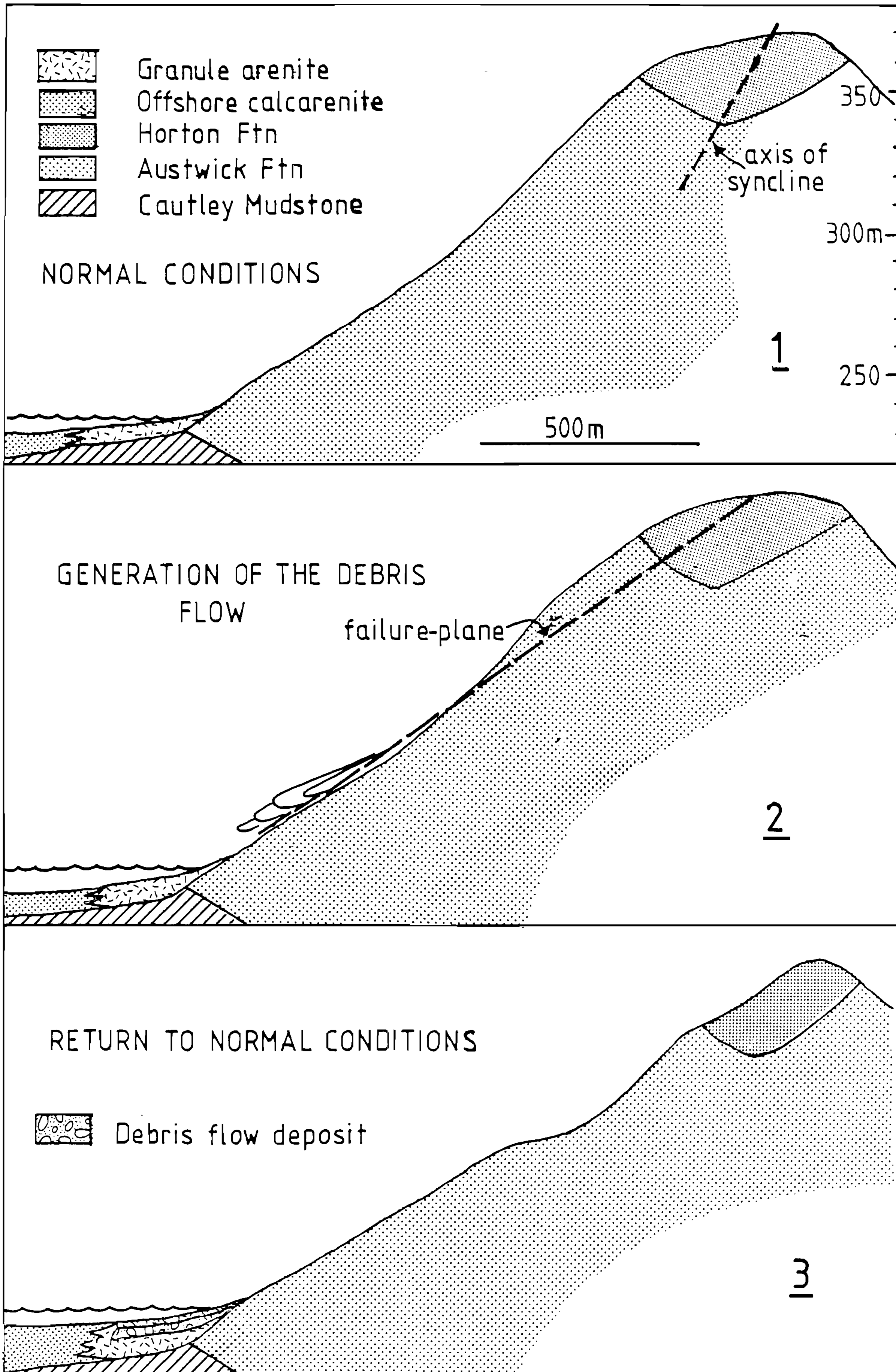


FIGURE 8.2. The origin of the debris flow deposit in the Thornton Force Formation at Nappa Scars. Diagram 1 depicts normal conditions. Diagram 2 illustrates the mechanism of generation of the debris flow. Diagram 3 shows the return to normal conditions after deposition of the debris flow at the foot of Nappa Scars.

The rudaceous deposits exposed at Dub Cote Gill in Ribblesdale are interpreted as a series of lens-like debris flow deposits which built up to form a small, subaerial fan. Source area lithologies which produce substantial amounts of fine detritus and which promote rapid erosion and run-off are necessary to produce an alluvial fan. The Lower Palaeozoic rocks in the immediate neighbourhood would supply such material. Subaerial fans commonly are orogenic deposits which are influenced by climate, rate and duration of uplift (Bull, 1972). Johnson (1970) gives excellent descriptions of modern alluvial fans and debris flow deposits. Each flow of a fan is poorly sorted and shows a decline in clast-size along the length of the flow away from the source area (Bluck, 1964). The localised nature of the deposits can be demonstrated at Dub Cote Gill where the individual lens-shaped beds are poorly sorted and unstratified. Most beds do not have erosional bases. Bluck (1965) describes individual alluvial fans 150-300m in length which are only 12 metres thick, thinning downstream. The clast-size distribution of these flows is between clay particles and boulders 2.5m in size. The maximum observable thickness of the fan at Dub Cote Gill is 5.85m, the largest clasts are 600x170x90mm, and the fan is at least 50 metres in length.

The red colouration of the lower part of the rudites at Dub Cote Gill is problematical. Red colouration of sediments has been the subject of an extensive literature (Glennie, 1970). Red alluvial fans are not palaeoclimatically significant although they may have been deposited within 20°-40° of the palaeoequator (Turner, 1980). There are no present day alluvial red beds and ancient ones are almost exclusively diagenetic in origin.

Diagenetic reddening can be divided into early and late phases. The early stage of reddening is an ageing process involving the infiltration of clay minerals, frequently containing iron hydroxides, into the deposit. This can only occur when there is available water, that is during and shortly after each flow and every time the fan surface is wetted by direct rainfall beyond the area wetted by a consequent mudflow. The clay reddens with time as iron oxides form in the oxidising groundwaters. Late stage reddening is the result of release of iron into the oxidising groundwaters from weathered framework silicates. For the retention of the red colouration it is vital that there is an absence of subsequent reduction (Turner, 1980).

Glennie (1970) discussed the earlier theories of the origins of red beds. These include formation in hot, wet tropical regions, tropical regions with seasonal rainfall, and in deserts where the red colour was derived from lateritic soils. Since, at the present-day, alluvial deposits in all these climatic regimes are grey or brown, reddening can only be a post-depositional diagenetic process.

The richly lithoclastic beds exposed unconformably overlying Lower Palaeozoic rocks at scattered localities in Crummack Dale are considered to be beach gravels. Beach gravels are unconsolidated, natural accumulations of rounded rock fragments (Novak, 1978). They occur only where coastal formations yield debris of a suitable size (pebbles, cobbles and boulders). Unfortunately, roundness, sphericity, oblateness, flatness and dissymetry have proved unreliable measurements for discrimatory purposes and it is impossible to differentiate between fluvial and shoreline deposits on clast shape alone (Brock, 1974). Pebble shape is a function of environmental characteristics as well as internal properties of the rock itself.

Splitting, crushing and spalling occur as boulders move against one another in a beach gravel. This generates fine, angular material. It appears that clasts larger than 128mm are not easily rounded under normal conditions and fracture to give particles mostly less than 64mm in size. Particles in this latter size range are angular fracture flakes showing little signs of abrasion (Bluck, 1969). Clasts 64-128mm do not undergo prominent breakage and the size fraction does not appear to receive products of breakage. Rounding, the result of abrasion, appears to occur only in this size fraction in which breakdown is not a prominent process under normal conditions (Bluck, 1969). The large rounded boulders in the shattered boulder-matrix (Plate 9b) and the pre-detachment rounding of graywacke outcrops indicate extremely violent activity, probably attained only during exceptional storms.

8.4.2 Rudites with calcarenite matrix (IV.ii)

This type of rudite is much more common and varies greatly in thickness. Rudites with calcarenite matrixes occur extensively in Kingsdale, Chapel-le-Dale, Crummack Dale and Silverdale.

In Kingsdale, above Pecca Falls and at Thornton Force (SD69487533), thin pebble rudites, with a bioclastic and granule lithoclast calcarenite matrix, unconformably overlie Ordovician slates and graywackes, probably infilling hollows. A boulder monolayer (boulders up to 640mm in length) is present at the top of the rudite at Thornton Force.

Similar deposits occur in Chapel-le-Dale either unconformably overlying Lower Palaeozoic rocks or cropping out only a few metres above. Stranded lithoclasts forming monolayers on top of undulose sandstone or limestone beds or in hollows in the unconformity are common.

Rudites with a framework of lithoclast cobbles and pebbles and a calcarenite matrix occur in Silverdale. The age of these deposits is problematical because of the sparse fauna and the non-exposure of diagnostic beds. Numerous clisiophyllids, *Lithostrotion* and *Syringopora* occur in the thin rudite at SD832619. A similar, but thicker, pebble rudite exposed at SD83356928 shows inverse grading.

There is only one exposure of a rudite with a calcareous matrix in the Douk Gill Formation, above Brackenbottom Farm (SD817721). The flat-pebble rudite with a sandy calcarenite matrix is poorly exposed at the base of the outcrop.

Boulder and cobble rudites occur at or near the base of the Horton Limestone and locally at the base of the Raven Ray Formation where they overlap the Lower Palaeozoic rocks. At most localities the boulder rudites are very poorly exposed with only the largest boulders cropping out; the calcarenite matrix is only occasionally seen. The rudites appear to form a series of wedges against the graywacke mounds at either side of Crummack Dale. The nature of the rudite beds, and their impersistence can clearly be seen at Studrigg Scars in the vicinity of Studrigg Quarry at the eastern side of the Dale. The lenses are thickest and contain the largest boulders at the western side of the Dale where the relief on the unconformity is the greatest. The largest boulders, usually at the base of the rudite, are rounded only in their upper parts, and frequently ribs of graywacke and siltstone show signs of abrasion and rounding. Cobbles and small boulders show the most extensive rounding. One boulder at least 4 metres in length provided a suitable firm substrate for a small colony of Lithostrotion. The lateral extent of the boulders and cobbles is small. No large clasts were observed either in west Ribblesdale or to the west in Clapdale. The Horton Limestone crops out only poorly at the east side of Clapdale but no large lithoclasts were seen in the excellent exposure north of Ingleborough Cave at the west side of the Dale. It is proposed that the graywacke ridge reached its greatest elevation in present Crummack Dale and that its slopes fell steeply to the west, ending between west Crummack Dale and Clapdale. Eastwards it seems to continue but widens, giving greatest shelter, probably accounting for the early alluvial fans at Douk Gill and certainly generating the wave-cut platform exposed under Moughton Nab (Plate 1b). The wide ridge would have so impeded waves that northward transport of coarse debris across the wider parts of the ridge would not have been possible. Thus the really coarse rudites were preferentially formed and deposited at the western point of the ridge where wave attack would be concentrated.

8.4.2.1 Environment of deposition

The profuse marine biota occurring in the associated limestones and frequently within the rudites themselves is indicative of deposition in a marine environment. Fragments of corals (Syringopora, Lithostrotion, Caninia) and bellerophontid gastropods up to 20cm across, and also poorly preserved brachiopods commonly occur with pebble-size lithoclasts in Chapel-le-Dale (Plate 2c).

Rudites with a calcarenite matrix in the Great Scar Group can be divided into two groups. The first type, thin layers and lenses filling small hollows in the unconformity or stranded on bedding planes a few metres above, occurs throughout the Thornton Force Formation. The second type, a much thicker and coarser rudite, is restricted in occurrence to Crummack Dale.

Good examples of the first type, layers and lenses of lithoclasts filling hollows in the unconformity and stranded on top of the overlying beds, can be seen in Kingsdale and Chapel-le-Dale. The rudite unconformably overlying slates at Thornton Force consists of pebbles and cobbles and sparse boulders in a lithoclastic calcarenite matrix topped by a monolayer of boulders. The presence of the monolayer suggests either increased rates of erosion during the deposition of the rudite or the winnowing of all but the coarsest lithoclasts from a rudite originally much thicker. The latter explanation is preferred. The products of winnowing could have supplied the lenses of granule and pebble lithoclasts which occur in hollows in the unconformity south of Thornton Force in Kingsdale.

It is probable that many of the rudites filling hollows in the unconformity consists of storm-worked pebbles. Many of the clasts are broken, perhaps the product of intense wave battering. Herringbone cross-lamination in the surrounding limestones is indicative of a shallow, nearshore, high energy environment. Occasional storms would introduce a new supply of lithoclasts and storm waves are known to have hurled huge objects onto the shore (Johnson, 1919). The tops of such-formed rudites are often reworked during later stages of marine inundation and the rudite may be winnowed of all but its largest clasts.

Pebbles, cobbles and small boulders of slate and graywacke occur sporadically in the overlying Thornton Force Formation. The clasts cannot have been derived from the unconformity at their present position, therefore, they require the existence of topographically higher ridges at no great distance. Lithoclasts occur in profusion up to 15 metres above the unconformity in the Thornton Force Formation in Kingsdale, and higher in the Raven Ray Formation and Horton Limestone of Crummack Dale, thus giving the minimum topographic relief of the unconformity in each area. The sporadic distribution of rudite layers indicates an intermittent supply of lithoclasts. During storm events the lithoclasts were introduced and in the intervening periods cross-laminated calcarenites were deposited. The largest clasts produced by erosion tend to be deposited closest to the shore whilst smaller clasts were carried much farther offshore, mostly by storm surges. Dott (1974) describes pebble-size lithoclasts of quartzite commonly being carried as far as 3km from the shore and being deposited in thin layers. Even rounded boulders up to 1 metres in diameter were carried as far as 300m offshore.

The size of the clasts composing the thin rudites stranded on bedding planes decreases rapidly upwards as the rudites become thinner and laterally more impersistent. This decrease in grain-size and frequently can be attributed to one or more of the following:-

a. Currents changing direction and therefore introducing fewer and smaller clasts
b. Current velocities decreasing and therefore introducing fewer and smaller clasts
c. Gradual burial of ridges under carbonate sand coupled with erosional reduction of ridge crests resulting in the production of fewer and smaller clasts

As the cross-lamina cosets remain constant at 20-30cm in thickness a consistent intensity of wave action and probably water depth is indicated. Therefore, it is unlikely that clast-diminution is the result of changing or waning currents and the third suggestion is thought to be the most plausible. Current-direction and velocity probably play some minor role.

The extremely coarse rudites in Crummack Dale can best be described by detailed comparison with similar Cambrian deposits at the Baraboo Range, Wisconsin (Dott, 1974). Kumar & Sanders (1976) quote these deposits as a good example of ancient shore-face storm deposits. Well-rounded boulders forming thick conglomerates are interstratified with Cambrian sandstone. Resistant hills of Precambrian quartzite were buried by dominantly marine Upper Cambrian and Ordovician sandstones and dolomites. Debris eroded from the quartzite hills occurs in strata adjacent to the old islands which were as much as 275m high at the beginning of deposition in Late Cambrian times. The Lower Palaeozoic islands in Crummack Dale were at least 140m high at the onset of Carboniferous sedimentation. The rudites of both Crummack Dale and Baraboo occur chiefly as halos fringing and covering the old islands.

There is an unusually broad range of sizes of lithoclasts in the rudites; 9.00m down to 2mm at Baraboo, and 5.00m down to 2mm at Crummack Dale. Well rounded clasts occur only in a restricted range up to 1.50m at Baraboo. Unfortunately, most of the boulder-sized clasts are poorly exposed in Crummack Dale, and it is not possible to determine the maximum size of well-rounded clasts. However, clasts up to 1.00m in diameter appear to be well-rounded. Whatever processes rounded the lithoclasts, they were incapable of significantly abrading larger boulders. Sufficient energy was available frequently enough to have moved and rounded the majority of clasts less than 1.00m in size at Crummack Dale (1.50m at Baraboo). Larger masses apparently fell from cliffs never to move again. Some of the larger blocks (at both Crummack Dale and Baraboo) show signs of rounding on one or two sides, the result of bombardment by smaller pebbles and sand grains (Dott, 1974). In Crummack Dale occasional inclined beds of Lower Palaeozoic rock which project through the early sediment cover show signs of rounding, probably by the same process. High energy impact between lithoclasts is the most important abrading mechanism.

The largest rounded boulders that are abraded on all sides provide a minimum estimate of wave magnitudes, whereas abundant, even larger angular blocks constrain the upper limit of maximum wave-competence.

Extrapolation of experimental results (Dott, 1974) indicates that a wave breaker height of at least 6-8m (for shoreface slopes of 20° and 10° respectively) is necessary to move quartzite boulders 1.50m in diameter at Baraboo. Such waves could disturb the largest boulders, but to move many of these very far might require breakers approaching 10m in height. Similar wave velocities and breaker heights must have existed in Carboniferous times in the Crummack Dale region to round boulders 1.00m in size. Still larger waves and sea surges must have occurred on occasion but too infrequently to cause appreciable rounding of larger boulders.

Where the bottom shoaled more gently, breakers greater than 8m in height would be required to tumble the 1.5m size boulders at Baraboo (Dott, 1974); some energy would be dissipated during uprush from a breaking point a few tens of metres from the beach in water perhaps 8-10m deep (Galvin, 1969). Rounded boulders are smaller at the eastern size of Crummack Dale where wave energy was lost because of impingement on the more gently shoaling seafloor.

Most boulders remain close to the island sources at both Baraboo and Crummack Dale. However, at Baraboo, thin layers of pebbles in sandstone occur 3km from shore and 1.00m sized-boulders occur 0.3km from shore. A very similar situation appears to exist in Crummack Dale although it is not possible to measure the lateral extent because of poor exposure. Large boulders could have been transported offshore by storm-initiated rip currents.

Even the palaeogeographic setting of Cambrian Baraboo and Carboniferous Crummack Dale are similar. Rudites of both areas were formed in vast, shallow epicontinental seas south of the palaeoequator. In Cambrian times Wisconsin lay between 10-20°S and in Lower Carboniferous times the Askrigg Block lay at about 15° south. In a similar modern setting 6m high wave breakers could be generated by winter storms (Dott, 1974). Waves greater than 8m high could have been generated locally in Cambrian times by storm winds over the shelf itself. Winds in the order of 2,400-3,000cm per sec. blowing over water

50m deep with a fetch of 180km and for at least 24 hours are required (Bott, 1974). There is nothing exceptional about the Cambrian storm waves and it is believed that Carboniferous storm waves had a very similar magnitude. The equator was close to Baraboo in Cambrian times and to the Askrigg Block in Carboniferous times, and it is probable that episodic violent storms occurred in the tropical latitude. Waves generated by such storms at the rate of only one per century could round many of the quartzite fragments on the shores of Baraboo islands and sweep some of the larger boulders offshore (Dott, 1974).

Finally, Dott concludes that normal currents were competent to disperse many of the small pebbles (15-20mm in size) down current for several kilometres. Tidal currents were kept to a minimum because the extreme shallowness and great lateral extent of epeiric seas reduce tidal action through a damping of the tidal wave by energy-loss due to frictional drag with the sea bed (Heckel, 1972). This situation has not materialised in all modern epeiric seas therefore it cannot be inferred that most ancient epeiric seas necessarily had negligible tidal circulation (Johnson, 1978). Dott (1974) proposed that hurricanes occurring at the same frequency as the present Gulf Coast crossed the Cambrian shelf, and up to 250,000 hurricanes could have struck the Baraboo islands during Late Cambrian times. Such storms would hardly be rare on a geologic time scale.

8.5 Arenites (V)

There is a limited distribution of arenite in the Great Scar Group. Arenites composed of quartz grains and lithic fragments are confined almost entirely to the Thornton Force Formation and Douk Gill Formation. Thin beds of quartz arenite were observed only at one location in each of the Raven Ray Formation and Horton Limestone.

Arenites of the Great Scar Group can be divided into two groups based on their physical appearance. The first group consists of granule arenites (2-4mm lithoclasts) with a variable calcarenite-quartz sand matrix. Such deposits occur only at Nappa Scar, Crummack Dale and poorly in Chapel-le-Dale. The second group of arenites comprises a number of different varieties, all of which are medium or fine grained. They can be divided into subgroups by the presence of absence of carbonate matrix or cement.

8.5.1 Granule arenites (V.i)

Granule arenite is excellently exposed at the separate outcrops at Nappa Scar (Fig. 4.10; 11B and 11C). The thickest sequence of granule arenite occurs at the most easterly exposure, where 8.80m of intermittently exposed granule arenite unconformably overlie Cautley Mudstone of Upper Ordovician age. The granules become smaller and more dispersed in the calcarenite to the southwest. Layers and lenses of pebble rudite occur infrequently. Planar cross-lamination and erosive partings were observed throughout and water release structures, spring pits, occur at 3.30m and 7.70m above the unconformity. Granule arenite is abruptly overlain by a wedge of cobble and boulder rudite and then by a higher granule arenite bed 0.70m thick. This bed comprises profuse granule lithoclasts and 20-30% intraclasts in a calcarenite matrix.

A similar sequence is exposed at the base of the middle buttress of Nappa Scar. The beds rapidly become less lithoclastic to the west as no granule arenite is seen at the most southwesterly exposure. Lithoclasts are much smaller and less common. The granule arenite appears to have passed gradually westwards into lithoclastic calcarenite. The upper and lower beds of granule arenite wedge out first, with the middle beds being more persistent. Yet they too have passed into bioclastic, lithoclastic calcarenite with intraclasts at the western buttress, a distance of some 50m.

Granule arenites occur between SD71447566 and SD71497572 at the northwest side of Chapel-le-Dale. There are two beds of granule arenite separated by 2-3m of calcarenite. At all exposures the lower bed of "natural concrete" immediately overlies calcareous quartz arenite. The bed thickness is variable, 0.50-1.50m, and it comprises layers of granule arenite and sparse pebbles 4-10mm in size with a calcarenite matrix. Corals and fragmented brachiopods are common in the bed. The upper granule arenite is more poorly exposed, approximately 0.60m thick and lithologically similar to the lower one. Both beds exist only as far as the rising graywacke ridge 20 metres to the northeast and pass laterally to the southwest into lithoclastic calcarenites.

A similar granule arenite occurs at SD71867593, on the northeastern side of the same ridge. It is incompletely exposed at the base of a small outcrop and is at least 0.30m thick. It passes rapidly to the northeast into lithoclastic calcarenite with layers and lenses of cobble rudite.

8.5.1.1 Environment of deposition

All the clastic detritus forming the various types of arenite must have been derived from erosion of pre-Carboniferous rocks in the study area or else must have been transported in from outside. The small quantities of arenite, the limited distribution and their location immediately above or adjacent to pre-Carboniferous rocks suggests that the former source is most plausible.

The granule arenites with calcarenite matrixes and lenses and layers of pebbles and cobbles occur immediately adjacent to mounds in the unconformity both at Nappa Scars and at Twisleton Scars. Perhaps the thickness of the deposit is related to the unconformity relief; in Chapel-le-Dale the relief is 20-25m, and at Nappa Scar the thick deposits occur at the base of a ridge which rises by 140m to the north. At both localities the granules (2-4mm) are well sorted, rounded and closely packed. Cross-stratification and dewatering structures were observed only in the more lithoclastic deposits of Nappa Scar.

Concurrent deposition of the two components of the deposit is suggested by their relative proportions (lithoclasts 65-70%, calcarenite 30-35%); the calcarenite is not a product of infiltration (Folk & Ward, 1957). Together the calcarenite and the marine biota indicate deposition in seawater (Heckel, 1972). It is most probable that the deposits formed in a non-barred, high energy shoreline environment as unconsolidated, natural accumulations of rounded rock fragments (Clifton & others, 1971). Rock fragments can only occur where coastal formations yield debris of a suitable size (Novak, 1978). The cross-stratification and occasional basal scour surfaces indicate a prevalence of eroding currents, possibly channelised, moving pebbly sand as dune bedforms. The occasionally observed pebble imbrication in the granule arenite is away from rising graywacke mounds, that is, seawards.

The lens-like shape of the granule arenite deposits and their lateral passage into lithoclastic calcarenites at both Nappa Scar and Twisleton Scars can be explained by offshore transport of breakdown products from the shoreline and reworking in an environment where calcarenites are being deposited (Bluck, 1967b). The excellent sorting and rounding of the granule lithoclasts in the granule arenites suggests extensive periods of reworking and sorting of sediment by wave-activity (Harms, 1975).

The large bioclasts, which include solitary and colonial corals and numerous fragments of brachiopods and gastropods, are all robust forms indicating that they inhabited high-energy environments with reduced clastic deposition. They were derived from these environments during storms and reworked into the sands during normal wave conditions as hydraulic equivalents of the smaller lithoclasts.

Two water-ejection structures, spring pits, were observed in the basal, most calcarenite-poor bed of granule arenite at the eastern section of Nappa Scar. Spring pits and sand volcanoes are known to occur on debris flow deposits and on slumps (Gill & Kuenen, 1957). They occur where underground flowing water is discharged through the surface of the deposit. Reineck & Singh (1975) describe spring pits in the backshore beach environment where they are produced by air escaping from below the sediment surface because of sudden flooding. Such an explanation would suit the origin of spring pits in the gravelly beach sands of Nappa Scar.

8.5.2 Medium and fine grained arenites (V.ii)

This second group of arenites comprises fine and medium grained quartz arenites and litharenites with or without a calcareous matrix or cement. Each arenite is distinctive and quite different. They bear no relationship to each other because of the great distances between outcrops and because of their different stratigraphic positions.

8.5.2a Calcareous quartz arenite

The arenite exposed along the northwestern side of Chapel-le-Dale is calcareous. It always overlies rudite, often with an erosional base. At most exposures it can be divided into two parts, a lower quartz arenite becoming increasingly calcareous upwards, and an upper interlaminated quartz arenite-calcarenite. The thickest development occurs at SD71357562 (Fig. 4.5; 3F) where 1.40m of quartz arenite are overlain by 0.50m of interlaminated, cross-laminated quartz arenite and calcarenite. Occasionally the top is scoured to a depth of 0.10m and isolated cobbles and pebbles of graywacke are stranded in the eroded hollows. In such cases the arenite is succeeded abruptly by cross-laminated calcarenite. Usually the transition is gradual. Lenses of pebble and sparse cobble lithoclasts occur in the more calcareous parts of the quartz arenite and wisps of quartz sand occur in the overlying calcarenite.

Northeastwards, towards the graywacke mound, the quartz arenite is overlain by a bed of granule arenite which replaces the interlaminated quartz arenite-calcarenite. The quartz arenite below is much thinner, 0.85m, and it thins towards the mound. It is 0.75m thick at the exposure immediately southwest of the graywacke mound (SD71497572).

Northeastwards, beyond the graywacke ridge, the quartz arenite is poorly developed and achieves a maximum thickness of 0.42m. Quartz arenite is locally developed at Dry Gill (SD71907595, Fig. 4.6; 4D). 0.62m of quartz arenite fine upwards into laminated siltstone. Mica flakes were observed on bedding planes of the thinly bedded arenite and small lithoclasts occur with feeding trails in the siltite. The siltite passes rapidly into mudstone which is overlain by 0.47m of calcareous quartz arenite containing graywacke lithoclasts to 140x160mm. Locally, the lithoclasts occur in large enough concentrations to form a framework.

Calcareous sandstone also crops out at the opposite side of the Dale in the vicinity of the old Ingleton Reservoir (SD714747). It is poorly exposed and becomes increasingly calcareous to the northeast as a graywacke ridge is approached. It is best exposed at SD71377466 where it comprises 1.80m of calcareous quartz arenite overlain by 1.00m of cross-laminated, crinoidal, quartz sand-rich calcarenite. Poorly preserved, large plant fragments (decorticated stems of Sublepidodendron up to 30cm in length, Plate 23a) were found in the calcareous sandstone.

Non-ferroan calcite cement predominates in the form of large syntaxial growths on crinoid ossicles and fragments which envelope neighbouring clasts. In the lithoclast-rich laminae there is close packing of the grains and the syntaxial cement is not well developed. There is evidence of compaction and micro-pressure solution in these laminae. The source of the calcite for cement is dissolution and compaction of bioclasts. Calcite can be provided internally by dissolution of very fine interstitial skeletal carbonate, mostly aragonite, but also calcite (Oldershaw & Scoffin, 1967). Ferroan calcite occurs in only the most inaccessible chambers of foraminifera and adjacent to lithoclasts. There is a freely available source of iron in the iron-bearing minerals of the slate and graywacke lithoclasts.

It is most probable that the arenites found at either side of the present valley were deposited at about the same time, although the two deposits need not be physically related. Near the old Ingleton reservoir the calcareous sandstone overlies calcarenite and not rudite as at Twisleton Scars.

The calcareous quartz arenites of Chapel-le-Dale contain an abundant marine fauna indicating deposition in seawater (Heckel, 1972).

Sedimentary structures are poorly exposed at outcrop but in thin section alternating laminae of bioclastic calcarenite with lithoclasts and lithoclastic quartz arenite with bioclasts can be seen. In both lamina-types the bioclasts are larger than the majority of lithoclasts and quartz grains. They were deposited together and, therefore, must have behaved as hydraulic equivalents. The bioclast and lithoclast grain size remains constant throughout, although their relative percentages vary, suggesting that the hydraulic conditions operating remained constant during deposition and that there was a fluctuating supply of lithoclasts.

Deposition of quartz arenite at Twisleton Scars was preceded by an erosional event which scoured the top of the rudaceous deposits over much of the area. The quartz arenite was deposited in a nearshore - beach shoreface environment and over much of its outcrop area reworked by wave and tidal action. This enabled the clay minerals and fine detritus to be winnowed out and the quartz and lithoclast sand to be well sorted and reworked into the calcarenites deposited offshore and later above. As calcarenite deposition and arenite working continued the deposit gradually became increasingly calcareous upwards.

These beds are cross-laminated indicating deposition above surge base. At some exposures there is only one bed of calcareous quartz arenite abruptly overlain by either calcarenite or granule arenite. In both cases the contact appears to be erosional. The granule arenite is deposited immediately adjacent to the graywacke ridge and is interpreted as a shoreline deposit, and calcarenite abruptly overlies quartz arenite only in the most offshore areas. It is possible that storm waves or tidal induced currents caused erosion of the quartz arenite in the nearshore environment.

Quartz sand wisps continue up into the overlying calcarenite where there is a gradational contact. The deposits are well sorted and often weakly cross-laminated. They are interpreted as having been formed in the nearshore environment above active wave base where there was a small supply of unconsolidated quartz sand which was reworked into the calcarenite. It is possible that the supply of sand was provided by erosion of parts of the quartz arenite in the offshore region.

Calcareous quartz arenite and lithoclastic-rich calcarenites are not exposed above Beezley Farm. It is probable that the quartz arenite has passed laterally into calcarenite in the offshore (southwest) direction.

Below White Scars, near the old Ingleton reservoir, large fragments of plants were observed in the calcareous quartz arenite. One fragment has been identified from Plate 23a as cf. Sublepidodendron in a decorticated state (W.G. Chaloner, pers. comm.). The genus is broadly of Lower Carboniferous age. Part of a Calamites stem, approximately 3 metres in length, has been observed lying on the unconformity in White Scar Cave (D. Moore, pers. comm). There is no sandstone at this locality; it appears to have wedged out towards the southwest also. The presence of plant material, particularly such large fragments of trees, implies that there was land above sea level with conditions in which plant life could flourish. Probably the plants were rafted into their depositional areas; they could have travelled some distance.

The ultimate source of the quartz sand was obviously the local graywackes. Deep weathering followed by marine erosion and winnowing would eliminate the chlorite matrix, releasing quartz sand. The limited extent of the quartz arenite supports this; marine-invasion stopped the weathering process and once the weathered profile had been stripped and its sand released no further supply was available. The brown stained rudites in Chapel-le-Dale (Section 8.4) are subsoil debris which went first by mass wasting as the sea arrived; the later arrival of the sand suggests that it came from more extensive and initially protected areas, that is, hollows between the ridge tops. These hollows, until invaded, would have permitted tree-growth.

The formation of quartz arenite-siltite and calcareous quartz arenite at Dry Gill, Twisleton Scars, is more complex. The lower sandstone bed contains only a small quantity of carbonate, is very finely laminated and passes upwards into siltite. There is no marine biota, indeed no biota was observed, and mica flakes and occasional browsing trails occur on lamina surfaces. Together, these observations suggest a quiet water, probably non-marine environment. The occasional lithoclasts (4-10mm in size) represent storm tossed pebbles flung over the barrier ridges of the unconformity. There is no other evidence of a high energy environment consequently the pebbles must have been derived from outside this isolated environment. The rootlets occurring in the silty shale, the lateral equivalent of the laminated siltstone, indicate a quiet environment. The water body may have been brackish or even fresh. The lack of a peat deposit and the presence of burrowing traces together imply oxygenated conditions. The water body may have been a freshwater pond or a brackish, isolated lagoon. The ridges of graywacke in the vicinity performed the vital role of protecting the microenvironment and allowing it to develop. Garwood (1922) describes deposits in the vicinity of Horton Quarry, Ribblesdale, which he interprets as lake and estuarine sediments. Again ridges of Lower Palaeozoic rocks created barriers protecting the environment from marine influence. Unfortunately, these deposits are no longer exposed but it is not improbable that a number of similar microenvironments existed protected by the irregular topography of the Lower Palaeozoic rocks.

The overlying sandstone at Dry Gill is a calcareous quartz arenite with lenses of pebbles which occasionally form a framework. Essentially, the deposit is similar to other calcareous quartz arenites in Chapel-le-Dale. It contains a sparse marine biota, thus was deposited in seawater (Heckel, 1972). The earlier brackish-fresh water isolated environment must have been overwhelmed, probably initially during storm periods and a truly marine sandstone containing lenses of storm-tossed pebbles and cobbles was deposited in the nearshore environment.

Calcareous quartz arenites of very similar characteristics occur near the base of the Thornton Force Formation only at either side of Chapel-le-Dale. It is possible that the sandstone was deposited virtually simultaneously over the whole of Chapel-le-Dale, implying as calcarenites occur below only at the western side of the Dale that, in this area, marine deposition commenced at an earlier stage.

8.5.2b Argillaceous quartz arenites and litharenites

Quartz arenites and litharenites are exposed in the lower part of the succession of the Douk Gill Formation. Most beds are less than 0.30m thick and interbedded with calcarenites or calcilutites. At Douk Gill 2.30m of poorly exposed, flat bedded, slightly calcareous, argillaceous arenite overlie fine grained calcarenite. Each bed of arenite is about 0.30m thick and parallel laminated. Above there are thin beds of quartz arenite and quartz litharenite interbedded with equally thin beds of calcilutite for 0.95m succeeded by 2.70m limestone above which are 0.05m of quartz arenite.

At Brackenbottom Farm the Douk Gill Formation is poorly exposed and quartz sand occurs in most thin beds of calcarenite. However, there is only one bed of finely laminated, shaly, quartz arenite (0.11m thick) which crops out near the top of the small exposure.

At Dub Cote Gill the sandstones are more calcareous and more thickly bedded (1.35m and 1.00m respectively) containing sparse cobble lithoclasts and separated by 0.55m of cobble rudite. The upper sandstone becomes increasingly argillaceous and grades upwards into shaly mudstone. Two thin beds of quartz arenite, locally graded or parallel laminated, occur above 1.10m of interbedded shales and calcarenites.

Quartz arenites and litharenites occur at Gillet Brae, the most westerly outcrop of the Douk Gill Formation. Argillaceous sandstones occur interbedded with shales and thin rudites. Disseminated plant material occurs throughout. Most sands are intensely bioturbated and only intermittently are very fine, parallel laminations preserved.

Although most of the thin bedded, argillaceous quartz arenites and quartz litharenites of the Douk Gill Formation are parallel laminated, those sandstones interbedded with limestones display more complex features. The upper part of the beds may be ripple cross-laminated and the beds either have erosional contacts with carbonate rocks or are bioturbated into overlying and underlying shales. Bioturbation is locally very intense and may destroy most of the lamination.

The arenites of the Douk Gill Formation have a matrix of very fine grained quartz and clay minerals. As such they are sublabile lithic arenites and labile lithic arenites of Crook (1960). They are clearly laminated in thin section, and each lamina can be seen to be graded. Occasionally laminae are reverse-graded. The grain size of the quartz sand dispersed phase is very variable (0.08-0.25mm). Most grains are single, subangular or subrounded crystals. Very sparse, more rounded clasts of sericitised plagioclase feldspar (0.20-0.30mm) and larger lithoclasts were observed. There is no calcarenite matrix and only very rarely carbonate cement; the quartz and sparse feldspar and lithoclastic grains are suspended in a weakly laminated matrix of very fine quartz grains (0.02-0.04mm) and clay minerals.

The sandstones and siltstones of the Douk Gill Formation vary in composition from locally calcareous litharenites to the more common argillaceous quartz arenites and litharenites. The former are associated with clean-washed calcarenites into which they are bioturbated. The ubiquitous marine fauna implies deposition in seawater and the presence of graded, reverse graded and cross-laminated thin beds indicate a shallow environment of deposition with some wave agitation.

The clay-rich sandstones are closely associated with shales, rudites and foetid calcilutites. Many of these sandstones are overlain or underlain by black shales into which they are intensely bioturbated. Often there are no vestiges of lamination remaining. A shallow, quiet water environment either at or just below wave base or a protected lagoon would be a suitable depositional site for such deposits. The profuse burrowing, poor sediment sorting and the lack of winnowing support this interpretation. The presence of tiny plant fragments indicates possible reworking of terrestrial material. The source of the plant fragments may be the same as the source of plant material for the overlying coal.

The source of the silt and clay matrix in the labile and sublabile litharenites is problematical. The primary source was the clay-rich, clastic, pre-Carboniferous rocks in the immediate neighbourhood. The clay mineral and quartz silt matrix could have resulted from one or more of the following processes:-

1. Original weathering and breakdown of Lower Palaeozoic rocks
2. Breakdown within the arenite of lithoclasts derived from Lower Palaeozoic rocks
3. Destruction of a mud flat composed of quartz silt and clay minerals derived from the Lower Palaeozoic rocks. Sand-sized mudclasts later breakdown within the arenite.
4. Possible bioturbation of quartz silt and sand into a shale bed, or shale into siltstone-sandstone.

In many of the arenites the boundaries between the fine grained quartz silt and clay mineral lithoclasts are difficult to distinguish from the surrounding quartz silt and clay mineral matrix. It is possible that the mechanisms outlined in 2 and 3 above could have provided the matrix material. However, it is impossible to distinguish between friable lithoclasts and "mudclasts". In either case the breakdown of the clasts would provide the quartz silt and clay minerals of the matrix and such a process would leave the primary bedding characteristics intact. In thin section lamination can be seen. Thus, the fourth mechanism given above is excluded as the resulting deposit would be intensely bioturbated with no vestiges of lamination.

The presence of pyrite in many of the clay-rich arenites is considered to be a diagenetic phenomenon. Intense bioturbation of the sediment makes it unlikely that anoxic conditions existed during deposition at the sediment-water interface. Reducing conditions must have occurred either some centimetres below the sediment-surface or much later, during burial diagenesis.

8.5.2c Carbonate-cemented arenites

Medium and thick beds of quartz arenite and calcareous quartz arenite occur in the Raven Ray Formation at Newby Cote Quarry (SD733707). The lowest bed containing quartz sand and silt crops out above 11.20m of dark grey, slightly foetid calcarenite and calcisiltite; it is a fine grained, parallel laminated, silty calcarenite grading up into cross-laminated calcareous quartz arenite 0.22m thick. It is overlain by 0.04m of laminated shale and then by 0.02m of weathered quartz arenite. Above, there are 1.36m of shale and calcarenite above which there are 0.07m of silty calcarenite, 0.05m of shale and then 0.26m of parallel laminated calcareous siltite-arenite. The base of the bed is intensely bioturbated and lamination is disrupted. Overlying it there are 0.06-0.22m of slightly calcareous quartz arenite containing numerous tiny plant fragments and vitrinite flecks. There is an erosional contact with the overlying shale which fills the hollows and which is in turn overlain by intensely bioturbated calcareous quartz arenite 0.20m thick. The remainder of the Raven Ray Formation at this exposure (4.20m) comprises bioturbated, foetid, dark grey calcarenite.

Sparse medium-thin beds of quartz arenite occur at the base of the Horton Limestone where it overlaps Lower Palaeozoic rocks in Crummack Dale. Arenite is restricted in distribution to three isolated exposures (SD76797126, SD76947134 and SD77027138). At the first and third of the referenced exposures a single bed of brown-weathering quartz arenite (0.10-0.15m thick) is isolated within the carbonate sequences. At SD76947134 there are two beds of quartz arenite in a sequence of pebble rudites and lithoclastic calcarenites. No primary sedimentary structures were observed in the quartz arenites at any of the three localities.

In thin section the quartz arenites described above comprise quartz grains cemented by carbonate. There is no calcarenite matrix. In the majority of cases the cement appears to be ferroan, frequently ferroan dolomite. Although the original porosity was very high, there is no early non-ferroan calcite cement. In limestones this cement is provided internally by the dissolution of very fine interstitial skeletal material (Oldershaw & Scoffin, 1967).

The quartz arenites are all fine grained (0.125-0.2mm) and well sorted. All the grains are subangular to subrounded. Occasional sericitised feldspar grains and larger slate lithoclasts are present. There is very faint lamination defined by the orientation of quartz grains. Sparse crinoid ossicles and brachiopod debris were observed in all samples. There are no syntaxial overgrowths developed on the degraded ferroan and non-ferroan calcite bioclasts. The lack of compaction of the sediment (Plate 24a) indicates that cementation was relatively early. There is no evidence of vadose weathering, consequently it is probable that the iron, and possibly the magnesium, were provided by the adjacent and overlying shales in the sequence if the cement is post-burial diagenetic in origin (Oldershaw & Scoffin, 1967).

Quartz arenites occur in the Raven Ray Formation only at Newby Cote Quarry. They contain exclusively marine fossils implying that these sands must have been deposited in seawater (Heckel, 1972). The source area of the quartz sand must have been very local because of their restricted distribution. The quartz sand is very well sorted and of the size most easily reworked (0.20mm). The very sparse bioclasts are slightly larger and must have behaved as hydraulic size-equivalents; they were subjected to the same currents as, and deposited with, the quartz sand.

There is very little interstitial silt or clay and each bed was deposited as one rapid pulse of sediment. There is no coarsening upwards sequence from clay or silt therefore the deposits are not deltaic. However, the carbonaceous streaks in the finer grained arenites do suggest some reworking of terrigenous sediment. The cross-lamination, parallel lamination and excellent sorting are indicative of sedimentation in an active nearshore environment where wave action reworked, sorted and winnowed the sediment. There is very little bioturbation of the quartz arenites and their erosive bases and truncated tops support an interpretation of an active, shallow, nearshore environment for their deposition.

The source of the quartz sand is unknown. During the period of deposition of the Raven Ray Formation much of the gentle relief of the Lower Palaeozoic rocks had been blanketed by the thickness of the Thornton Force Formation in the Ingleton and Clapdale areas. Only occasional very small ridges protruded through the carbonate sediment in those regions. The only known exposed ridge at this time was in Crummack Dale. It is possible that parts of Ribblesdale were elevated above sealevel at this time. The medium and fine grained graywackes of the Silurian Austwick Formation of Crummack Dale are a suitable source of quartz sand and silt. Unfortunately, arenites do not occur in Clapdale and there are no other intervening exposures. The only other possible source of the sand is south or southwest of Newby Cote, beyond the southern edge of the Askrigg Block. No rocks of a suitable lithology or age are exposed south of the Askrigg Block at present. It is unfortunate that the exposure of Newby Cote Quarry is so limited and difficult of access. A larger exposure would have provided more information as to the source of the quartz sand.

Sandstones in the Horton Limestone were deposited in a very similar environment to those of Newby Cote Quarry. However, in this case, the source of the quartz sand is known. The laterally impersistent quartz sands probably are attenuated representatives of boulder rudite lenses located to the south and southwest. There is surprisingly little quartz sand adjacent to the ridge in Crummack Dale; it appears to have generated mainly boulders, and the sand must have been transported into the offshore - outer shelf.

To conclude, the limited occurrence of the arenaceous rock-types implies an intermittent and local supply of quartz sand into an environment where mainly limestones were being deposited. During Douk Gill Formation and Raven Ray Formation times quartz arenites and litharenites lacking a calcarenite component were formed. This implies a lack of simultaneous carbonate and clastic deposition, probably the consequence of sudden pulses of clastic material temporarily suppressing carbonate production.

The sandstones in each area show quite individual characteristics, with their only common feature being the marine fauna and their deposition in seawater. Otherwise, the sandstones are entirely unrelated, both in space and in time.

8.6 Lutites (VI)

Lutite beds, especially thin beds, are common in the Great Scar Group. The majority are fissile and thus are shales; the remainder are nodular mudstonès. Lutites occur most frequently in the Douk Gill Formation, Raven Ray Formation and Kingsdale Limestone. Only in the Kingsdale Limestone has it been possible to demonstrate their great lateral extent (Waltham, 1971); the shales and mudstones in the underlying formations appear to be laterally impersistent and more restricted in their occurrence.

Lutites exposed in the four formations of this study can be divided into two sub-groups by their colour. Black lutites occur within the Douk Gill Formation, Raven Ray Formation and also within the Horton Limestone. They can be subdivided further using the presence or absence of calcium carbonate. Brown, green, grey and yellow lutites occur in all four formations. Most of the lutites in this group are not fissile and are, therefore, mudstones. Laminated shales occur very infrequently in all formations.

8.6.1 Black lutites (VI.i)

Calcareous black lutites occur throughout the outcrop area of the Raven Ray Formation and in the Thornton Force Formation at Stainforth and Mill Scar Lash. The Raven Ray Formation, over much of the study area, comprises interbedded, thin, black, foetid calcarenites, calcisiltites (biomicrites) and black calcareous lutites. Black calcareous mudstones occur especially at the base of the Formation whereas above the lutites are laminated and occur in thicker more persistent beds.

Calcareous black shales, similar to those described above, also occur in the upper part of the Douk Gill Formation where thin and medium beds are intercalated with calcilutite. The marine fauna is very sparse in the laminated lutites which are usually only 2-3cm thick, although they occasionally range up to 10cm. The thickest developments of calcareous lutite are in the Douk Gill Formation where beds may be up to 50cm.

Fissile, non-calcareous black shales are uncommon in the studied sequence. At Newby Cote Quarry, fissile shales are locally common in the Raven Ray Formation, underlying or overlying clean-washed quartz arenites. Lutites are altogether uncommon in the Horton Limestone and there is only one occurrence of black, fissile shale overlain by paper shale at Selside, Ribblesdale. Laminated black shales, of variable thickness, are commonly associated with rudites and litharenites of the Douk Gill Formation. A paper shale occurs at the top of this formation in Douk Cote Gill.

There is one example of a third type of black lutite. It is the seatearth below the coal in Meal Bank Quarry, Chapel-le-Dale. The black-grey shale fills a solution hollow in the top of the limestone. The shale, 1.40-3.30m thick, fills the 1.90m deep hollow and overlies the limestone. It is full of pyritised rootlets and sparse Stigmaria which have completely destroyed the original lamination. Many coal fragments are present in the uppermost 0.50m of shale, and it is overlain by 0.10-0.24m of coal.

3.6.1.1 Environment of deposition

The thin, black lutites interbedded with limestones often contain faunas compatible to those of the dark calcilutites and therefore can be considered to have been deposited in a similar environment. In general, the more fossiliferous lutites formed offshore whereas the non-fossiliferous shales were deposited closer to higher rates of clastic sedimentation which discouraged sessile benthos. Locally gradational contacts between the lutites and either limestones or sandstones suggest that lutites pass laterally into other rock-types. The zone of transition between carbonate deposition and lutite accumulation oscillated across the Askrigg Block with time during the formation of the Raven Ray Formation, as a result of fluctuations in the volume of terrigenous mud supplied. This has given rise to the interbedded limestones and lutites of the Raven Ray Formation. A modern transition between nearshore terrigenous clastics and shelf-lagoon lime muds is seen off southern Belize (Matthews, 1966). This parallels the situation envisaged for the Raven Ray Formation.

The shale with rootlets observed in Meal Bank Quarry is considered to be a seatearth. A very similar succession, a solution hollow filled with shale, shale and rootlets and overlain by coal, can be seen at the top of the Skateraw Limestone near Dunbar (Hemingway, 1968).

The seatearth can be formed by deposition within the basin of fine terrigenous material followed by *in situ* acid leaching and diagenesis related to plant growth. Alternatively, the clastic material could have suffered considerable alteration during transport and the later plant action and leaching may have had minimal effect. Frequently the depositional processes and later diagenesis create a strong vertical profile (Wilson, 1965). The construction of this profile is the result of the following sequence of events. After deposition of the first lutite it is colonised by plants. The plants retard the water velocity in the swamp encouraging deposition of finer material. As the plants grow more thickly the water velocity is further retarded. Eventually, the transporting medium loses all its power allowing semi-stagnant reducing conditions and coaly material is preserved at the top of the seatearth (Huddle & Patterson, 1961; Wilson, 1965). As a consequence of these processes laminated silts or shales pass up into non-bedded shales with abundant rootlets. The laminated coal in the upper part of the seatearth (vitrinite fragments are seen in Meal Bank Quarry) also suggests transition from seat rock formation to coal accumulation conditions. Finally, Moore (1968) points out that although coals and seatearths are a common association, it is not necessary to have both together. Coal-peat advances across areas of soil accumulation with a non-sequential relationship. It is possible for peat formation and soil accumulation to take place at the same time in different areas during early stages of the final coal-peat colonisation. The two are commonly associated because the soil phase is an important phase to be established before a peat phase in the general area (Moore, 1968).

8.6.2 Variably coloured lutites (VI.ii)

Brown, green, grey and yellow lutites occur in all four formations studied. The majority of these are not fissile and are therefore mudstones. Laminated shales occur infrequently in all of the formations.

A thick, laminated, shale occurs at only one exposure of the Thornton Force Formation. At the old quarries at Twisleton Scars (SD71287556), Chapel-le-Dale, 0.30m of laminated grey to yellow weathered shale overlie weathered Lower Palaeozoic slate. There is a gradation from weathered slate into the shale which is abruptly overlain by a matrix-supported rudite. The shale is preserved in an isolated pocket in the unconformity.

Thick laminated brown shale was observed at only one outcrop of the Raven Ray Formation. The lower part of this Formation at Ten Pound Gill (SD71837504) comprises typical interbedded, thin rubbly calcarenites and calcareous mudstones. However, the upper part consists of more thickly bedded calcarenites and a single thick (0.20-0.30m), variably laminated shale. Both overlying and underlying limestone beds have irregular contacts and the shale appears to have been deposited in an erosion or solution hollow. The shale is laterally impersistent and does not crop out in adjacent localities.

Thin brown mudstones occur in the Thornton Force Formation and less frequently in the Horton Limestone. At least one thin mudstone is present in the majority of exposures of the Thornton Force Formation. Usually the mudstones, 1-5cm thick, are located between limestone beds. Less frequently they overlie quartz arenite or matrix-supported rudite. The bedding contacts are sharp and often the top of the underlying bed appears to be eroded. In Kingsdale the mudstone at Thornton Force (SD69487533) probably correlates with the shale at SD69437512 , in the limestone quarry. Both lutites rest on the top of an irregular, eroded surface. At the latter locality the lutite can be seen to pass southwards into a granule sand at SD69447501. Mudstones are common in exposures of the Thornton Force Formation of Chapel-le-Dale but occur less frequently elsewhere, partly due to the reduced quality and extent of exposure.

Only one brown mudstone bed was observed in the Horton Limestone. At Horton Quarry, Ribblesdale, a thin brown mudstone occurs within the Moughton Calcilutite Member. It is only 1-5cm thick occurring along a stylolite parting. However, Waltham (1971) has observed numerous clusters of brown mudstones in the region of the Moughton Calcilutite Member in underground exposures on Whernside and Ingleborough.

Thin, grey-green mudstones are present in the lower clastic parts of the Douk Gill Formation at Gillet Brae and Dub Cote Gill, Ribblesdale. Black shales and mudstones are associated with the overlying limestones and grey or green mudstones with sandstones and rudites. The mudstones, mainly less than 0.10m thick, frequently contain concretions.

There is no fauna or flora in the shales and mudstones and frequently there are no bioturbation trails. All the brown, green or grey shales and mudstones are laterally impersistent and usually cannot be used to correlate even adjacent exposures.

3.6.2.1 Environment of deposition

The thin and laterally impersistent lutites described above were deposited in a number of complex micro-environments. The brown-yellow weathered lutite which grades down into weathered slate at Twisleton Scars has been interpreted by Tellam (1977) as an in situ Carboniferous weathering profile. There is a sharp boundary between the weathered shale and the overlying rudite which contains common lithoclasts but otherwise has a very similar composition. Tellam (1977) has suggested that the rudite represents reworked weathered soil profile material. The mineralogy suggests that the soil was a pedalfer, but as the soil is dominated by the parent material it is not possible to ascribe a type (Tellam, 1977).

The soil type, mineralogical composition and physical characteristics can be used to interpret the palaeoclimate. The effects of the parent material are difficult to eliminate, but the appreciable chemical and mineral changes in the soil indicate that the conditions were neither cold nor dry. Also the absence of kandites and the presence of feldspars imply that the climate was not hot and humid. There is no leaching typical of laterites. These features, together with the weathering of slate to 30m below the unconformity and the presence of montmorillonite are considered to suggest moderate to low rainfall in a warm climate. The degree and style of leaching indicates that the soil is immature (Tellam, 1977).

Transgression of the sea from the southwest stripped off the soils in exposed areas but left soils in isolated sheltered pockets, as at the old quarries. Some of the higher parts of soils were redeposited by mass-wasting from unstripped ridge tops creating the rudites seen along Twisleton Scars. Lesser slumping at Dry Gill left the 'B' horizon of the soil almost intact.

Many of the brown, thin lutites occur isolated within carbonate sequences. Although barren of fossils, it is probable that many were deposited in a marine environment as the lutites are enclosed in marine limestones. The lutites may be the products of winnowing of calcarenites in the active nearshore environments with the fine detritus being washed offshore and deposited in quiet, sheltered conditions.

Stable, quiet conditions with supressed carbonate production rates are necessary.

The thin brown mudstone occurring on top of the Moughton Calcilutite Member in Horton Quarry could have formed during a period of subaerial exposure. The Moughton Calcilutite Member is represented by a complex sequence of peritidal and subtidal calcilutites with sedimentation taking place so close to sea-level that only slight fluctuations in conditions could result in a short period of subaerial exposure. Walkden (1972) has described similar clay "wayboards" from the Holkerian and Asbian limestones of Derbyshire suggesting that many of them formed by diagenetic alteration of volcanic ash falls. Similar bentonitic shales have been described from the Asbian limestones of the study area by Waltham (1971).

The shales and mudstones in the variable clastic sediments at the base of the Douk Gill Formation are usually green or grey. They probably formed in a number of environments from freshwater to marine, wherever conditions were suitable for the deposition of clay minerals. The lutites are very thin and laterally impersistent, probably passing into and being interbedded with sandstones and siltstones. A brackish to marine lagoonal environment followed by a tidal flat environment would create suitable conditions for deposition of the above suite of sediments.

8.7. Coal (VII)

Coal is uncommon in the Great Scar Group; it occurs at only two greatly separated stratigraphical horizons. It is limited to three exposures and it is probable that both coals are very local features having restricted vertical and lateral extent.

The lowermost coal occurs at the top of the Douk Gill Formation. It is exposed at two localities at either side of Ribblesdale in the vicinity of Horton. The coal is poorly exposed in Gillet Brae (SD800719). Only 0.02m thick, it overlies 0.03m of shale, the upper

0.01m of which is non-laminated. Above the coal there are 0.02m of calcareous shale with a marine biota. At Douk Gill Scar (SD816725) the exposure is better; 0.12m of coal overlie 0.13m of weathered, poorly and discontinuously laminated shale. Above the coal there are 0.09m of shale containing coal films. The shale and coal occur in irregular hollows in the top of the underlying limestone bed; the base of the overlying limestone is virtually horizontal. Consequently, as in the extent of the outcrop the relief on the underlying bed gradually decreases to the northeast, the thickness of the shale and coal is reduced.

Coal is not seen in other exposures of the Douk Gill Formation, although it is possible that the 0.06m paper shale at Dub Cote Gill (SD819718) is an attenuated lateral equivalent.

In hand specimen the thin coal from Gillet Brae and the blocky shales of Douk Gill Scar clearly are a clarain composed of rapidly alternating thin laminae of durite and vitrite. Occasionally vitrite layers greater than 5mm thick were observed although, usually, durite dominates the clarain.

The second coal, much higher in the stratigraphical succession, is exposed to the south of the North Craven Fault. It crops out at the top of the Horton Limestone in Meal Bank Quarry, Chapel-le-Dale. Solution hollows up to 1.90m deep were infilled with, and overlain by, a thick black shale with rootlets (seatearth) and coal. The coal deposit, 0.10-0.24m thick, was first described in detail by Shelley (1967). It is unweathered and has a higher rank than seams in the nearby Ingleton Coalfield. The coal, with 90% carbon matter, closely resembles the coking steam coals of South Wales. There is a high organic sulphur content as well as a high pyritic sulphur content. The high organic sulphur and very low carbon dioxide content are striking features of coals closely associated with limestones (Shelley, 1967).

In hand specimen the coal can be seen to be composed of centimetre thick layers of durain, a black, dull coal with a greasy lustre. Thin

(2-3mm) layers of bright, shiny and brittle vitrain occur at irregular intervals in the hard durain.

8.7.1 Environment of deposition

Both coals are restricted in occurrence laterally and vertically. They overlie marine successions and are abruptly overlain by coarse grained marine limestones. The coals occur in solution hollows or in irregularities in the surface of the underlying limestone bed suggesting that there was a period of erosion or subaerial exposure prior to coal formation. The modern drowned karst in the Yucatan peninsula is a probable analogue.

Perhaps the periods of plant growth and peat formation were related to the tectonic regime. The Douk Gill Formation coal occurs in an area of downwarping, located close to the important Sulber Fault. The Meal Bank coal was deposited following tilting of the Horton Limestone lying to the south of the North Craven Fault. Activity along the latter fault line locally elevated the area to the south and subaerial solution of the tilted surface occurred.

The restricted vertical and lateral extent of both coals suggest that conditions for plant growth, peat formation and coalification must have been short-lived. A thick seatearth occurs below the Meal Bank coal showing that conditions suitable for plant growth occurred at an earlier stage. The presence of Stigmaria and rootlets suggest that large plants, possibly including Calamites, Sigillaria, Lepidodendron, Cordaites and pteridosperms, grew (Raistrick & Marshall, 1939; Van Krevelen, 1961). The seatearth provided the substrate for the Meal Bank coal.

Exposures of the Douk Gill Formation coal are very weathered and no rootlets were observed in the underlying lutites. The lack of lamination in some parts of the lutite could be the result of bioturbation by rootlets. Plants are not observed in either coal or underlying shale but Calamites and Sublepidodendron do occur in the Thornton Force Formation which is probably of a similar age.

The lower part of the Douk Gill Formation coal at Douk Gill Scar contains a large quantity of clastic material. This could be due to reworking or transportation of coal into an area of clastic deposition, in which case the coal is allochthonous. Alternatively, it is possible that the silt was washed into the area of peat formation, in which case the coal is autochthonous. There is no evidence of clastic detritus in the upper part of the coal at Douk Gill Scar. It probably formed in situ, with the plants using the lower silty coal as an anchorage.

Forest swamps were common during the Carboniferous Period. The warm, wet climate promoted rapid plant growth which, on decay and coalification, resulted in vitrain-rich bituminous coals with exinite-poor clarites. Peat could only accumulate to form thick deposits where there was slow, continuous subsidence and the water table was thus rising, so as to preserve the peat. The protection of the swamp area against inundation and a hinterland with low relief, therefore, a restricted supply of detritus, are also necessary. Both coals of this study are thin and laterally impersistent; probably conditions for coal formation occurred only very locally and were short-lived. It is likely that there was no natural sediment barrier and the peat deposits were drowned by the next marine incursion.

Peat is only preserved in areas of subsidence particularly where there is an acid pH, reduced bacterial activity and, therefore, a greater potential for preservation. The temperature of the peat near and at the surface is important as it controls the rate of decay and low Eh is required for peatification, coalification and putrification. The water must be almost stagnant not to introduce oxygen and thus preserve plant material.

CHAPTER NINE

THE DEPOSITIONAL HISTORY OF THE THORNTON FORCE FORMATION, DOUK GILL FORMATION, RAVEN RAY FORMATION AND HORTON LIMESTONE

The basic processes of carbonate sedimentation result in certain stratigraphic relations and in predictable facies patterns which are widespread in the geological record. The favoured realm of carbonate sedimentation is in warm shallow water on or bordering shelves in tectonically stable areas. In such areas sedimentation is mostly autochthonous, the locally-produced organic carbonate generally accumulating close to its site of origin (Shaw, 1964; Anderson, 1971,1974). On a very gently sloping shelf there is a tendency for a seaward, low energy zone to develop below wave base and a zone of higher wave energy to be situated somewhat shoreward where waves drag to bottom and where maximum organic productivity occurs (Irwin, 1965; Wilson, 1974). A third, interior or shoreward low-energy zone also develops. Muddy carbonate accumulates in the low energy zones and cross-laminated carbonate in the high energy zone. These sediments may reach considerable thickness, where subsidence and/or eustatic rise of sea-level keep pace with sedimentation. Thus they normally form a carbonate ramp or platform.

The hydrologic, climatic and organic controls exerted on the *in situ* production of carbonate sediment elaborate this simple trio of environmental belts (basin, shelf margin, and "backreef") into a number of sub-environments. Wilson (1974,1975) has identified nine sub-environments which result from a combination of effects of slope, geological age, water-energy and climate, and as these vary so do the patterns that they control. Also, any influx of terrigenous material will affect these patterns. Nonetheless, they are expressed by a surprisingly regular facies sequence which exists in various tectonic settings. It is significant that this sequence is so persistent: it offers essentially a single model for prediction of the geographical distribution of rock types.

Modern carbonate shelves contain shoreward lime sands which are not geologically typical, their sedimentary patterns resulting from geologically recent inundation and showing only the beginning of a sedimentary cycle of propagation. Ahr (1973) and Anderson (1974) describe a carbonate ramp situation in which a higher energy zone exists along the coast and grades outward across the shelf into fine carbonate mud deposited in open marine conditions. This ramp-type geological model is rare in the stratigraphic record.

Tectonism will, by controlling subsidence, influence thickness, facies and the vertical sequence of the facies belts. However, climatic, hydrographic and organic controls are so strong that the basic pattern will occur in varied tectonic provinces (Wilson,1975).

The standard sequence of facies (Wilson, 1975) is based on the sedimentary construction of a wedge-shaped platform or ramp on a gently subsiding planar surface and the consequent development of a submarine topography with a seaward face of variable steepness. The ultimate volume of accumulated sediment is dependent upon the increased production rates plus the stabilization processes and mechanical piling, less the normal processes of sediment-removal. The belt of maximum carbonate accumulation on a planar surface is usually at some distance from land, down the palaeoslope in shallow water, and usually parallel to the old coastline. Accelerated carbonate production along this preferred zone promotes rapid linear buildups, creating a steepened offshore gradient and a sheltered inshore lagoon. Enhanced wave attack erodes the seaward margin of the buildups and casts the debris into the lagoon, ultimately filling it. Eventually a near-level platform is constructed behind the positive area. It is by this process that a carbonate ramp builds up into a carbonate platform.

9.1 The Thornton Force Formation

Sedimentation of the Great Scar Group commenced with the formation of a complex sequence of laterally impersistent rock-types, together comprising the Thornton Force Formation. These earliest Carboniferous sediments overlie Lower Palaeozoic rocks with profound unconformity throughout the study area. They are thickest in the south, nearest the edge of the block, thinning and wedging out to the north. Superimposed on this general trend are local variations in thickness related to the topography of the rocks over which the sediments lie.

The thickest sequences, occurring in topographically lower hollows along the southern edge of the Askrigg Block, probably started to accumulate sediment during an earlier stage of the marine transgression. Consequently, by comparison with Nappa Scar, the thinner Thornton Force section represents only the upper part of the Nappa Scar development. Consideration of the relative resistance to both weathering and erosion of the Silurian/late Ordovician rocks of Crummack Dale and the early Ordovician rocks of Chapel-le-Dale would support this: thus Chapel-le-Dale probably persisted as a low island with gentle undulating topography when the Nappa Scar area had been submerged below sea level.

Sedimentation at Nappa Scar commenced with the accumulation of cross-laminated, well sorted granule arenites with a matrix of calcarenite. It is considered that these deposits formed in a non-barred, high energy shoreline environment as unconsolidated, natural accumulations of rock fragments (Clifton & others, 1971). The cross-lamination and basal scour indicate the prevalence of eroding currents, possibly channelised, moving pebbly sand as dune bedforms. The lens-like shape of the granule arenite deposit and its lateral passage into lithoclastic calcarenites can be explained by offshore transport of breakdown products from the shoreline and reworking in an environment where calcarenites were being deposited (Bluck, 1967b). The good sorting and rounding result from an extensive period of reworking in a regime of constant wave activity (Harms,1975). Water ejection structures seen in the deposit have been described in the backshore beach environment (Reineck & Singh, 1975).

Into this environment an unsorted boulder rudite composed almost exclusively of angular clasts of the Silurian Horton Flags Formation was introduced. At the moment of deposition, the main mass of rudite must have been travelling almost horizontally over the surface of the granule arenite (Sedgwick, 1982a; Moore, pers.comm. who estimated at least 200m of horizontal travel). No Horton Formation nor graywacke boulders are seen in the underlying granule arenite, although graywackes, locally present in a calcarenite matrix in the rudite, do occur close to the unconformity in Crummack Dale. Consequently, it is considered that the graywacke boulders and their calcarenite matrix were entrained in the rudite close to the contemporaneous contact of granule arenite and the Austwick Formation outcrop and were then carried the 200m or so without mixing. The scenario for this deposit requires a steep high cliff of Austwick Formation graywackes overlooking an open shallow sea. Calcarenite sands with well rounded pebbles extend through the inshore zone, rising to form a gently sloping beach at the cliff foot. At the top of the cliff the graywackes are overlain by the interbedded cleaved mudstones and laminated quartz arenites of the Horton Flags Formation. According to King & Wilcockson (1934) the Horton Flags lie in the core of a syncline; structure and weathering would combine to produce a hollow and watertrap on the Horton Flags Formation. Given that the unconformity in Crummack Dale has a visible relief of 140m, most of the cliff must have been prone to mass-wasting, especially when subject to onshore storms. Waterlogging of the cliff-top hollow would enhance the tendency to mass-wasting. It is proposed that cliff collapse, probably induced during a millenial storm, triggered a high-density debris flow which reached such velocity that at the cliff-foot, it ploughed into the boulder-strewn beach pebbly calcarenite and bulldozed some of it infront of the flow until momentum ceased some 200m from the cliff-foot. Subsequent wave erosion of the front of the debris flow is suggested by the occurrence of three isolated rounded graywacke boulders up to 30m beyond the last trace of the debris flow.

As sea-level continued to rise more of the land surface was submerged. Continuous wave action in the shore zone rapidly stripped the weathered profile down to fresh bedrock on which the winnowed remnants were deposited. Above the reach of the waves, remnants of the old weathered profile hung precariously. Sudden wetting, especially by rainstorms, so reduced their strength as to result in mass-wasting collapse, whereupon the material slid freely down the sea cliffs to the the beach below. Most of these deposits would have been quickly eliminated on the open beaches by non-storm wave reworking; however, such deposits are locally preserved in Chapel-le-Dale where several parallel graywacke ridges created a more sheltered nearshore environment. One such debris flow of reworked weathered profile overlies and preserves the <u>in situ</u> weathered profile in a small sheltered hollow. Although Ordovician slates are weathered to a depth of 30m beneath the unconformity, the degree and style of leaching suggest that the soil was immature, probably having formed in a warm climate with moderate to low rainfall. In no place is there more than a single debris flow. It is possible that all of them, at Nappa Scar as well as in Chapel-le-Dale, were formed in a single storm and thus form a timeplane permitting correlation of the Nappa Scar and Chapel-le-Dale outcrops

Above the debris flows, lithoclastic calcarenites were deposited over most of the study area. In Chapel-le-Dale, however, quartz arenites of limited lateral extent are present. They lie on the southwest side of a prominent ridge, against which they seem to be gently banked, and thin out southwesterly in a few hundred metres. In fresh outcrops they contain considerable amounts of poorly preserved plant debris including logs. Upwards they pass by intermixing into calcarenites which then become lithoclastic. They are obviously derived from the underlying graywackes; lack of a chloritic matrix and slate lithoclasts favours a two-stage process involving initial disintegration by weathering of the graywackes, followed by wave-winnowing of the sand from the weathered profile. A small amount of sand found in Dry Gill, on the northeast side of the ridge, was either washed round or more probably over the ridge summit. The latter route is favoured; it also accounts for a pocket of boulder rudite with sand matrix occurring just below the ridge-crest and close to Dry Gill.

Dry Gill is unique in preserving laminated silts and clays between the debris flow and the thin quartz arenite. Its position in the lee of the ridge provides adequate explanation for this. The lutites are waterlain; they represent the finer fractions of the weathered profile carried in suspension into sheltered areas where deposition was possible. Rootlets in the top of these lutites indicate near-emergence of the sediment surface.

All these deposits fit into a simple scenario: marine-incursion over a deeply weathered, vegetated land surface progressively swept the weathered profile away, partly by sudden mass wasting which produced debris flows, mostly by gradual erosion and winnowing of the soil so as to separate the components by grain size. The process was inevitably limited; once the soil was removed the process had to end. Fresh bedrock could generate lithoclasts but not lutite, clean quartz sand nor debris flows of weathered rock.

Pebble, cobble and occasional boulders rudites are present at the base of the limestone sequence filling small hollows in the unconformity, or stranded on bedding planes a few metres above. Most of the rudite layers and lenses were probably introduced by occasional storms, and their tops were reworked during later stages of marine inundation and frequently were winnowed of all but their largest clasts. The sources of the clasts were the topographically higher ridges at no great distance. Their sporadic distribution can be explained by intermittent supply of lithoclasts during storms. The decrease in size of lithoclasts upwards in the calcarenite sequence was mainly due to the loss of source areas by burial and lithoclasts, therefore, had to be supplied from much farther afield.

By far the greater thickness of the Thornton Force Formation consists of cross-laminated calcarenites. Lithoclastic calcarenites were probably being deposited in a nearshore-shoreface environment along the southern edge of the Askrigg Block some time before inundation of the topographically higher area to the north. Indeed, carbonate sedimentation may have been initiated at an even earlier stage at

Stainforth in Ribblesdale, where the whole of the thick sequence can be seen to consist of variably lithoclastic limestones.

As marine inundation proceeded and sea-level continued to rise the shoreline moved gradually northwards. Cross-laminated calcarenites continued to accumulate in the deeper water near the shelf edge, probably forming small sand banks. Level, duration and direction of physical energy flux (storms, tides, waves) strongly control the distribution of bank margin facies (Hine & Neumann, 1977). The storms probably shaped the bank, whereas the normal ebb and flow of the tides merely modified its shape (Hine, 1977). It has been observed that large-scale features of sand shoals do not change over a several-year period where there are no large storms (Ball, 1967;Bathurst, 1971). Only during storms did the sand bodies migrate shorewards, reworking and incorporating earlier sediments as intraclasts.

Tidal channels and the topography of the bedforms controlled the environment of deposition, resulting in rapid changes in the depositional regime; within the troughs of sand waves a low density community of green algae and sub-sea cementing processes occurred, whilst at the same time, well sorted calcarenites were being deposited on the sand waves above surge base.

Locally, ooliths are present in the calcarenite sequence. Usually they are only superficial ooliths, implying that conditions suitable for oolith-formation did not persist for long. It is probable that they were washed in from more favourable offshore environments by storm surges.

The location of the sand bank, as with the major sand banks of the Bahamas, appears to have been influenced by a rock floor high, although the major controlling factor was the influence of oceanic waves with the shelf break. The bottom topography, through its influence on currents, controlled sand body geometry, internal structure, composition and texture. Once the sand bodies had formed, they themselves became bottom topographic features which influenced the character of the associated sediment accumulations.

9.2 The Douk Gill Formation

The Douk Gill Formation, restricted in its outcrop area to the immediate vicinity of Horton-in-Ribblesdale, was probably deposited at approximately the same time as part of the Thornton Force Formation. The eastwards extension of the ridge of Lower Palaeozoic rocks seen in Crummack Dale provided shelter to the Horton-in-Ribblesdale area, allowing the accumulation of this markedly different suite of rocks. The wide ridge would so have impeded the waves that northward transport of debris across the ridge would not have been possible.

At all localities where the base of the formation is seen the oldest rocks are marine or non-marine clastics. The initial deposits at the most southerly exposure in Dub Cote Gill, nearest the ridge of Lower Palaeozoic rock, comprise lens-like beds of poorly sorted pebble, cobble and boulder rudite. These lens-like bodies are considered to be debris flow deposits which built up to form a small subaerial fan, suggesting a source area of considerable relief. The deposits are very localised, dying out northwards in less than 1km on the eastern side of the dale and present only thinly in the only visible outcrop on the western side (Gillet Brae), where they are interbedded with sandstones and shales, suggesting that individual debris flows were initiated on the steep ridge immediately to the south. The polymictic deposits reflect the complexity of the source rocks.

In Dub Cote Gill and Gillet Brae the rudites are interbedded with, and overlain by, argillaceous quartz arenites, calcareous quartz arenites and foetid calcilutites. To the north, in Douk Gill, thin bedded, slightly lithoclastic calcarenites pass upwards into calcilutites which are apparently overlain by 2 metres of quartz arenite. The argillaceous quartz arenites are locally parallel laminated or graded, bioturbated and often contain disseminated plant debris. Those interbedded with limestones are occasionally ripple cross-laminated and are either bioturbated into or have erosional contacts with the overlying or underlying sediments. The sandstones contain a sparse marine biota. The associated sediments indicate that there was a sudden change in depositional conditions. The protected area was invaded by the sea and much of the deposition of shales and foetid calcilutites appears to have taken place below wave base or in a protected lagoon. Quartz sand was introduced into this environment and usually deposited in a shallow conditions with some local wave action, creating the laminated or graded sediments seen. The presence of plant fragments suggests either local vegetation or small streams.

The argillaceous quartz arenites become much less common upwards as carbonate rock-types become more common. Most of the Douk Gill Formation comprises thinly bedded, mid grey and dark grey foetid calcilutites with occasional beds of calcarenite or calcisiltite. Fenestral calcilutites with low faunal diversity are best developed near the top of the succession. These calcilutites formed only where ridges of Lower Palaeozoic rocks provided shelter from waves and tidal currents. Carbonate sand probably built up from the end of the ridge to form a spit as the result of long shore drift, further restricting the effects of winds and tides and allowing the lagoonal deposits to accumulate in the lee. High sedimentation rates ultimately resulted in the infilling of the lagoon to above low tide level with the associated development of intertidal-supratidal fenestral calcilutites. Periodically, storms overwhelmed the barriers, introducing firstly argillaceous quartz arenites and calcareous quartz arenites and later carbonate sheet sands composed of oolitic, pelletoidal and intraclastic grains. On return to the normal, quiet conditions these storm sheet sands were commonly bioturbated into the lagoonal-tidal flat sediments.

A thin clarain coal is present at the top of the Douk Gill Formation. It succeeds the marine sequence abruptly at two localities, lying in hollows in the top of the limestone beds. The limestone appears to be a storm-pulse deposit which would have had a naturally undulose top. It could have built up above sea level, if only locally, so as to cut off the sea and allow a temporary freshwater swamp to establish. As the area lies close to the important Sulber Fault, it is possible that there was some tectonic control over the development of the coal. The coal is very thin and has a restricted lateral extent, suggesting that conditions for coal formation were not only very short-lived but also localised.

The presence of silt and sand in the lower part of the coal and the lack of rootlets in the underlying shale indicate the possibility of this coal having an allochthonous origin. Alternatively the silt and sand could have been washed into the area of peat formation, consequently the coal would be autochthonous. The lack of clastic detritus in the upper part of the coal suggests that if formed in situ with the plants using the lower silty coal as an anchorage. There was probably no natural sediment barrier and the peat deposits were drowned by the next marine incursion.

9.3 The Raven Ray Formation

The Raven Ray Formation disconformably overlies the Thornton Force Formation over most of the study area. It overlies the Douk Gill Formation in Ribblesdale and locally unconformably overlies Lower Paleozoic rocks where ridges project through the earliest Carboniferous sediment cover.

The presence of a disconformable contact between the Raven Ray Formation and the underlying Thornton Force Formation suggests an interval of erosion prior to the deposition of this formation. In Chapel-le-Dale it was noted that there appeared to be local angular disconformity between the two formations indicating not only erosion but also possible folding prior to Raven Ray Formation deposition. The top of the Thornton Force Formation is usually exposed as steep-sided mounds up to 0.50m high, but in parts of Chapel-le-Dale the contact between the two formations can be seen to be bioturbated. Considering the possiblility of folding prior to deposition of the Raven Ray Formation, it is considered that those upfolded areas were elevated above sea-level, were rapidly lithified and then a karstic surface was created by dissolution. This process would account for the absence of Thornton Force Formation lithoclasts in the Raven Ray Formation. At the same time those down folded areas remained below sea level in an incompletely lithified state and on recommencement of deposition the sediments were bioturbated into the base of the Raven Ray Formation. It is not necessary to have considerable folding to create such a situation; only local gentle warping, perhaps over basement faults, is required.

The rock-types of the Raven Ray Formation contrast with the mixed carbonate and clastic shallow water and subaerial deposits of the Thornton Force Formation and Douk Gill Formation. They represent deposition in a markedly different environment. The Raven Ray Formation required a sheltered, subtidal environment with virtually no wave activity. The calcarenites may well be storm pulses into an otherwise lime mud lagoon. High organic productivity induced semi-foetid conditions but burrowers were plentiful. The rock-type which occupied the shelf edge is unknown, but it is probable that a belt of shallower water existed there with the dark, foetid calcarenites and calcisiltites and shales forming in a slightly deeper, shelf lagoon. The wavy bedding, presence of thin shales and intense bioturbation are typical of shelf lagoon limestones (Pettijohn & Potter, 1964). These deposits are significant in that they represent environmental conditions differing widely from those which existed throughout the deposition of the major part of the Great Scar Group. The formation represents a period when relatively uniform conditions were established over most of the Askrigg Block.

The situation described above is typical of the shelf platform model described by Wilson (1975). During the marine transgression there was progradation of the carbonate shelf as a consequence of accumulation of carbonate debris. Ultimately, the rate of up-building at the shelf edge was greater than the change in sea-level resulting in the creation of a belt of shallow water shoal sediments and the shelf lagoon so typical of the carbonate platform model (Wilson,1975).

The depositional conditions which existed during the formation of the Raven Ray Formation are closely comparable with the modern carbonate lagoon/shoal complex of Belize (Matthews, 1966). There is a rapid disappearance of sand-size debris away from the shoals even in the tidal channels of varying size which carry the onshelf tidal flow and distribute normal salinity sea water along and behind the barrier shoals. This situation would account for the sparsity of crinoid debris in the Raven Ray Formation with bioclastic debris (including corals) being most common near the southern edge of the study area, closest to the shoals along the shelf edge.

The abundant micrite matrix of the dark and mid grey calcarenites and calcisiltites suggests that deposition took place below surge-base. However, deposition was sufficiently close to surge-base for agitation, winnowing and sorting of the sediments deposited as small shoals over small ridges and as beaches against larger ridges of Lower Palaeozoic rock in Chapel-le-Dale and Crummack Dale. Except for sedimentation over and against ridges, the waves operative over the shelf during deposition of the Raven Ray Formation calcarenites and calcisiltites failed to sort the grains or winnow out the lime mud.

Quartz sand and silt, as thin interbeds within a typical sequence of dark grey, foetid calcarenites and calcisiltites, was observed at one isolated outcrop probably close to the palaeo-shelf edge. The source of the sand is problematical. There is very little silt or clay and carbonaceous streaks suggest some reworking of terrigenous sediment. Each bed represents one rapid pulse of sediment with the lamination and sorting indicating deposition in an active near shore environment. At this time much of the gentle relief on the Lower Palaeozoic rocks had been blanketed by the thickness of the Thornton Force Formation with the only known exposed ridge being Crummack Dale and possibly parts of Ribblesdale. Although the Silurian Austwick Formation is a suitable source of quartz sand there are, unfortunately, no arenites in Clapdale and no other intervening exposures. Alternatively, the sand could have been derived from south or southwest beyond the southern edge of the Askrigg Block. This sand is in the appropriate stratigraphic position for the Ashfell Sandstone, which is known in Garsdale and in the Raydale and Beckermonds Scar boreholes. It is possible that the sandstone in the Newby Cote outcrop could be a tongue of the Ashfell Sandstone (Moore, pers.comm.) which occurs in the Beckermonds Scar and Raydale Boreholes.

9.4 The Horton Limestone

Generally, the Horton Limestone appears to be conformable on the underlying Raven Ray Formation, except in Crummack Dale where it oversteps the underlying Carboniferous deposits to overlie Lower Palaeozoic rocks with profound unconformity. In Wharfedale and Littondale the apparent conformity disappears. Instead, there are sharp erosional contacts between the two formations. This variation cannot be explained by a eustatic change in sea-level and it is proposed that the local erosion surface at the contact between the two formations was the result of local tilting or variable uplift of the eastern part of the study area.

Following this erosion, carbonate sedimentation recommenced, apparently conformably, over the greater part of the study area. The lowest limestones are commonly dark grey or mid grey slightly foetid calcarenites interbedded with occasional thin shales. These deposits appear to have accumulated either on the shelf below surge-base or in a protected shelf lagoon environment. The bulk of the formation consists of mid to pale grey, cross-laminated calcarenites deposited as shoals in a shallow marine environment. The paling of the colour upwards resulted from the reduction in the supply of clays, lithoclasts and organic matter as the source area was gradually buried by Carboniferous sediment.

The location of these sand shoals appears to have been controlled by the influence of deep water waves with the shelf break; irregularities in the topography of the rock-floor may also have had some influence. The sand bodies, once formed, then became bottom topographic features which were able to influence the character of the associated sediment accumulations.

Sedimentation apparently kept pace with change in sea-level and shoal sediments continued to be formed at the shelf edge above surge base. However, where ridges of graywacke protruded through the earlier Carboniferous cover, creating islands in the shelf sea, coarse shoreline deposits accumulated. The ridge in Crummack Dale is one such example. Pebbles, cobbles and boulders of Lower Palaeozoic rock with a clastic or carbonate matrix preferentially formed and were deposited at the western point of the ridge, where wave attack was concentrated. These rudites, formed only where coastal formation yielded debris of a suitable size, are considered to be beach gravels. Similar storm shoreface deposits have been described by Dott (1974) and Kumar & Sanders (1976). Sufficient energy was available frequently enough to have moved and rounded the majority of clasts less than one metre in size. Larger masses fell from cliffs, never to be moved again, and were rounded on one or two sides by bombardment by smaller clasts. Locally, undetached ribs of graywacke show signs of rounding by the same abrasional process. Storm winds would have been needed to generate breakers of sufficient height and strength to round bounlders of this size. Waves generated by millenial storms in the tropical latitudes could have rounded the graywacke fragments on the shores of Crummack Dale islands. Ultimately, the graywacke islands were buried and overwhelmed by the carbonate shoal sands.

Throughout the period of deposition of the Horton Limestone there was continuous formation of cross-laminated calcarenites as shoal sands at the shelf edge. However, as a consequence of the increased rate of carbonate production at the shelf edge, the original carbonate ramp developed, with time, into a shelf platform typical of the model of Wilson (1975). Behind this protective belt of shallower water at the shelf edge, quiet water sediments accumulated in the shelf lagoon environment in the lee. These sediments (the Moughton Calcilutite Member), mainly pale grey calcilutites lacking a truly marine biota, probably formed in a restricted environment. Truly marine forms were inhibited by abnormal salinity or a high sedimentation rate and the only marine forms present were tolerant of a wide range of environmental conditions.

The accumulation of carbonate muds and thin sands in this environment was dependent upon local, often rapid, changes in sea water agitation due to storms, unusual tides, or the formation or removal of small, yet effective barriers to water movement. When the barrier shoals remained at the shelf edge, the sheltered lagoon infilled with sediment creating a tidal flat environment. Heterogeneity of rock-types seems to be typical of tidal flat deposits as in the deposits are recorded the rapid and frequent changes of the depositional regime. Migration of islands, shifting of tidal channels or prograding of carbonate mud flats are all the result of complicated local patterns of deposition which bear no consistent relationship to the major topographic or hydrographic features of the basin.

Locally fenestrae are developed in the upper parts of the calcilutite horizons. These are interpreted as representing intervals of subaerial exposure as these features are only preserved in active diagenetic environments (Shinn, 1983a). Consequently, the sediments are considered to have formed high on the tidal flat environment. Normally, the calcilutites were not exposed to persistent subaerial conditions, probably having formed low on the tidal flat or in a lagoonal environment. Oncolites, observed at one locality, support a lagoonal setting.

Periodically, the lagoonal-tidal flat environment was overwhelmed as the barrier of carbonate shoals was breached; cross-laminated shoal sands were re-deposited over the whole of the lagoonal environment. On re-establishment of the barrier shoals at the shelf edge, the lagoon was able to reform. This sequence of events appears to have occurred at least twice throughout the study area, culminating in the youngest calcilutite which is the thickest and has the greatest areal distribution. Only during the formation of this calcilutite did the sedimentation rate exceed the change in sea-level allowing local development of tidal flats subject to subaerial exposure. Deposition was taking place so close to sea-level that only slight fluctuations in conditions resulted in short periods of subaerial exposure.

The absence of laterally extensive subaerial exposure surfaces, the rapid variations in thickness of calcilutite horizons, and the presence of a very thin earlier calcilutite horizon (in the Chapel-le-Dale area) below the two main calcilutite horizons suggests that eustacy was not the prevalent controlling mechanism. The initial formation of the lagoon was dependent upon the development of an effective barrier. Shoals could only have developed to near sea-level at the shelf edge where the sedimentation rate exceeded the local subsidence rate and the consequent rise in sea-level. Intermittently, there was a more rapid rise in sea-level or rate of subsidence resulting in the barrier shoals being breached and the calcilutite lagoon overwhelmed.

The platform lagoon environment was short lived, being finally overwhelmed by more pale grey cross-laminated shoal sands. A poorly exposed erosion surface, with relief of 0.5-1.5m, occurs some 6-11 metres above the top of the Moughton Calcilutite Member. It is probable that this surface, although widespread, resulted from minor tectonic activity in the area. Immediately south of the North Craven Fault there is an angular discordance of some $2-4^{o}$ between the eroded top of the Horton Limestone and the base of the overlying Kingsdale Limestone; this can only be explained by local tilting prior to deposition of the Kingsdale Limestone. It is probable that this tectonic event had some affect on the area to the north of the fault, resulting in the erosion surface seen.

A coal and underlying sea earth are present in a local hollow, eroded into the top of the Horton Limestone, at a single locality south of the North Craven Fault. The presence of this coal indicates a significant change in environmental conditions; subaerial exposure of the top of the limestone is required. The coal and shale filling the hollow together have a thickness of over 3 metres. There would have to be at least this amount of uplift above sea-level to produce the solution hollow. In the hollow, freshwater collected and stagnated, and providing a suitable environment for the preservation and coalification of plants which grew therein. The environment of coal formation was very short lived as the coal is neither laterally nor vertically extensive. It is likely that no natural sediment barrier existed and the peat deposits were drowned during the next marine incursion.

9.5 Controls over Carboniferous Sedimentation

The major controls over the formation of the Thornton Force Formation, Douk Gill Formation, Raven Ray Formation and Horton Limestone were the topography of the substrate, tectonism, the rate of sedimentation and the water depth. There is no evidence of eustacy regulating the formation of the various rock-types.

Early in the history of deposition of Lower Carboniferous sediments, the surface topography of the pre-Carboniferous rocks was the most significant control of sedimentation. Tectonism and the rate of sedimentation locally influenced the type of deposit which accumulated. Pebble, cobble and boulder rudites derived from the local Lower Palaeozoic rocks accumulated in the hollows, whilst virtually lithoclast-free calcarenites were deposited over the eminences. Variations in topography allowed freshwater-brackish water lagoons to develop in protected environments before being overwhelmed by normal marine calcarenites. In the lee of the extensive graywacke ridge of Crummack Dale and Ribblesdale gradual inundation of the protected environment resulted in the accumulation of lagoonal and tidal flat sediments above terrigenous subaerial deposits.

As the ridges of pre-Carboniferous rocks were buried by Carboniferous deposits their influence was significantly reduced. The ridges were no longer of sufficient height or lateral extent to create protected micro-environments in their lee and the reduction of the source area resulted in less clastic material being supplied to the depositional environment. Instead, tectonism, the rate of sedimentation and water depth became more significant controls.

The effects of tectonism can be demonstrated throughout the deposition of the four studied formations. The angular discordance between the Horton Limestone and overlying Kingsdale Limestone south of the North Craven Fault can only be explained by tectonism and the erosion surface seen at the top of the Horton Limestone in the area to the north can only have formed at the same time. Also the local development of erosion surfaces on the tops of both the Thornton Force Formation and the Raven Ray Formation can best be explained by minor tectonism resulting in flexure of the Askrigg Block. It is probable that variable rates of subsidence controlled the intermittent development of the lagoonal-tidal flat environment of the Moughton Calcilutite Member. The Sulber Fault appears to have been active during deposition. North of this fault, the lower beds of the Moughton Calcilutite Member are unusual in that they are mid grey to black. Sedimentary structures and slump structures in the associated beds of calcarenite suggest a source to the north.

The influence of the rate of sedimentation can be demonstrated most clearly during deposition of the Horton Limestone. The sedimentation rate must have out-paced the rate of subsidence to form barrier shoals at the shelf edge, allowing a protected platform lagoon to develop in their lee. Once the lagoon was formed, intermittent and local increased sedimentation rates resulted in the development and progradation of tidal flats and, periodically, subaerial exposure. A second example of the influence of the sedimentation rate is the Douk Gill Formation. The rate of sedimentation was more rapid than the rate of inundation of this area, resulting in progressive infilling with lagoonal, then tidal flat and finally subaerial deposits.

The influence of water depth on sedimentation was a less significant process during deposition of the studied formations, however its influence can be demonstrated. During the formation of the cross-laminated calcarenites of the Thornton Force Formation the crests of the sand waves on the sand bank were above surge depth and the troughs below. Consequently, whilst coarse grained, moderately to well sorted, abraded calcarenites were being deposited on the crests, finer grained, more poorly sorted calcarenites with a dusty sparite cement were being formed in the troughs. The depth of water during deposition of the Raven Ray Formation is difficult to ascertain. However, where occasional ridges of graywacke protruded through the earlier Carboniferous sediment cover, the substrate was sufficiently elevated for deposition of coarse grained, cross-laminated, bioclastic calcarenites above local surge-base. For the most part, deposition of the Raven Ray Formation was below local surge-base. In a sheltered lagoon, surge-depth would be shallower than in the open shelf.

Finally, to conclude, it has been suggested by Miller & Grayson (1982) that the block and basin model is not the most satisfactory mechanism for explaining features seen in the Carboniferous successions of Northern England. This model explains subsidence as being the result of isostatic readjustment of the basement (Johnson, 1967). The discovery of the concealed Weardale Granite beneath the Askrigg Block and the Wensleydale Granite beneath the Alston Block gave strong support to this mechanism.

The block-basin transitions are not always as abrupt as the advocates of the hypothesis might require. To account for these variations, Miller & Grayson (1984) have developed the tilt-block model. These authors felt that this model could be used with far more precision to account for the thickness and facies variations displayed by Dinantian sediments.

CHAPTER TEN

PROBLEMS OF CORRELATION

Owing to its economic importance, the biostratigraphy of the Carboniferous System has attracted more attention than any other Palaeozoic System. For many decades, it was the only System to have its own symposia and international meetings. Subdivision of the System has generated much argument exacerbated by the American practise of splitting it into two discrete Systems:- Mississippian and Pensylvanian. Multiple ad hoc divisions of the Carboniferous System in Western Europe have been made over the years and adopted, with varying success and accuracy, farther afield. The Carboniferous Congress in Moscow (1975) drew attention to the prevailing chaos but failed to resolve it. Since then Western Europe and Russia have tacitly decided to go their own ways: in Western Europe the Dinantian Subsystem has been defined and divided into two Series, Visean and Tournaisian, based on outcrops in southeast Belgium. George & others (1976) divided the British Dinantian into six stages, the younger five being later equated with the Visean Series and the earliest stage (Courceyan) subsequently modified to equate with the Tournaisian Series (Ramsbottom & Mitchell, 1968). Shortly afterwards, Belgian geologists proposed to divide the Tournaisian Series into two stages, Ivorian and Hastarian (Conil & others, 1977). There are still those who dissent; Chlupac & others (1981) believed that there was no cogent reason to elevate Tournaisian and Visean to the rank of Series; they insisted that no intermediate scale of units was needed between the Tournaisian and Visean and the biostratigraphic zones.

An assertion has been made recently that the primary factor in Carboniferous deposition was eustacy (Ramsbottom, 1973;1974;1977 and 1982). Subsisdence, other than isostatic, took place mainly in basinal areas. Shelf sediments have frequently been interpreted as cyclothemic, comprising deposits formed during a large number of small transgression and regression. These have been grouped into larger scale cycles of trangressions and regression called mesothems; several mesothems constitute an ever larger unit, the Carboniferous Synthem. The eustatic stratigraphical units are considered to be time-significant (Ramsbottom, 1973) and to exist in parallel with the orthodox chronostratigraphic units of series and stages. Ramsbottom (1977) identified 11 mesothems in the Dinantian Subsystem with the rather slow transgressions occupying most of the period allocated to that mesothem. The occurrence of a regressive lowering of sea-level between each of the major transgressions in the British Dinantian Subsystem was inferred (Ramsbottom, 1973) from the presence of karsts and erosional non-sequences in marginal areas.

George (1978) challenged the eustatic hypothesis on lithostratigraphic and structural grounds, concluding that "pulsed diastrophism during British Dinantian times was of a magnitude to subsume and obliterate most or all signs of oceanic changes in sea level". He was supported by G.A.L. Johnson and M.R. Leeder (Discussion, 1978, pp 254-262, who concluded that Ramsbottom's interpretation of trangression-regression as eustatic rise and fall could "simply record a pattern of episodic transgression, each sea-level rise being followed by compensatory coastline progradation before the next transgressional event".

Stages have, by definition, a definitive base and top and a type-section, whereas cycles have no definite boundaries and frequently have been modified. Definition of a stage lacks any allusion to a major cycle or group of minor cycles, or to any particular kind of lithology, although stages have been stated to be "approximately equivalent" to major cycles or groups of minor cycles (George & others, 1976). George (1978) quotes numerous examples of miscorrelation between different areas using the eustatic hypothesis and lists many changes which have been made to the boundaries of cycles.

The top of the Horton Limestone can be identified, though not without some difficulty, in the west of the study area. The contact between it and the overlying Kingsdale Limestone is an erosion surface, occurring at the foot of the lowest thick "post" of the Kingsdale Limestone and some 6-11 metres above the highest, thickest and most extensive development of calcilutite in the Moughton Calcilutite Member. This very distinctive calcilutite has been used by previous workers

(Garwood & Goodyear, 1924; Doughty, 1968; Waltham, 1971 & 1974; Ramsbottom, 1974) as a convenient boundary between the Holkerian Horton Limestone (the youngest rocks here studied) and the Asbian Kingsdale Limestone, because it is easily identifiable in the field. Although the present stratigraphic subdivision of Great Scar Group into the formations described in this study approximately equates with the biostratigraphic subdivisions constructed by Garwood & Goodyear (1924), no link with biostratigraphic zones is implied. The boundaries between the formations have been defined on purely lithostratigraphic grounds.

Recent work by Conil & others (1979) and Fewtrell & others (1981) on age determination of Dinantian rocks using microfossils has not clarified the situation. Their poor reporting of specimen localities, including the lack of lithological detail, makes it virtually impossible to assign ages to the studied formations. However, using their published data together with the published biostratigraphy of the Beckermonds Scar borehole (Strank, 1982) it is possible to place the studied succession within a time-stratigraphic framework and to locate the Holkerian-Asbian boundary.

In the Beckermonds Scar borehole the Garsdale Limestone consists of strata of late Holkerian and early Asbian age and, as such, partially equates with the Horton Limestone of the Ribblesdale area (Wilson & Cornwell, 1982). The uppermost 10 metres of the Formation contain a restricted Asbian foraminiferal assemblage whereas the major part contains a typical Holkerian assemblage. It may be significant that a very fine grained limestone containing abundant varied calcispheres is present at the abrupt contact between the Holkerian and Asbian assemblages (Strank, 1982). This horizon could equate with the Moughton Calcilutite Member. The Kingsdale Limestone of Yew Cogar Scar and Gordale Scar have been identified of being go early Asbian age (Fewtrell & others, 1981), whereas the presence of Holkeria avonensis (A.R.E.Strank, pers. comm.), a foraminifer found only in the Holkerian of the British Isles, restricts the Horton Limestone to a Holkerian age. It is proposed tha the Holkerian/Asbian boundary is located at the position of the erosion surface at the top of the Horton Limestone in the Ribblesdale area. The present of this surface could account for the lack of an early Asbian fossil assemblage in this area (Ramsbottom, 1974). The Holkerian/Asbian boundary cannot be accurately located in the Scaleber Force Limestone at Scaleber Bridge near Settle. Whereas Arundian foraminifera have been identified at the base of the succession by Conil & others (1979) and Asbian foraminifera in the upper part of the Scaleber Force Limestone (Fewtrell & others, 1981), no Holkerian microfossils have been recorded at this locality.

10.1. Problems of Correlation within the Study Area

Correlation is made more difficult in the study area by (i) the sporadic exposure of the oldest Carboniferous rocks through a veneer of till, alluvium or scree, (ii) rapid change in lithology of sediments unconformable on the Lower Palaeozoic rocks and (iii) the lack of palaeontological and lithological marker horizons. Correlation has been further complicated by the introduction of new stratigraphic nomenclature inadequately described and incorrectly applied in the literature, and by the misuse of existing stratigraphic terminology.

The Horton Limestone, a new formation (Ramsbotton, 1974), was created because the limestones, although of Holkerian age, were not closely comparable in either age or lithology with the Holkerian Ashfell Limestone of Ravenstonedale. In defining this formation, Ramsbottom excluded the underlying Gastropod Beds (Garwood & Goodyear, 1924) but included the Porcellanous Band (Moughton Calcilutite Member) which they had previously placed in the base of the *Dibunophyllum* Zone. Later, creating more confusion, Ramsbottom (in Ramsbottom & others, 1981) incorporated the Gastropod Beds and the *Michelinia grandis* Beds (of Arundian age) in the base of the Horton Limestone. In doing so he incorporated within the Horton Limestone beds with contrasting lithological characteristics and fossil assemblages.

The top of the Horton Limestone, previously taken to be the Porcellanous Band (Moughton Calcilutite Member) is considered, in this report, to be a pronounced erosion surface some 6-11 metres higher in the sequence. This separates massive, thick bedded limestones of the Kingsdale Limestone from the poorly bedded, blocky jointed and obscurely bedded limestones of the Horton Limestone. As such, the Porcellanous Band becomes an integral part of the Horton Limestone. Ramsbottom (1974) mentions local unconformity, occasionally associated with dolomite, between the Horton Limestone and Kingsdale Limestone; possibly he is referring to this surface. Eastwards, the Porcellanous Band fails, occurring only in the most northerly part of the study area. In the areas of non-exposure or non-occurrence of the Moughton Calcilutite Member it becomes extremely difficult to distinguish between the Horton Limestone and overlying Kingsdale Limestone. Doughty (1974) identified the boundary between the Holkerian (Horton) and Asbian (Kingsdale) limestones in the area of Stainforth, between the Craven Faults, by using the jointing patterns that he had observed during his earlier studies (Doughty, 1968). This technique has not been applied, in detail, to the area north of the Craven Faults.

Below the Horton Limestone (as used in this report), correlation becomes more problematic because of the role of the unconformity in the control of rock-types immediately above it. The problems are exacerbated by exposure which is sporadic and frequently extremely poor. However, it appears that the Douk Gill Formation is at least a partial equivalent of the Thornton Force Formation because both are overlain by limestones typical of the Raven Ray Formation. The age of the oldest Carboniferous deposits has been questioned by some workers. Waltham (1976) stated that the oldest beds in Kingsdale were of S_1 age (Upper Arundian) and Ramsbottom (1974) ascribed all limestones exposed at Twisleton Scars to the Holkerian Horton Limestone. However, recent foraminiferal dating has shown that the limestones of Thornton Force, Kingsdale, and therefore its equivalents in Chapel-le-Dale are of Arundian age (Ramsbottom & others, 1981).

The recent introduction of new terminology by the Institute of Geological Sciences (Mundy & Arthurton, 1980) has not clarified the situation. They retain the term Horton limestone although it now comprises only the upper pale grey calcarenites and overlying calcilutite(s), the mid and dark grey calcarenites at the base being incorporated in the newly defined Kilnsey Limestone (Wilson & Cornwell, 1982, Fig.2.). This new formation incorporates, as well as the lower part of the Horton Limestone, the underlying, dark grey, foetid, locally shaly calcarenites and calcisiltites of the Raven Ray Formation and the pale grey, cross-laminated calcarenites of the Thornton Force Formation. In so doing, no attention has been paid to the distinct lithological and palaeontological differences between these formations, as described in this report, and to the obvious erosion surfaces developed on top of the formations. One such surface, the contact between the foetid, shaly, dark grey calcarenites of the Raven Ray Formation and the overlying massively bedded, mid grey calcarenites of the Horton Limestone, is particularly well exposed a few metres above the base of the exposure at Kilnsey Crag itself.

It is extremely difficult to locate the top of this new Kilnsey Limestone from the brief descriptions given by both Mundy & Arthurton (1980) and Wilson & Cornwell (1982). As mid grey limestones pass gradually into pale grey limestones through a thick interval of interbedded pale grey and mid grey limestone beds, is the top of the Kilnsey Limestone placed at the lowest occurrence of pale grey limestone or at the highest bed of mid grey limestone?

10.2. Correlation with Garsdale and the Raydale and Beckermonds Scar Boreholes.

An outline of the correlation of the Dinantian rocks of the Beckermonds Scar and Raydale Boreholes with sediments of similar age on the southern edge of the Askrigg Block is provided by Wilson & Cornwell (1982). This report is complicated by the introduction of new stratigraphic nomenclature, inadequately described and defined, for both limestones of the Wharfedale-Kingsdale area and the sediments of the boreholes. The new stratigraphic terminology applied to the rocks of the Beckermonds Scar and Raydale Boreholes has been extrapolated from Garsdale, where these new formation names were first proposed after detailed lithological mapping by the Institute of Geological Sciences. Unfortunately, this work has not yet been published and the criteria used to define the formation boundaries remains unknown. These new formations replace the adequate but antiquated terminology of Garwood (1913). The approximate equivalent of the Michelinia grandis Beds is the Tom Croft Limestone, overlain by beds of the Ashfell Sandstone (equivalent in age to the Gastropod Beds). The overlying beds of the Cyrtina carbonaria Subzone and part of the Nematophyllum minus Subzone have been termed the Fawes Wood Limestone and the overlying Garsdale

Limestone comprises the remainder of the *Nematophyllum minus* Subzone and the lowest part of the *Dibunophyllum* Zone.

Wilson & Cornwell (1982) proposed that the Garsdale Limestone (a sequence of late Holkerian and early Asbian dark grey biomicrites and 10 porcellanous calcilutites approximately 41 metres thick) was probably equivalent to the Horton Limestone of the Ribblesdale area, although contrasting greatly in colour. Wilson & Cornwell (1982) found no trace of the Horton Limestone in the Beckermonds Scar Borehole but concluded that is passed laterally into the Garsdale Limestone. This correlation is plausible; beds of dark shaly limestones occur not far above in northern Ribblesdale. Jefferson (1980) claimed that the outwardly uniform Horton Limestone contained nine sedimentary cycles which Wilson & Cornwell (1982) suggested may be, in some way, related to the apparent cycles in the Garsdale Limestone. There is one problem with this correlation, Jefferson identified his cycles in the Horton Limestone as defined by Ramsbottom (1974) whereas Wilson & Cornwell refer to the Horton Limestone as the upper pale grey limestones only. Hence, there are fewer cycles present in their reduced Horton Limestone. At the same time, these cycles are unrecognisable in field exposures except in Garsdale, and individual cycles cannot be identified or correlated without the exposure of either the top or the base of the Formation.

Much of the Fawes Wood Limestone is considered by Wilson & Cornwell (1982), using lithological and faunal evidence, to be broadly equivalent to the upper part of the Kilnsey Limestone (previously the lower part of the Horton Limestone). The Fawes Wood Limestone, 55.80m thick in the Beckermonds Scar Borehole, comprises mid to dark grey limestones, mainly intraclastic calcarenites, and is thus closely comparable with limestones of a similar age along the southern edge of the Askrigg Block. The authors considered the underlying Gastropod Beds of the southern edge of the Askrigg Block to be of Holkerian age and thus incorporated them in the Kilnsey Limestone.

The sandstones at the top of the Raven Ray Formation in Newby Cote Quarry are a possible extension of the Ashfell Sandstone. Both at Raydale and Beckermonds Scar Boreholes, identification of the Ashfell

Sandstone is based on stratigraphic position not on determination of source area nor of palaeocurrent orientation and the sand at Newby Cote Quarry is at the appropriate stratigraphic level. This outcrop is particularly important in that other exposures of the top of the Raven Ray Formation show no significant sand.

The Ashfell Sandstone, whose top marks the base of the Holkerian Stage, consists of alternations of cross-laminated, fine grained sandstone and some mudstone with beds of dark grey limestone as seen in Garsdale where a similar thickness is exposed (Turner, 1959). The Ashfell Sandstone at Garsdale and in the Beckermonds Scar and Raydale Boreholes is an attenuated representative of the 150 metre-thick formation of that name at Ravenstonedale, where it consists of four pulses of terrigenous clastics separated by limestones.

The Arundian Tom Croft Limestone, including a Michelina megastoma fauna, is equivalent to the lower part of the Kilnsey Limestone with a similar fauna (Michelina grandis Beds of Garwood & Goodyear, 1924). Wilson & Cornwell (1982) described only the dark grey limestones of Kingsdale as being typical of this part of the Kilnsey limestone, ignoring the pale grey, coarser grained limestone, frequently containing lithoclasts, below.

Wilson & Cornwell (1982, Fig.6) describe the thickening of Arundian and Holkerian sediments northwards, away from the southern edge of the Askrigg Block, into a "basinal" area. At the same time, the abundance of shallow water phenomena, particularly fenestral calcilutites and coal seams in the Garsdale Limestone, suggested a pattern of repeated shallowing of the sea over a long period spanning Holkerian to latest early Asbian times. Wilson & Cornwell (1982) did not find it easy to relate these facts to the concepts of cyclicity and periods of low sea level events (Ramsbottom, 1977).

10.3 Correlation Skyreholme and Greenhow

Anderson (1928) has described the limestones exposed in the Skyreholme Anticline. Lithologically and faunally, these limestones appear to be more closely related to the shelf limestones along the southern edge of the Askrigg Block than to the basinal sequence of the Pennine Basin. The oldest exposed beds (S, or Holkerian age) are crinoidal limestones almost devoid of fossils. The upper limit of these limestones is defined by a Porcellanous Band and Anderson suggested that the presence of strong permanent springs at the base of the limestones indicated the presence of pre-Carboniferous rocks.

The limestones comprising the succession at Greenhow have been described by Dunham & Stubblefield (1945). The limestones, poorly exposed and forming small anticlines, are separated into a number of inliers by small faults, They range in age from S_2 (Holkerian) to D_2 (Brigantian), although it it possible that the lowest limestones may be older. The poorly exposed Timpony Limestone was considered by Dunham & Stubblefield (1945) to be of S_2 age and, therefore, a lateral equivalent of the Horton Limestone. Lithologically it is similar to the cherty black limestones with shale partings of probable Holkerian age at Scaleber.

10.4 Correlation with Furness and Arnside.

Lower Visean macrofaunas are well developed in the Martin Limestone, Red Hill Oolite and Dalton "Beds" of the Furness-Grange area and the rocks of equivalent age in Ravenstonedale. The brachiopods and corals contained therein are listed by Mitchell (1972, p153). Mitchell considered that the assemblages recovered from the Dalton Beds were typical of those from Garwood's (1913) Michelinia grandis Zone of the Northwest Province, resulting in his correlation of the Dalton Beds with the Michelinia grandis Beds of Ravenstonedale. He concluded that there was no evidence of a Tournaisian faunal assemblage being present in the Martin Limestone and that all beds of the Furness-Grange area were of lower Visean age.

The Furness-Arnside sequence (described in detail by Dunham & Rose (1941) and Rose & Dunham (1978) has been correlated with adjacent areas by Ashton (1970) and Mitchell (1978). The Red Hill Oolite has an abrupt disconformable base, overlying the Martin Limestone, and the top is transitional over a few metres into the overlying Dalton Beds. Adams & Cossey (1981) describe the local development of calcrete at the junction between the Martin Limestone and Red Hill Oolite. The thickness averages some 60m although a thickness of nearly 75m has been recorded by Ashton (1970) near Plumpton. He thought that the Red Hill Oolite increased in thickness at the expense of the overlying Dalton Beds which thin rapidly in this direction. Ashton (1970) considered these beds to be equivalent in age, although varying considerably in lithology, to the Ravenstonedale Limestone of Ravenstonedale and Garsdale and to the pale grey limestones at the base of the Carboniferous succession (Thornton Force Formation) along the southern edge of the Askrigg Block. The faunal assemblage of the Red Hill Oolite of the Furness-Arnside area is similar to that of the Thornton Force Formation, both of which are predominantly pale grey, cross-laminated, intraclastic calcarenites. Some notable differences occur:- the Red Hill Oolite consistently overlies the Martin Limestone and is wholly of limestone. Its top 15m contains small organic buildups ("reefs"), especially well exposed in Elliscales Quarry, Cumbria (SD22457480), and there is a conformable passage into the overlying Dalton Beds. The Thornton Force Formation, invariably resting on Lower Palaeozoic rocks and wedging out against them in several places, contains abundant clasts from the Lower Palaeozoic rocks, particularly at the contact; its top is in many places an emersion surface, abruptly and disconformably overlain by the Raven Ray Formation.

Adams & Cossey (1981) state that the placing of the boundary between the Martin Limestone and Red Hill Oolite by Dunham & Rose (1941) appears to be arbitary, being taken at an algal nodule "band". This is within a sequence, interpreted by Adams & Cossey as being deposited under subaerial and terrestrial conditions and only locally developed in the vicinity of the Leven estuary. Adams & Cossey therefore considered that local tectonic movement, not eustatic fluctuation, was responsible for a period of emergence at the Martin Limestone/Red Hill Oolite contact.

Dark grey fossiliferous limestones of the Dalton Beds (Dunham & Rose, 1941) crop out in the Furness and Arnside areas and correlate with limestones of similar age and lithology (Raven Ray Formation) exposed along the southern edge of the Askrigg Block (Ashton, 1970). The Dalton Beds, varying between at least 130m and 255m thick, are conformable on the Red Hill Oolite and are conformably overlain by the Park Limestone in Furness and the Knipe Scar Limestone in Arnside. The thickness variation is attributed to diachronous base and top by Nicholas (1968) who considered that the Dalton Beds were a combination of basin-facies sediment and shelf-facies fauna. Along the southern edge of the Askrigg Block the Raven Ray Formation is less uniform in lithology, much thinner (generally less than 15m) and locally disconformable on the Thornton Force Formation or disconformable beneath the Horton Limestone. Without a more detailed study of the faunas contained therein, it is not possible to determine to which part of the Dalton Beds the Raven Ray Formation is equivalent.

The Knipe Scar Limestone of Arnside and the Park Limestone of Furness are equivalent in age to the Horton Limestone of Ramsbottom (1974) of the Askrigg Block. Ashton (1970) states that the Knipe Scar Limestone originally defined in the Shap area by Garwood (1913) and dated as upper Asbian by Ramsbottom (1979, p151), can be traced throughout the area occupied by the Ravenstonedale Limestone and its equivalents in the Furness to Kendal area. Deposition of the Knipe Scar and Park Limestones coincides with widespread deposition on the block areas, and correlatives include the Melmerby Scar Limestone of the Alston Block, the Seventh, Sixth, Fifth and the base of the Fourth Limestones in West Cumbria, as well as the Horton Limestone on the Askrigg Block (Ashton, 1970).

More recently the stratigraphy of the Carboniferous of the northern parts of England has been re-interpreted. Mitchell (1978) correlates the Park Limestone of the Furness area with the Ashfell Limestone of Ravenstonedale assigning both to the Holkerian Stage, whereas the Knipe Scar Limestone, Melmerby Scar Limestone, Sixth, Fifth and lower part of the Fourth Limestones are re-assigned to the late Asbian Stage. Everywhere except in Ravenstonedale, where the Potts Beck Limestone occurs, there is a considerable hiatus of early Asbian age.

Mitchell (1978) also reports the presence of Arundian faunas (Thysanophyllum pseudovermiculare and foraminifera) in the lower part of the Seventh Limestone at its southwestern and southeastern limits, re-identifying what was first listed as Lonsdaleia duplicata. If the corals are Thysanophyllum pseudovermiculare then they are of early Arundian age and the overlying part of the Seventh Limestone is either a condensed deposit or includes a non-sequence omitting late Arundian rocks. Nudds (1981) reports the presence of Dorlodotia briarti, a fasciculate Lonsdaleid coral, intermediate in character between Thysanophyllum and true Lonsdaleia, from Ravenstonedale but omits to record that his specimens came from the Thysanophyllum Bed of the Scandal Beck Limestone. He places Dorlodotia in the late Arundian Stage, thus eliminating the need for condensed sedimentation or non-sequence in the Seventh Limestone. This looks like an evolutionary lineage but it needs much more evidence before it can be relied upon. All published records of pre-Brigantian Lonsdaleids must be regarded as unreliable and in need of modern reappraisal. Since they have been used to define the Chadian and Arundian Stages one has to regard designations of these stages as suspect.

10.5 Correlation with Areas to the South

Satisfactory correlation of the Great Scar Group with the succession in the Pennine Basin has not yet been achieved, although several attempts have been made (Rayner, 1953; Ramsbottom, 1974). The black limestones exposed at Scaleber Quarry near Settle may be of similar age to the late Arundian early Holkerian limestones on the block. Further south, the Holkerian Stage lies within the Worston Formation (Fewtrell & Smith, 1980). Rocks of Arundian age comprise the upper part of the Clitheroe Formation and the lowest part of the Worston Formation (Fewtrell & Smith, 1980).

The Derbyshire Dome consists predominantly of Carboniferous limestone of Holkerian, Asbian and Brigantian age. Older limestones have been proved in boreholes. These shelf limestones have been described by many authors, and are considered to have been deposited predominantly as a consequence of eustatic changes in sea level.

Limestones of a similar age to the Horton Limestone have been assigned to the Woo Dale Limestone by Aitkenhead & Chisholm (1982).

In North Wales the late Holkerian-early Asbian Ty-nant Limestone has been described by Somerville (1979). It consists of cycles 2-4m thick, comprising lower argillaceous limestones and shales deposited in a subtidal environment overlain by peritidal porcellanous limestones, developed as prograding/regressive episodes during a major Dinantian trangression (Gray & Somerville, 1984). At least twenty cycles, each reflecting a proximal shelf environment with progradation of peritidal facies over transgressive phase subtidal facies, have been recognized in the Llangollen Embayment. Interestingly, it is with these limestones that Wilson & Cornwell (1982) draw their closest parallel with the Garsdale Limestone of the Beckermonds Scar Borehole.

Somerville & Strank (in press) record *Dorlodotia briarti* in North Wales, thus extending the age of the Dinantian limestones there down into the Arundian Stage. They acknowledge Dr. Nudds for critical comments, so one may rely on their identifications of *Dorlodotia*.

Mitchell (1972) discusses the faunal assemblages of the northwest and southwest of England suggesting that the Red Hill Oolite (and therefore the Thornton Force Formation) may at least in part be equivalent in age to the Gulley Oolite of the Bristol area. The Martin Limestone may correlate with the Sub-Oolite Bed, the faunal link between the two provinces being provided by the occurrence of *Thysanophyllum pseudovermiculare* in the Martin Limestone and *Levitusia humerosa* in the Sub-Oolite Bed at Weston. Hudson & Dunnington (1945) record these two species as members of the lowest Visean assemblage in the Central Province.

CHAPTER ELEVEN

SUMMARY AND CONCLUSIONS

1. The lowermost four formations of the Great Scar Group, together comprising approximately 100 metres of the 200 metres total thickness, have been defined, described and mapped across their entire outcrop area. In general, the formations, first described by Garwood & Goodyear in 1924, are recognisable throughout the study area. However, at the top of the studied sequence, where the Porcellanous Band, a distinctive marker unit fails, it becomes difficult to separate the studied formations from the remainder of the Great Scar Group.

2. The Thornton Force Formation, which is the lowermost formation of the Great Scar Group on the Askrigg Block, has been mapped across its entire outcrop area on a scale of 1:10,000 or 1:10,560. Thickness variations of the formation as a whole, and of its individual members, have been recorded. The formation is incompletely exposed along the southern edge of the Askrigg Block, but is at least 20 metres thick at Stainforth Force. Complete exposures occur to the north of the North Craven Fault and display a general thinning from 21.95m to zero in a northerly direction. Superimposed on this simple trend is a complex variation in thickness intimately related to the topography of the underlying Lower Palaeozoic rocks. Generally, the shales, slates and siltstones of the Lower Palaeozoic rocks are less resistant than the graywackes and, consequently, tend to form hollows. These hollows are frequently filled with pebble, cobble or even boulder rudites, with sporadic shales, and are overlain by variably lithoclastic, cross-laminated calcarenites. Calcareous sandstones overlie the rudites only in Chapel-le-Dale.

3. The Douk Gill Formation is restricted at outcrop to a small area in the vicinity of Horton-in-Ribblesdale. It overlies Lower Palaeozoic rocks unconformably and is probably at least a partial

time-equivalent of the Thornton Force Formation. However, it has been designated a separate formation because of the greatly contrasting rock-types contained therein. Named after the thickest and most complete sequence at Douk Gill (16.88m), the formation is exposed at only three other localities. It is definitely absent on Moughton Nab, in Crummack Dale as far north as Studrigg and in Silverdale. A complex sequence of non-marine clastic rocks and marginal marine mixed carbonate and clastic rocks occurs at the base of the formation. The sequence is dominated by sparsely fossiliferous, foetid, mid to dark grey calcilutites. A thin coal (2-12cm thick) is present at the top of the formation at two of the localities.

4. The Raven Ray Formation has been mapped across its entire outcrop area on a scale of 1:10,000 or 1:10,560. The formation is thickest (about 24m) along the southern edge of the Askrigg Block, where it overlies the Thornton Force Formation disconformably, thinning to the north where it oversteps onto Lower Palaeozoic rocks. The characteristic sequence of foetid, black calcarenites and calcisiltites interbedded with black mudstones is best developed to the north of the Craven Faults. Near the North Craven Fault more crinoidal, thicker bedded, non-foetid limestones, with erosive bedding contacts, are more common, and in a single exposure south of this fault quartz siltstones and sandstones occur at the top of the limestone sequence. Locally, pebble, cobble and boulder rudites are present at the base of the formation where it unconformably overlies lower Palaeozoic rocks. In Ribblesdale, the Raven Ray Formation overlies the Douk Gill Formation abruptly. The upper part of the formation is seen in Wharfedale, where it retains its foetid character. Its base is not exposed here.

5. The Horton Limestone has been mapped across its entire outcrop area on a scale of 1:10,000 or 1:10,560. Generally, the formation varies in thickness between approximately 61 metres and 96 metres, except where it oversteps the underlying Raven Ray Formation to lie with profound unconformity on Lower Palaeozoic rocks. In Crummack

Dale the Horton Limestone thins to only about 25 metres. The Moughton Calcilutite Member, a distinctive mappable unit, occurs near the top of the formation in the northern part of the study area, thinning and failing to the south and east. In its absence it is difficult to distinguish the calcarenites of the Horton Limestone from those of the overlying Kingsdale Limestone.

6. Sixteen rock-types (intraclastic calcarenites; oolitic calcarenites; bioclastic calcarenites; lithoclastic calcarenites; medium to thinly bedded, often shaly, mid to dark grey calcarenites and calcisiltites; fenestral calcilutites; featureless calcilutites; rudites with a clastic matrix; rudites with a calcarenite matrix; granule arenites; calcareous quartz arenites; argillaceous quartz arenites and litharenites; carbonate-cemented arenites; black lutites; variably coloured lutites; coal) have been defined on the basis of field and petrological characteristics. For each rock-type, the faunas, bioclast and/or grain contents, diagenetic history, distribution and thickness-variations have been described. The environments of deposition have been discussed and interpreted. Sources have been proposed for bioclasts and clastic grains.

7. The bulk of the studied part of the Great Scar Group consists of intraclastic calcarenites. The Thornton Force Formation and Horton Limestone are dominated by this rock-type and it is locally developed in both the Douk Gill Formation and the Raven Ray Formation. Intraclasts are of many types and probably have more than one origin. Subrounded micritic intraclasts, formed by abrasion of compacted, semi-lithified lime mud, are most abundant. Locally, calcarenite intraclasts, formed by erosion of beach rock, or the disintegration of shallow channel-fills of cross-laminated calcarenite, are present. Grapestones, the product of interaction of water turbulence and the growth of encrusting organisms, occur in the Thornton Force Formation. The well sorted and well rounded intraclasts are closely comparable with the modern carbonate sands described by Folk & Robles (1964) and Hoskins & Sundeen (1975), in

that they reflect the ability of gentle currents to achieve good sorting. The depositional characteristics are similar to those of the Lily Bank sand shoals in the Bahamas described by Hine (1977). The sands probably occurred as large, storm-generated sand banks having an area of several square kilometres and a thickness of several metres, determined by the available water depth. Normal tidal ebb-and-flow reworked the surface of the banks to a depth of 10cm to 20cm, generating the cross-lamination visible at outcrop. Sedimentation occurred around surge base: well sorted, cross-laminated calcarenites formed on the crests of bedforms above surge base, whereas poorly sorted, more micritic sediments accumulated in the sheltered troughs below surge base. The major controlling factor over the positioning of the shoal bodies was the influence of oceanic waves with the shelf break (Enos & Perkins, 1978), although the positions of rock floor ridges had some lesser influence. The early environment probably resembled modern, shallow water, low energy, lagoonal mud dominated areas such as those of modern Florida Bay (Enos & Perkins, 1976). However, following a rise in sea-level, water-exchange on and off the bank became more vigorous and the energy level within the bank increased, resulting in the creation of sand ridges and sand waves. During this time, storms generated a net bankward flux and the sand body responded by migrating bankward over the lagoonal sediments. These periodic storms totally destroyed all evidence of the lagoonal environment, incorporating the detritus as abundant intraclasts in the shoal sediments. Sea-level continued to rise and tidal and storm-generated flow velocities decreased with the result that parts of the sand wave field on the shoal became inactive, colonised and stabilised.

8. Oolitic calcarenites have a very limited distribution occurring at isolated outcrops in all four studied formations. However, the presence of this rock-type is significant as it implies that very specific conditions for oolith-generation existed within the Dinantian environment. The modern oolith/aggregate assemblage is essentially restricted to chlorozoan areas (Lees,

1975) and is inhibited by minimum temperatures below 15°C. Other conditions also required for oolith-formation are an abundant supply of calcium carbonate, a good source of nuclei, water depths of less than 5 metres, water and grain-agitation, and hydraulic control sufficient to keep the ooliths within their growth-promoting environment (Weyl, 1967; Bathurst, 1975). The ooliths observed in the Great Scar Group are mainly superficial ooliths (Leighton & Pendexter, 1962), only rarely becoming the dominant carbonate grain. It is concluded that the ooliths were introduced from a more favourable environment by currents and waves, and washed into the intraclastic calcarenites by storm surges. This implies the existence of oolith shoals farther offshore, up the onshore storm tracks.

9. Bioclastic calcarenites are not common in the Great Scar Group; the rock-type is locally developed at the base of the limestone sequence where limestones succeed coarse clastic deposits or unconformably overlie Lower Palaeozoic rocks. It is best seen in the Thornton Force Formation and Raven Ray Formation of Chapel-le-Dale. The rock-type comprises fragments of common normal marine biotas, many of which are altered, having thick micrite envelopes. By analogy, the presence of abundant, broken and abraded, thick shelled brachiopods and crinoid ossicles is indicative of deposition in an agitated normal marine environment. Although specific depositional conditions cannot be determined for the majority of the biota contained therein, the dasycladacean algae are indicative of very specific environmental conditions. They are indicators of warm, quiet, shallow water regions near the coast or in lagoons, and therefore deposition in a shallow subtidal environment either below wave base or sheltered from tidal and wave activity. This conflicts with the interpretation of the coarse grain size, fragmented and abraded bioclasts, and cross-lamination, all of which are indicators of a turbulent environment. However, since many of the algal fragments are enclosed within micritic intraclasts or are heavily micritised, they clearly entered the turbulent environment as bioclasts or intraclasts derived from a

muddy environment, rather than lived within the turbulent zone. These clasts are considered to be reworked remnants of lagoonal sediments destroyed by periodic high energy events and incorporated in, and overwhelmed by, shoal sands. Micritised bioclasts, cortoids, are abundant in the bioclastic and intraclastic calcarenites. Many mechanisms have been proposed for their formation, but it is considered that those of the Great Scar Group formed by micritisation (Bathurst, 1966). Having observed that various abundances of micritic bioclasts occur at different water depths, a number of researchers have used micritic carbonate bioclasts as palaeobathymetric indicators, usually postulating their formation in water depths of less than 15-20m. However, the application of microborings as bathymetric indicators hinges on depth zonations recognised from modern endoliths and the persistence of similar forms through geological time. A clear distinction between photosynthetic microborers and endolithic marine fungi as well as the recognition of types restricted to the deep sea environment is necessary to yield valuable criteria for palaeobathymetric interpretation of ancient carbonates.

10. Lithoclastic calcarenites are common near the base of the Great Scar Group where limestones succeed clastic deposits or unconformably overlie Lower Palaeozoic rocks. In this rock-type, lithoclasts comprise a smaller percentage of the rock than do the allochems, however, they provide vital information about the geography and geology of the study area at the time of their deposition. Five types of lithoclast have been identified, all obviously derived from Lower Palaeozoic rocks in the immediate neighbourhood. Commonly, the lithoclasts occur as laminae within the calcarenites, alternating with allochem-rich laminae. Good sorting and rounding imply deposition after considerable abrasion in an agitated environment. This interpretation is supported by the association with broken and abraded bioclasts, sparry calcite and cross-lamination. The distinct trend of upward-decreasing grain size and frequency of lithoclasts records the gradual burial of ridges of Lower Palaeozoic rock under carbonate sand, coupled

with erosional reduction of ridges, so that fewer and smaller clasts would be produced. The presence of small lithoclasts high above the unconformity at any one locality is indicative of exposure and erosion elsewhere on the Askrigg Block.

11. Medium and thinly bedded, often shaly, mid to dark grey calcarenites and calcisiltites are common in the Great Scar Group, comprising the whole of the Raven Ray Formation, and occurring locally in the Thornton Force Formation, Douk Gill Formation and Horton Limestone. Although the rock-type represents only a small proportion of the thickness of the Great Scar Group studied it is widespread. Within the Raven Ray Formation, the beds represent a period when relatively uniform conditions were established over much of the Askrigg Block. The rock-type consists of foetid, organic-rich lime muds containing variable amounts of bioclasts, except adjacent to Lower Palaeozoic rocks where it passes rapidly into lithoclastic or bioclastic calcarenites. No absolute depth limits have been proposed for this group of limestones but they are assumed to have formed in deeper water than the pale grey calcarenites. Water depth need not have been the controlling factor here. Given adequate shelter, even very shallow water can deposit muddy silts. The rock-type which occupied the shelf edge is unknown, but it is probable that a belt of shallower water existed there with the dark calcarenites and calcisiltites forming in a slightly deeper, protected shelf lagoon. The abundant micrite matrix suggests that deposition took place below surge base. However, deposition was sufficiently close to surge base for agitation, winnowing and sorting of sediments deposited over small ridges of Lower Palaeozoic rocks. Except for sedimentation over ridges, waves operative in shelf lagoon during deposition failed to sort the grains or winnow out the lime mud. The lagoonal environment of this rock-type compares favourably with the carbonate lagoon/shoal complex of Belize (Matthews, 1966). It is probable that there was an onshelf tidal flow which dispersed into smaller channels to distribute normal salinity sea water along and behind the barrier-shoals. The sparsity of crinoid debris in the

lagoonal sediments, although abundant along the shelf edge, can be explained by this process.

12. Fenestral calcilutites are less common in the Great Scar Group than any of the rock-types previously summarised. Although thin they have an extensive areal distribution, occurring in the Douk Gill Formation and in the Moughton Calcilutite Member. Four different types of fenestrae (abundant, near-spherical or ovoid, spar-filled cavities less than 1mm in size; near-vertical or inclined, spar-filled tubular fenestrae; isolated large, irregularly shaped fenestrae; patchily developed, near-horizontal, irregular, laminoid fenestrae) have been recognised. The calcilutites never occur near the shelf edge, which was an area of continuous deposition of cross-laminated calcarenites. Therefore, a protective belt of shallow water existed along or near to the shelf edge, with calcilutites forming in a slightly deeper area in their lee. The low-diversity biota is indicative of a high stress environment. No truly marine forms are present, probably having been inhibited by abnormal salinity or a high sedimentation rate. The presence of fenestrae provides a significant indicator to depositional conditions; it has been suggested that fenestrae could be used as reliable indicators of supratidal conditions because they are formed in an active diagenetic environment with early lithification and rapid cementation (Shinn, 1968, 1983a and b; Grover & Read, 1978). Periods of subaerial exposure are thus indicated, with deposition having occurred on tidal flats. These conditions developed only locally as fenestral calcilutites pass both laterally and vertically into featureless calcilutites. The accumulation of carbonate muds and thin sands (tidal channel deposits) in these environments depends upon local, often rapid, changes in sea water agitation due to storms, unusual tides, or the formation or removal of small, yet effective, barriers to water-movement. Migration of islands, shifting of tidal channels or prograding of carbonate mud flats are all the result of complicated local patterns of deposition.

13. Featureless calcilutites are the most common forms of calcilutite in the Douk Gill Formation and occur within all the calcilutite horizons of the Moughton Calcilutite Member. Beds are thin and laterally discontinuous. These sediments almost certainly formed in similar depositional conditions to the fenestral calcilutites but the lack of fenestrae and associated vadose silts or phreatic cements suggest that these sediments were not exposed to subaerial conditions. It is envisaged that the sediments were deposited in a lagoonal environment; they overlie shallow normal marine sediments and frequently are directly overlain by intertidal-supratidal fenestral calcilutites. The key to the depositional conditions which prevailed is provided by the oncolites observed in the Moughton Calcilutite Member at Horton Quarry. They appear to have formed in similar conditions to those described by Monty (1972); not in constantly agitated waters but in a sheltered, quiet lagoonal setting. Currents powerful enough to disturb the oncolites were infrequent. Conditions for oncolite formation must have been local and short-lived since they have been discovered only at Horton Quarry.

Eventually the calcilutite-depositing lagoonal environment was overwhelmed. High rates of sedimentation resulted in the infilling of the Douk Gill Formation lagoon to above low tide level, and the Horton Limestone barrier shoals at the shelf edge were periodically breached and their calcarenites deposited over the Moughton Calcilutite Member lagoon.

14. Rudites with a clastic matrix are present at the base of the Great Scar Group where Carboniferous rocks directly overlie Lower Palaeozoic rocks. The lack of hydraulic sorting and marine fossils suggests that the majority formed as subaerial gravity flows. These flows were too viscous to separate clay and sand particles from cobbles and pebbles. Usually, only solitary debris flow deposits are present demonstrating that debris flow events were infrequent. In Chapel-le-Dale the rudites, preserved only in gentle hollows eroded into the Lower Palaeozoic rocks, appear to

have been generated by slumping of the regolith. At one locality in the Douk Gill formation, lens-like debris flow deposits built up to form a small subaerial fan. The localised nature of such deposits has been described by Bluck (1965). Red colouration of the lower beds is considered to be a diagenetic phenomenon, since, at the present-day, alluvial deposits in all climatic regimes are grey or brown. In contrast to the debris flow rudites, rudites with a clastic matrix at the base of the Horton Limestone in Crummack Dale are considered to be beach gravels. The great diversity of clast sizes was generated by splitting, crushing and spalling as boulders moved against one another in the gravel. The large rounded boulders, the shattered boulder-matrix and pre-detachment rounding of graywacke outcrops indicate extremely violent activity, probably attained only during exceptional storms.

15. Rudites with a calcarenite matrix are more common and vary greatly in thickness. They occur in Kingsdale, Chapel-le-Dale, Crummack Dale and Silverdale where Carboniferous rocks unconformably overlie Lower Palaeozoic rocks. The profuse marine biota in associated limestones and in the rudites is indicative of marine deposition. There are two types: the first consists of thin layers and lenses filling small hollows in the unconformity or stranded on bedding planes within the overlying calcarenites; the second comprises thick beds of much coarser debris, restricted in occurrence to Crummack Dale. The former consist of storm-worked debris, broken as the result of intense wave battering. Occasionally, monolayers of boulders cap the rudites, the result of winnowing of all but the coarsest lithoclasts from an originally much thicker deposit. Rudites within a limestone sequence cannot have been derived from the unconformity at that locality, and therefore require the existence of topographically higher ridges at no great distance. Lithoclasts occur in profusion up to 15m above the unconformity in Kingsdale and even higher in Crummack Dale, thus recording the minimum topographic relief of the unconformity in each area. The sporadic distribution of rudite layers is the result of an intermittent supply of lithoclasts; lithoclasts were

introduced only during storms, the normal non-storm sediment being cross-laminated calcarenites. The upward decrease in size and frequency of clasts in the sequence is attributed to the gradual burial of graywacke ridges under carbonate sand coupled with erosional reduction of ridge crests. The second variety of rudite is closely comparable to Cambrian deposits of the Baraboo Range, Wisconsin (Dott, 1974), which have been described by Kumar & Sanders (1976) as being a good example of ancient shore-face storm deposits. Frequently, the wave energy was adequate to round clasts less than 1 metre in size and to abrade larger blocks on their upper sides, the result of bombardment by smaller clasts. Breaker heights of approximately 6 metres would have been necessary for this. Such waves could have been generated in Dinantian times by storm winds over the shelf. The equator was close to the Askrigg Block in Carboniferous times, and it is probable that episodic violent storms occurred in the tropical latitudes as at the present day. Such storms would hardly be rare on a geological time scale and would suffice to create the boulder matrix of Crummack Dale.

16. Granule arenites occur at only two localities at the base of the Thornton Force Formation. In the form of lens-shaped bodies, they wedge out from ridges of Lower Palaeozoic rock and pass laterally into cross-laminated, lithoclastic calcarenites. The granules are well sorted and well rounded, suggesting extensive periods of reworking and sorting of sediment by waves. Concurrent deposition of calcarenite and granules implies a marine environment of deposition. The rock-type formed in a non-barred, high energy shoreline environment and cross-stratification and scours demonstrate the prevalence of eroding currents, possibly channelised, moving pebbly sand as dune bedforms. The passage offshore into lithoclastic calcarenites is the result of offshore transport of breakdown products from the shoreline and reworking in an environment where calcarenites were being deposited.

17. Calcareous quartz arenites occur only in the Thornton Force Formation of Chapel-le-Dale. Frequently the beds have erosional

bases and pass upward into the overlying lithoclastic calcarenites by becoming increasingly calcareous. Occasionally, plant remains are preserved. There is a marine biota, and the bioclastic and lithoclastic components were deposited together, acting as hydraulic equivalents. The change in percentage of lithoclasts in individual laminae was controlled by the fluctuating supply of lithoclasts. It appears that deposition was preceded by an erosional event which scoured the underlying rock-types. The sandstone was deposited in a nearshore, beach shore-face environment and reworked by wave and tidal action resulting in a well sorted winnowed sediment. Reworking continued in the offshore environment resulting in an increasingly calcareous deposit. Calcareous quartz arenite passes laterally into calcarenite in the offshore direction. The quartz is derived from the Lower Palaeozoic graywackes, but unlike the lithoclasts, requires an intervening process of total disintegration before final deposition. During this disintegration the chlorite matrix of the graywackes was eliminated, thus indicating that the intervention was a process of deep weathering. The two main outcrops of quartz arenite abut the southwestern side of a graywacke ridge which is faced with very coarse grained graywacke. The top of the ridge is flattish, with broad shallow hollows wherein enhanced weathering of the graywackes would be very probable, and which would offer the necessary protection during marine erosion of the ridge-flanks. One major storm, sweeping waves across the ridge top for the first time, would strip the whole of the weathered zone from the hollows, winnow it and dump the sand (and logs) offshore.

The limited extent of the sandstone is explained by this process. Once the weathered profile had been stripped and its sand released, no further supply was available. The later arrival of sand after the formation of rudites supports the model proposed, it came from initially protected areas. At one outcrop in Chapel-le-Dale a thin fine grained sandstone passes upwards into a shale with rootlets. The sandstone contains little carbonate and no marine biota and is considered to have formed in a brackish to freshwater isolated lagoon. Ridges of graywacke in the vicinity performed the vital role of protecting the microenvironment and allowing it to develop. The overlying calcareous sandstone is typically marine, the earlier brackish-freshwater environment having been overwhelmed. Although the calcareous quartz arenite deposits of Chapel-le-Dale do not appear to be physically related, it is probable that they were deposited at approximately the same time.

18. Argillaceous quartz arenites and litharenites occur only in the lower part of the Douk Gill Formation. The medium to thin beds are interbedded with calcarenites, calcisiltites, rudites and shales. Locally the deposits are calcareous, and they are graded, parallel laminated or occasionally cross-laminated. At some exposures the arenites are very intensely bioturbated. The rock-type comprises sublabile lithic arenites and labile lithic arenites (Crook, 1960). There is an ubiquitous marine fauna in arenites interbedded with calcarenites, and lamination and bedding are considered to imply deposition in a shallow environment with some wave agitation. A shallow, quiet water environment either at or just below wave base or a protected lagoonal environment is considered to represent the depositional environment of the arenites associated with shales and rudites.

19. Carbonate-cemented arenites occur in the Raven Ray Formation only at Newby Cote Quarry and in the Horton Limestone of Crummack Dale where it overlaps Lower Palaeozoic rocks. The carbonate cement is frequently ferroan dolomite, there is no calcarenite matrix, however the presence of sparse shell debris implies a marine environment of deposition. The source area of quartz sand probably was local because of the restricted distribution, although carbonaceous streaks do suggest some reworking of terrigenous sediment. The sedimentary structures of the arenites are typical of sedimentation in an active nearshore environment where wave action reworked, winnowed and sorted the sediment. The source of the quartz sand found in the Raven Ray Formation is unknown. The

sands are either a late analogue of the Thornton Force Formation sands, i.e. swept out of a hollow, in which case the top of the Crummack Dale ridge or its westward continuation presents the most likely source, or alternatively, they are a tongue of the Ashfell Sandstone, which is known from Garsdale (thickness comparable with Newby Cote) and from thicker sequences in the Raydale and Beckermonds Scar Boreholes. It is unlikely that the source area was to the south or southwest beyond the southern edge of the Askrigg Block. Virtually all known sources of detritus in this area of the Askrigg Block lie to the northeast of their deposits and no suitable source rocks are exposed to the south of the Askrigg Block. The source of sand in the Horton Limestone is known; the arenites probably are attenuated representatives of boulder lenses in Crummack Dale. There is surprisingly little sand, the graywacke ridge appears to have generated mainly boulders and the sand must have been transported offshore.

20. Black lutites, varying greatly in thickness, occur in the upper part of the Douk Gill Formation, locally in the Thornton Force Formation, and throughout the Raven Ray Formation. They are usually interbedded with foetid calcarenites and calcilutites and may be either calcareous mudstones or fissile, non-calcareous shales. The faunas are compatible with the dark, foetid calcisiltites and calcarenites and are, therefore, considered to have formed in a similar lagoonal environment. The non-calcareous, sparsely fossiliferous shales were deposited closest to the shoreline where higher rates of sedimentation discouraged sessile benthos. Gradational contacts between lutites and limestones or sandstones suggest that lutites pass laterally into other rock-types. A modern, closely comparable, transition between nearshore terrigenous clastics and shelf-lagoon lime muds is seen off southern Belize (Matthew, 1966). It parallels the situation envisaged for the Raven Ray Formation. A second type of black lutite occurs only in solution hollows formed in the top of the Horton Limestone at Meal Bank Quarry. The deposit contains

abundant pyritised rootlets and occasional Stigmaria and is therefore a seatearth.

21. Variably coloured lutites occur sporadically in all four formations studied. There is no fauna and flora and frequently bioturbation trails are not present. All the coloured shales and mudstones are laterally impersistent and usually cannot be used to correlate even adjacent exposures. They were deposited in a number of complex microenvironments. A thick lutite in Chapel-le-Dale, unconformably overlying Lower Palaeozoic rock and overlain by a rudite, is considered to represent an in situ weathering profile. The mineral composition and physical characteristics, together with weathering to a depth of 30m below the unconformity, indicate that the climate was warm with moderate to low rainfall. The transgressing sea stripped off soils in exposed areas and left those in isolated pockets. The coloured lutites in carbonate sequences, although barren of fossils, were probably deposited in a marine environment, possibly as the products of winnowing of calcarenites in the nearshore environment. The fine detritus was washed offshore and deposited in quiet, sheltered conditions. Coloured shales occur interbedded with coarser clastic rock-types at the base of the Douk Gill Formation. They are laterally impersistent and formed wherever there were suitable conditions for the deposition of clays. Lutites are sparse in the upper part of Horton Limestone. The mudstones occurring at the top of the Moughton Calcilutite Member, a complex sequence of peritidal and subtidal calcilutites, contrast with the previous water-lain lutites in that they formed during an interval of subaerial exposure. Similar clay "wayboards" described from Dinantian sequences of Derbyshire are said to have formed by diagenetic alternation of volcanic ashfalls.

22. Coal deposits occur at two greatly separated horizons, at the top of the Douk Gill Formation and the top of the Horton Limestone. The deposits are local features having a restricted vertical and lateral extent. They overlie marine successions and are abruptly

overlain by coarse grained marine limestone. The coals occur in hollows formed in the tops of the formations, implying a period of erosion or subaerial exposure prior to coal formation. The restricted extent of both coals is the consequence of short-lived conditions for plant growth, peat formation and coalification. The protection of the swamp area against inundation, and a hinterland with low relief therefore supplying little detritus, were both necessary. However, it is unlikely that a natural sediment barrier existed and the peat deposits were drowned by the next marine incursion.

23. Investigation of the individual rock-types has permitted interpretation of the overall environment of each of the studied formations. Sedimentation of the Great Scar Group commenced with the formation of a complex sequence of laterally impersistent rock-types together comprising the Thornton Force Formation. These earliest Carboniferous sediments overlie Lower Palaeozoic rocks with profound unconformity throughout the study area. Sedimentation probably commenced at the southern edge of the Askrigg Block, where the thickest sequences are found, some time before areas to the north were inundated. The earliest sediments, cross-laminated granule arenites, accumulated in a non-barred, high energy shoreline environment and passed offshore into lithoclastic calcarenites. Into this environment, a high energy debris flow, possibly the product of cliff-erosion and collapse, was introduced. As sea-level continued to rise, conditions favouring calcarenite deposition were established at the southern edge of the Askrigg Block. At this time more of the gently undulating land to the north was submerged and debris flows, products of the reworked weathered profile, were deposited. Remnants of the weathered profile were winnowed and re-deposited as calcareous quartz arenites. The cobble-pebble rudites found in hollows in the unconformity, and also within the overlying limestone sequence, are the product of storm reworking and deposition of lithoclasts generated from topographically higher ridges at no great distance. Their sporadic distribution is the result of an intermittent supply

of lithoclasts. By far the greatest thickness of the Thornton Force Formation consists of cross-laminated calcarenites, which probably formed small sand banks, initially at the shelf-edge. Storms probably shaped the banks whereas normal tide action created the bedforms and structures preserved. Sedimentation was close to surge base; whereas cross-laminated calcarenites were being deposited on shoal crests above surge base, a low energy community and associated sediments formed in the troughs below surge base. Locally, ooliths are present in these calcarenites, usually comprising only a small part of the rock. Their presence implies that conditions suitable for oolith-growth existed elsewhere at the time of Thornton Force Formation deposition; they were washed in by storm surges from a more favourable environment offshore.

24. The Douk Gill Formation, restricted in outcrop area to Horton-in-Ribblesdale, probably was deposited at about the same time as the Thornton Force Formation. The eastwards extension of the ridge of Lower Palaeozoic rocks seen in Crummack Dale provided shelter to the Horton-in-Ribblesdale area, allowing accumulation of completely different sequence of rocks. Isolated debris flows, generated on the surrounding slopes, occur interbedded with argillaceous sandstones and shales at the base of the sequence. At one locality debris flows built up to form a small subaerial fan. The sandstones were deposited in the protected lagoonal environment, at or just below surge base. With erosional reduction and burial of the graywacke ridges the input of clastic detritus was reduced, and calcilutites deposited in the lagoonal environment. Occasionally the small barrier shoals developed at entrances to the lagoon were breached during storms and firstly calcareous sandstones and later calcarenites were deposited within the lagoonal sequence. Carbonate sedimentation outpaced subsidence, resulting in infilling of the lagoon and subaerial exposure. A thin coal, with a restricted lateral extent, formed within the hollows. Conditions for coal formation were short lived; there was no natural sediment barrier and the deposits were overwhelmed by the next marine incursion.

25. The Raven Ray Formation generally is disconformable on the Thornton Force Formation, although locally, it oversteps to overlie Lower Palaeozoic rocks unconformably. A period of uplift, possible folding, and emergence resulting in local solution, probably occurred prior to deposition of the Raven Ray Formation. The rock-type which occupied the shelf edge is unknown, but it is probable that a belt of shallower water existed there with the dark, foetid calcarenites, calcisiltites and shales forming in a slightly deeper shelf lagoon. Depositional conditions are closely comparable to the modern carbonate lagoon/shoal complex of Belize (Matthews, 1966). There is a rapid disappearance of sand-sized debris away from the shoals and more bioclastic, coarser grained calcarenites are observed only near the southern edge of the field area, closest to the shoals at the shelf edge. Deposition took place below surge base, but was sufficiently close for agitation, winnowing and sorting of sediments deposited as shoals over small ridges of Lower Palaeozoic rocks. Except for sedimentation over and against ridges, the waves operative over the shelf during deposition of the Raven Ray Formation calcarenites and calcisiltites failed to sort the grains and winnow out the lime mud. Quartz sand and silt occur near the top of the formation at only one locality. The source of this sand is problematical; the only known exposed ridges were in Crummack Dale, but no arenites occur in the exposures between. Alternatively, the sands are a tongue of the Ashfell Sandstone which is known from Garsdale, the Beckermonds Scar Borehole and the Raydale Borehole.

26. The Horton Limestone is generally conformable on the Raven Ray Formation except in Crummack Dale where it oversteps onto Lower Palaeozoic Rocks, and in Wharfedale and Littondale where there is apparent disconformity between the two formations. Local erosion, the result of minor tilting or uplift, is implied in this area. The initial sedimentation of poorly sorted, mid grey calcarenites occurred on the shelf below surge base. The bulk of the formation, cross-laminated, pale grey calcarenites, was deposited as shoals and sandbanks in a shallow subtidal environment, above surge base.

The paling of the colour was due to the change in the depositional environment and the reduction in the supply of terrigenous detritus and organic matter. The location of the shoals appears to have been controlled by the interaction of deep water waves with the shelf break and influenced by irregularities in the topography of the rock-floor. Sedimentation, for the most part, kept pace with the change in sea-level and shoals continued to form at the shelf edge. Locally, ridges of graywacke formed islands, and coarse shoreline deposits accumulated preferentially where wave attack was concentrated. Waves, generated by episodic violent storms in the tropical latitudes, could have rounded graywacke boulders. Ultimately the islands were buried by the storm shoreface deposits and carbonate shoals sands. With the passage of time the carbonate ramp developed into a carbonate shelf platform with shelf edge shoals protecting the shallow shelf lagoon in their lee. In this environment calcilutites of the Moughton Calcilutite Member were deposited. The sediments which accumulated in this restricted environment were dependent upon local, often rapid, changes in sea water due to storms, tides or the formation or removal of barriers to water movement. Locally, there was subaerial exposure (as indicated by fenestrae, vadose silts and phreatic cements). Normally, calcilutites were not exposed to prolonged subaerial conditions, probably having formed low on the tidal flat or in a lagoonal environment. Deposition was taking place so close to sea-level that only slight fluctuations in conditions resulted in short periods of subaerial exposure. Periodically, the lagoon-tidal flat environment was overwhelmed as the barrier of carbonate shoals was breached, and shoal sands were deposited over the lagoon. On re-establishment of barrier shoals at the shelf edge, the lagoon was able to reform. The platform lagoon environment was short-lived, eventually being overwhelmed by shoal sands.

The top of the formation is marked by a widespread erosion surface, and south of the North Craven Fault there appears to have been some tilting at this period resulting in subaerial exposure; a thin coal with a restricted lateral extent occurs in a solution hollow in the top of the formation. There was no natural sediment barrier and peat deposits were drowned by the next marine incursion.

27. It is concluded that the major controls over the development of the varied rock-types in the studied formation are substrate topography, tectonism and subsidence, rate of sedimentation and water depth. There is no evidence of eustacy regulating their formation. The topography of the pre-Carboniferous land surface was a significant control early in the history of deposition of Dinantian sediments. Pebble, cobble and boulder rudites and sandstones, with lithoclasts and quartz sand derived from the Lower Palaeozoic rocks, accumulated in the hollows whereas virtually lithoclast-free calcarenites were later deposited over the eminences. In the lee of ridges, quiet water sediments were laid down in protected environments. Gradually these ridges were buried and their influence waned and, instead, tectonism, rate of sedimentation and water depth became more important processes. The effects of tectonism are recorded by the angular discordance between the Horton Limestone and overlying Kingsdale Limestone south of the North Craven Fault, and the widespread erosion surface at the top of the Horton Limestone to the north of the fault. Erosion surfaces are locally present at the top of the Thornton Force Formation, Douk Gill Formation and Raven Ray Formation resulting from the flexure or tilting of the Askrigg Block. Variable rates of sedimentation in response to subsidence probably influenced the periodic formation and destruction of the protected lagoonal environment of the Moughton Calcilutite Member. The Sulber Fault is considered to have influenced sedimentation in Dinantian times; the Douk Gill Formation crops out between it and a graywacke ridge to the south and only to the north of the fault are dark limestones present in the upper part of the Moughton Calcilutite Member. The influence of the rate of sedimentation can be clearly demonstrated during deposition of the Horton Limestone. It outpaced the rate of subsidence resulting in the creation of

barrier shoals at the shelf edge, allowing the development of the Moughton Calcilutite Member lagoon in their lee. The effects of varying water depth are more difficult to quantify because accurate water depths for depositional environments are not known. Only locally can its influence be demonstrated. In the Thornton Force Formation, deposition of the calcarenites took place approximately at surge depth resulting in formation of cross-laminated calcarenites above surge base on the shoal crests, and muddier limestones below surge base in the troughs. The influence of water depth can most clearly be demonstrated in the Raven Ray Formation. For the most part deposition was below surge base. However, where graywacke ridges protruded through the earlier Carboniferous sediment cover, the substrate was sufficiently elevated for deposition to occur above surge base.

28. Finally, although the studied formations and the rock-types contained therein can usually be mapped and correlated over their outcrop area, it has proved difficult to correlate them with the Carboniferous sequences in adjacent areas. The introduction of new, as yet undefined, stratigraphic terminology by the Institute of Geological Sciences has not improved the situation. It is the opinion of the author that, until the Dinantian Subsystem has been adequately zoned, by means of both macrofaunas and microfaunas, correlations can only be tentative. Only when the biostratigraphic zones are firmly established will it be possible to correlate adjacent areas and to interpret the sedimentary and structural history of the Dinantian Subsystem adequately.

REFERENCES

ADAMS, A.E. & COSSEY, P. J. 1981. Calcrete development at the junction between the Martin Limestone and the Red Hill Oolite (Lower Carboniferous), south Cumbria. Proc.Yorks.Geol.Soc., 43: 411-431.

AGASSIZ, A., 1894: A reconnaissance of the Bahamas and of the elevated reefs of Cuba. Bull. Museum of Comp. Zool., Havard 26:203pp.

AHR, W.M. 1973. The Carbonate Ramp: An Alternative to the Shelf Model. Trans. Gulf Coast Assoc. Geol.Socs. 23:221-225

AITKEN, J.D. 1967. Classification and environmental significance of cryptalgal limestones and dolomites, with illustrations from the Cambrian and Ordovician of Southwestern Alberta. J. Sediment. Petrol. 37:1163-1178

AITKENHEAD, N. & CHISHOLM, J. I. 1982. Standard nomenclature for the Dinantian Formations of the Peak District of Derbyshire and Staffordshire. Rep.Inst.Geol.Sci. No. 82/8

ALEXANDERSSON, T. 1972. Micritization of carbonate particles: processes of precipitation in modern shallow-marine sediments. Bull. Geol. Inst. Univ. Uppsala, N.S., 3:201-236.

ALLEN, J.R.L., 1963. The classification of cross-stratified units with notes on their origin. Sedimentology, 2:93-114.

ANDERSON, E. J. 1971 Environmental models for Palaeozoic communities Lethaia 4: 287-302.

ANDERSON, E. J. 1974. Principles of benthic community analysis (notes for short course), Community Patterns. In Sedimenta IV, Comparative Sedimentology Laboratory, Fischer Island, Miami, Florida.

ANDERSON, F.W. 1928. The Lower Carboniferous of the Skyreholme Anticline, Yorkshire. Geol. Mag., 54:518-527.

ASHMEAD, P. 1974. Development of the caves of Casterton Fell pp. 250-272. In Waltham A.c.(ed). The Limestones and Caves of Northwest England. David & Charles, Newton Abbot.

ASHTON, P. R. 1970. Sedimentology of the Ravenstonedale Limestone and its correlatives in Westmorland and in the Furness District of Lancashire. Unpublished Ph.D. Thesis, University of Southampton, 374pp.

ATKINSON, T.C., HARMON, R.S., SMART, P.L. and WALTHAM, A.C. 1978. Palaeoclimatic and geomorphic implications of 230Th/234U dates on speleothems from Britain. Nature, 272:24-28.

BALL, M.M. 1967. Carbonate Sand Bodies of Florida and the Bahamas. J. Sediment. Petrol. 37:556-591.

BASAN, P.B. 1973. Aspects of sedimentation and development of a carbonate bank in the Barracuda Keys, South Florida. J. Sediment. Petrol. 43:42-53.

BATHURST, R.G.C. 1966. Boring Algae, Micrite Envelopes and Lithification of Molluscan Biosparites. Geol. Jour., 5:15-32.

BATHURST, R.G.C. 1976a. Oolitic films on low energy carbonate sand grains, Bimini Lagoon, Bahamas. Marine Geol. 5:89-109.

BATHURST, R.G.C. 1976b. Subtidal gelatinous mat, sand stabilizer and food, Great Bahama Bank. J.Geol., 75:736-738.

BATHURST, R.G.C. 1968. Precipitation of ooids and other aragonitic fabrics in warm seas. In MULLER, G. & FRIEDMAN, G.M., eds. Recent Developments in Carbonate Sedimentology in Central Europe: 1-10, Springer, Berlin-Heidelberg-New York.

BATHURST, R.G.C. 1975. Carbonate sediments and their diagenesis (2nd enlarged ed.). Developments in sedimentology 12, Elsevier, Amsterdam, 658 pp.

BERNER, R.A. 1970. Sedimentary Pyrite Formation. Amer. Jour. Sci. 268: 1-23.

BISAT, W.S. 1924. The Carboniferous goniatites of the north of England and their zones. Proc.Yorks.Geol.Soc. 20:40-124

BISSELL, H.J. & CHILINGAR, G.V. 1967. Classification of sedimentary carbonate rocks. In LARSEN, G. & CHILINGAR, G.V., eds. Carbonate Rocks: Origin, Occurrence and Classification. Developments in Sedimentology 8:87-167, Elsevier, London.

BLACK, M. 1933. The precipitation of calcium carbonate on the Bahama Bank. Geol.Mag. 70:455-466.

BLACK, W.W. 1950. The Carboniferous geology of the Grassington area, Yorkshire. Proc.Yorks.Geol.Soc. 28:29-42.

BLESS, M.J.M., BOUCKAERT, J., BOUZET PH., CONIL, R., CORNET, P., FAIRON-DEMANET, M., GROESSENS, E., LONGERSTAEY, P.J., MEESSEN, J.P.M. Th., PAPROTH, E., PIRLET, H., STREEL, M., van AMERON, H.W.J. & WOLF, M. 1976. Dinantian rocks in the subsurface north of the Brabant and Ardenno-Rhenish Massifs in Belgium, the Netherlands and the Federal Republic of Germany. Meded.Rijks.Geol.Dienst, N.S. 27:81-195

BLUCK, B.J. 1964. Sedimentation of an alluvial fan in southern Nevada. J.Sediment Petrol. 34: 395-400.

BLUCK, B.J. 1965. The sedimentary history of some Triassic conglomerates in the Vale of Glamorgan, South Wales. Sedimentology, 4:225-245.

BLUCK, B.J. 1967a. Deposition of some Upper Old Red Sandstone conglomerates in the Clyde area: A study in the significance of bedding. Scott. J. Geol. 3:139-167.

BLUCK, B.J. 1967b. Sedimentation of beach gravels: Examples from South Wales. J.Sediment. Petrol. 37:128-156.

BLUCK, B.J. 1969. Partial rounding of beach gravels. Geol.Mag. 106: 1-14.

BOTT, M.H.P. 1961. Geological Interpretation of Magnetic Anomalies over the Askrigg Block. Quart. J.Geol.Soc.Lond. 117:481-495.

BOTT, M.H.P. 1967. Geophysical investigations of the northern Pennine basement rocks. Proc.Yorks.Geol.Soc. 36:139-168.

BOTT, M.H.P. & JOHNSON, G.A.L. 1967. The controlling mechanism of Carboniferous cyclic sedimentation. Quart.J.Geol.Soc.Lond. 122;421-441.

BROCK, E.J. 1974. Coarse sediment morphology: a comparative study. J.Sediment. Petrol. 44:663-672.

BROOK, D. 1974 The caves of Chapel-le-Dale and Newby Moss pp 335-342. In WALTHAM, A.C. ed., The Limestones and Caves of Northwest England. David & Charles, Newton Abbot.

BROOK, A., BROOK, D., DAVIES, G. M. AND LONG, M.H. 1981. Northern Caves, Vol. 3 Ingleborough. 144pp Dalesman Publishing Co., Clapham, North Yorkshire.

BUCHANAN, H., STREETER, S. & GEBELEIN, C.D. 1972. Possible living algal-foraminiferal consortia in nodules from modern carbonate sediments of the Great Bahama Bank. Am.Assoc.Petrol.Geol. Ann. Meeting, 56, No.3, 606.

BULL, W.B. 1972. Recognition of alluvial fan deposits in the stratigraphic records In RIGBY, J. K. & HAMBLIN WK. eds Recognition of Ancient Sedimentary Environments. Soc.Econ.Palaeontologist and Mineralogists.Spec.Publ. 16: 63-83.

BURGESS, C.J. 1979. The development of a Lower Jurassic carbonate tidal flat, Central High Atlas, Morocco, 2: Diagenetic history. J.Sediment.Petrol. 49; 413-428.

BURGESS, I.C. (In press). Lower Carboniferous sections in the Sedbergh district, Cumbria. Trans.Leeds Geol. Assoc.

BUTTERFIELD, J.A. 1920. The conglomerates underlying the Carboniferous Limestone in northwest of England. Naturalist, 1920: 249-252 and 281-284.

CAMPBELL, C.V. 1967. Lamina, laminaset, bed and bedset. Sedimentology 8:7-26.

CAROZZI, A.V.1960. Microscopic Sedimentary Petrography John Wiley, New York. 485pp.

CHILINGAR, G.V., BISSELL, H.J. & FAIRBRIDGE, R.W. eds. 1967. Carbonate Rocks: Origin, Occurrence and Classification Elsevier, Amsterdam. 471pp.

CHLUPÁČ, I., FLUGEL, H.& JAEGER, H. 1981. Series or Stages within Palaeozoic Systems? Newsl. Stratigr. 10: 78-91.

CHOQUETTE, P.W. & PRAY, L.C. 1970. Geological nomenclature and classification in sedimentary carbonates. Bull. Am. Assoc. Pet. Geol. 54:207-250.

CLIFTON, H.E., HUNTER, R.E. & PHILLIPS, R.L. 1971. Depositional structures and processes in the non-barred high energy nearshore environment. J. Sediment.Petrol. 41:651-670.

CLOUD, Jr. P.E. 1962. Environment of calcium carbonate deposition west of Andros Island, Bahamas. Prof.Paper U.S. Geol.Surv. 350: 1-138.

CONIL, R., GROESSENS, E. & PIRLET, H. 1977. Nouvelle charte stratigraphique du Dinantien type de la Belgique. Ann.Soc.Geol.Nord, 96: 363-371.

COUSINS, J. 1976. The Sedimentology of Middle, Underset and Crow Limestones of the mid-Carboniferous Yoredale Group on the Askrigg Block. Unpublished Ph. D. Thesis, Southampton University.

CRESSMAN, E.R. & NOGER, M.C. 1976. Tidal flat carbonate environments in the High Bridge Group (Middle Ordovician) of central Kentucky: Lexington Univ. Kentucky, Kentucky Geol. Survey, Series X, Rept. of Invest. 18, p 1-15.

CROOK, K.A.W. 1960. Classification of arenites. Amer.J.Sci. 258:419-428.

DAKYNS, J.R. 1891. On the changes of the Lower Carboniferous rocks in Yorkshire from south to north. Proc. Yorks.Geol. Polytech. Soc. 11:353-362.

DAKYNS, J. R. 1893. Glacial Phenomena of Wharfedale, between Bolton Abbey and Kettlewell. Proc.Yorks.Geol.Soc. 12: 299-305

DAKYNS, J.R., TIDDEMAN, R.H., GUNN, W. & STRAHAN, A. 1890. The geology of the country round Ingleborough, with parts of Wensleydale and Wharfedale. Mem. Geol.Surv. U.K., H.M.S.O., London.

DALTON, W.H. 1872. On the geology of Craven. Proc.Yorks.Geol.Soc. 6:16-22.

DAVIES, G.R. 1970. Carbonate bank sedimentation, eastern Shark Bay, Western Australia. In LOGAN, B.W., DAVIES, G.R., READ, J.F. & CEBULSKI, D.E., eds. Carbonate Sedimentation and Environments, Shark Bay, Western Australia. Am.Assoc. Pet. Geol.Mem. 13:85-168.

DAVIES, R.B. 1980. Conodont-distribution of some British Dinantian shelf sediments; The Gayle Limestone (Brigantian) of North Yorkshire and selected sections (Courceyan-Brigantian) in the South Wales-Mendip Area. Unpublished Ph.D.Thesis, Southampton University.

DE BOER, G. 1974. Physiographic Evolution. In RAYNER, D.H . & HEMINGWAY, J.E., eds. The Geology and Mineral Resources of Yorkshire. p 271-292. Yorkshire Geological Society.

DICKSON, J.A.D. 1965. A modified staining technique for carbonates in thin section. Nature, 205:587.

DICKSON, J.A.D. 1966. Carbonate identification and genesis as revealed by staining. J.Sediment. Petrol. 36:491-505.

DIXEY, F. & SIBLY, T.F. 1918. The Carboniferous Limestone Series in the south-eastern part of the South Wales Coalfield., Quart. J. Geol. Soc. Lond. 73:11-164.

DOTT, R.H.Jr. 1974. Cambrian tropical storm waves in Wisconsin. Geology, 2:243-246.

DOUGHTY, P. S. 1962. Stratification and Jointing in the Great Scar Limestone of Northwest Yorkshire. Unpublished M.Sc. Thesis, Nottingham Unversity.

DOUGHTY, P.S. 1968. Joint densities and their relation to lithology in the Great Scar Limestone. Proc.Yorks.Geol.Soc. 36:479-512.

DOUGHTY, P.S.1974. Davidsonina (Cyrtina) septosa (PHILLIPS) and the structure of the Visean Great Scar Limestone north of Settle, Yorkshire. Proc.Yorks.Geol.Soc. 40, 41-48.

DRAVIS, J. 1979. Rapid and widespread generation of Recent oolitic hardgrounds on a high-energy Bahamian platform, Eleuthera Bank. J.Sediment.Petrol. 49, 195-208.

DREW, G.H. 1911. The action of some denitrifying bacteria in tropical and temperate seas, and the bacterial precipitation of calcium carbonate in the sea. J.Marine Biol.Assoc. U.K. 9,142-155.

DREW, G. H. 1914. On the precipitation of calcium carbonate in the sea by marine bacteria, and on the action of denitrifying bacteria in tropical and temperate seas. Paper Tortugas Labs., Carniegie Inst. Wash.Publ. 182: 7-45.

DUNHAM, K. C. 1959. Epigenetic mineralization in Yorkshire. Proc.Yorks Geol.Soc 32: 1-29

DUNHAM, K.C. 1974. Granite beneath the Pennines in North Yorkshire. Proc.Yorks.Geol.Soc. 40:191-194.

DUNHAM, K.C., BOTT, M.H.P., JOHNSON, G.A.L. & HODGE, B.L. 1961. Granite beneath the northern Pennines. Nature 190:899-900.

DUNHAM, K.C., HEMINGWAY, J.E., VERSEY, H.C. & WILCOCKSON, W.H. 1953. A guide to the geology of the district round Ingleborough. Proc.Yorks.Geol.Soc. 29: 77-115.

DUNHAM, K.C.& ROSE, W.C.C. 1941. Geology of the iron-ore field of south Cumberland and Furness. Wartime Pamph, Geol. Surv. G.B. 16:26pp.

DUNHAM, K.C. & STUBBLEFIELD, C.J. 1945. The stratigraphy, structure and mineralisation of the Greenhow mining area, Yorkshire. Quart.J.Geol.Soc.Lond. 100:209-268.

DUNHAM, R.J. 1962. Classification of carbonate rocks according to depositional textures. In HAM, W.E., ed. Classification of Carbonate Rocks. Am.Assoc.Pet.Geol.Mem. 1:108-121.

EBANKS, W.J. & BUBB, J.N. 1975. Holocene Carbonate Sedimentation, Matecumbe Keys Tidal Bank, South Florida. J.Sediment.Petrol. 45:422-439.

EDWARDS, B.D. & PERKINS, R.D. 1974. Distribution of microborings within continental margin sediments of the southeastern United States. J.Sediment.Petrol. 44:1122-1135.

ENOS, P. & PERKINS, R.D. 1976. Evolution of Florida Bay interpreted from island stratigraphy (abs). Am.Assoc.Pet.Geol.Bull 60:669.

ENOS, P. & PERKINS, R.D. 1978. Holocene carbonate sediments, South Florida shelf margin. In ENOS, P. & PERKINS, R.D. eds. Quaternary Sedimentation in South Florida. Geol.Soc.America Mem. 147.

EVAMY, B.D. & SHEARMAN, D.J. 1965. The development of overgrowths from echinoderm fragments. Sedimentology 5:211-233.

EVAMY, B.D. & SHEARMAN, D.J. 1969. Early stages in development of overgrowths on echinoderm fragments in limestones. Sedimentology, 12: 317-322.

FEWTRELL, M., RAMSBOTTOM, W.H.C. & STRANK, A.R.E. 1981. Carboniferous Foraminifera. In MURRAY, J. & JENKINS, G. eds. A Stratigraphical Atlas of Foraminifera, 15-59. Ellis Hopwood.

FEWTRELL, M. D. & SMITH, D.G. 1980. Revision of the Dinantian stratigraphy of the Craven Basin, N. England. Geol.Mag. 117: 37-49

FISCHER, A.G. 1964. The Lofer cyclothem of the Alpine Triassic. Kansas Geol. Surv.Bull., 169:107-149.

FLUGEL, E. 1982. Microfacies Analysis of Limestones. Springer-Verlag. Berlin-Heidelberg-New York. 633pp.

FOLK, R.L. 1959. Practical petrographic classification of limestones. Bull.Am.Assoc.Pet.Geol. 43:1-38.

FOLK, R.L. 1962. Spectral subdivision of limestone types. In HAM, W.E. ed. Classification of Carbonate Rocks. Am.Assoc.Pet.Geol.Mem. 1: 62-84.

FOLK, R.L. 1965. Some aspects of recrystallisation in ancient limestones. In PRAY, L.C. & MURRAY, R.C., eds. Dolomitisation and Limestone Diagenesis. Soc.Econ.Paleontologists and Mineralogists Spec. Publ. 13:14-48.

FOLK, R.L. & ROBLES, R. 1964. Carbonate sands of Isla Perez, Alacran Reef complex, Yucatan. J.Geol. 72:255-292.

FOLK, R.L. & WARD, W. 1957. Brazos River bar: A study in the significance of grain size parameters. J.Sediment. Petrol. 27:3-26.

FOWLER, A. 1944. A deep bore in the Cleveland Hills. Geol.Mag. 81:193-206, 254-265.

FRIEDMAN, G.M., GEBELEIN, C.D. & SANDERS, J.E. 1971. Micrite envelopes of carbonate grains are not exclusively of photosynthetic algal origin. Sedimentology 16:89-96.

FRIEDMAN, G.M., AMIEL, A.J., BRAUN, M. & MILLER, D.S. 1973. Generation of carbonate particles and laminites, examples from sea-marginal hypersaline pools, Gulf of Aqaba, Red Sea. Bull.Am Assoc. Pet.Geol. 57, 541-558.

GALVIN, C.J.Jr. 1969. Breaker travel and choice of design wave height. Am.Soc.Civil.Engineers Proc.Jour.Waterways and Harbors Div., WW2: 175-200.

GARWOOD. E.J. 1907. Faunal succession in the Carboniferous Limestone of Westmorland. Geol.Mag. 44:70-74.

GARWOOD, E.J. 1913. The Lower Carboniferous succession in the north-west of England. Quart. J.Geol.Soc.Lond. 68:449-596.

GARWOOD, E.J. 1922. On a freshwater shale with Viviparus and associated beds from the base of the Carboniferous rocks in Ribblesdale, Yorkshire. Geol.Mag. 59:289-293.

GARWOOD, E.J. & GOODYEAR, E. 1924. The Lower Carboniferous succession in the Settle district and along the line of the Craven Faults. Quart.J. Geol. Soc.Lond. 80:184-273.

GASCOYNE, P. 1978. Mass-wasting deposits. In FAIRBRIDGE, R.W. & BOURGEOIS, J.,eds. Encyclopedia of Sedimentology, 479-480. Encyclopedia of Earth Science Series Vol. 6. Dowden, Hutchinson & Ross; Stroudsburg.

GEBELEIN, C.D. 1969. Distribution, morphology, and accretion rate of Recent subtidal algal stromatolites, Bermuda. J.Sediment.Petrol. 39:49-69.

GEBELEIN, C.D. 1976. Open marine, subtidal and intertidal stromatolites (Florida, the Bahamas and Bermuda). In WALTER, M. R. ed. Stromatolites. Developments in Sedimentology, Elsevier, New York. p381-388.

GEORGE, T.N. 1958. Lower Carboniferous palaeogeography of the British Isles. Proc. Yorks. Geol.Soc. 31:227-318.

GEORGE, T.N. 1969. British Dinantian stratigraphy. Compte Rendu 6e Congres Intern. Strat. Geol.Carbonif., Sheffield, 1967, 1:193-218.

GEORGE, T.N. 1978. Eustasy and tectonics: Sedimentary rhythms and stratigraphical units in British Dinantian correlation. Proc.Yorks.Geol.Soc. 42:229-262.

GEORGE, T.N., JOHNSON, G.A.L., MITCHELL, M., PRENTICE, J.E., RAMSBOTTOM, W.H.C., SEVASTOPULO, G.D. & WILSON, R.B. 1976. A correlation of Dinantian rocks in the British Isles. Geol.Soc.Lond.,Spec.Rep. 7:1-87.

GILL, W.D. & KUENEN, P.H. 1957. Sand volcanoes on slumps in the Carboniferous of County Clare, Ireland. Quart.J.Geol.Soc.Lond. 113:441-460.

GINSBURG, R.N. 1956. Environmental relationships of grain size and constituent particles in some South Florida carbonate sediments. Am.Assoc.Pet.Geol.Bull. 40:2384-2427.

GINSBURG, R.N. 1960. Ancient analogues of recent stromatolites. Internat.Geol.Congr. 1960, 22:26-35

GINSBURG, R.N. ed. 1975. Tidal Deposits, A Casebook of Recent Examples and Fossil Counterparts. Springer-Verlag. Berlin-Heidelberg-New York 428pp.

GINSBURG, R.N. & JAMES., N.P. 1974. Holocene carbonate sediments of continental shelves. In BURKE, C.A . & DRAKE, C.L. eds. The Geology of Continental Margins. Springer-Verlag, New York. p137-155.

GINSBURG,R.N. & LOWENSTAM, H.A. 1958. The influence of marine bottom communities on the depositional environment of sediments. J.Geol. 66:310-318.

GINSBURG, R. N., SCHROEDER, J. H. & SHINN, E.A. 1971. Recent synsedimentary cementation in subtidal Bermuda reefs. In BRICKER, O. P. ed. Carbonate Cements. The John Hopkins Univ. Studies in Geology, No. 19: 54-58.

GLENNIE, K.W. 1970. Desert Sedimentary Environments. Developments in Sedimentology 14, Elsevier, Amsterdam. 222pp.

GLOVER, R.R. 1973. Gaping Gill-some geological controls of development. J.Craven Pothole Club 5: 8-11.

GLOVER, R.R. 1974. Gaping Gill-some underground controls of development. J.Craven Pothole Club. 5: 58-65.

GOLUBIĆ, S.T., PERKINS, R.D. & LUKAS, K.J. 1975. Boring microorganisms and microborings in carbonate substrates. In FREY, R.W. ed. The Study of Trace Fossils, p229-259. Springer-Verlag; Berlin-Heidelberg-New York.

GRABAU, A.W. 1905. On classification of sedimentary rocks. Am.Geologist. 33:228-247.

GRABAU, A.W. 1913. Principles of Stratigraphy Seiler & Co., New York, 1185pp.

GRAY, D. & SOMERVILLE, I.D. 1984. EDE'84 Field Excursion to Dinantian Rocks around Llangollen, 10 April 1984.

GREEN, J.R.N. 1917. Note on the correlation of the Ingletonian slates. Proc.Geol.Ass. 28:95-97.

GROVER, G.Jr. & READ, J.F. 1978. Fenestral and associated vadose diagenetic fabrics of tidal flat carbonates, Middle Ordovician, New Market Limestone, southwestern Virginia. J.Sediment.Petrol. 48:453-474.

GUNATILAKA, A. 1976. Thallophyte boring and micritization within skeletal sands from Connemara, Western Ireland. J.Sediment.Petrol 46:548-554.

HALLEY, R.B. 1975. Peritidal lithologies of Cambrian carbonate islands, Carrara Formation, Southern Great Basin. In GINSBURG, R.N. ed. Tidal Deposits, 279-288 Springer-Verlag. New York.

HALLIWELL, R. 1979. Caves, limestones and others. J.Craven Pothole Club 6, 38-40.

HAM, W.E. 1952. Algal origin of the "birdeye" limestone in the McLish Formation. Proc.Oklahoma Acad.Sci. 33:200-203.

HAM, W.E. 1954. Collings Ranch conglomerate, Late Pennsylvanian, in the Arbuckle Mountains, Oklahoma. Bull.Am.Assoc.Pet.Geol. 38:2035.

HAM, W.E. & PRAY, L.C. 1962. Modern concepts and classification of carbonate rocks. In HAM, W.E., ed. Classification of Carbonate Rocks. Am. Assoc. Pet.Geol.Mem. 1:2-19.

HANDFORD, C.R. 1978. Monteagle Limestone (Upper Mississippian). Oolitic Tidal-Bar Sedimentation in Southern Cumberland Plateau. Bull.Am.Assoc.Pet.Geol. 62:644-656.

HARDCASTLE,C.1889. Physical features of Ingleton; lecture to the Leeds Geological Association delivered in March, reported in detail. Lancaster Gazette. Apr. 6; supplement p.3 columns def.

HARMS, J.C. 1975. Stratification and sequence in prograding shoreline deposits. In Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences. Soc.Econ.Palaeontologists and Mineralogists Short Course 2:81-102.

HECKEL, P.H. 1972. Recognition of Ancient Shallow Marine Environments. In RIGBY, J.K. & HAMBLIN, W.K., eds. Recognition of Ancient Sedimentary Environments. Soc.Econ.Paleontologists and Mineralogists Spec.Publ. 16:226-286.

HEMINGWAY, J.E. 1968. Sedimentology of coal-bearing strata. In MURCHISON, D. & WESTOLL, T.S. eds. Coal and Coal Bearing Strata. Oliver & Boyd, Edinburgh-London. p43-69.

HINE, A.C. 1977. Lily Bank, Bahamas: History of an active oolite sand shoal. J.Sediment.Petrol. 47:1554:1582.

HINE, A.C. & NEUMANN, A.C. 1977. Shallow carbonate bank margin growth and structure, Little Bahama Bank, Bahamas. Am.Assoc.Pet.Geol.Bull. 61: 376-406.

HINE, A.C., WILBER, R. J. & NEUMANN, A.C. 1981. Carbonate sand bodies along contrasting shallow bank margins facing open seaways in northern Bahamas. Am.Assoc.Pet.Geol.Bull 65:261-290.

HOOKE, R. LeB. 1967. Processes on arid-region fans. J.Geol. 75:438-460.

HOROWITZ, A.S. & POTTER, P.E. 1971. Introductory Petrography of Fossils Springer-Verlag, Berlin - Heidelberg - New York. 302 pp.

HOSKIN, C.M. & SUNDEEN, D.A. 1975. Relationship between grain size of source rock and derived sediment, Biorka Island Tonalite, southeastern Alaska. J.Geol. 83:567-578.

HUDDLE, J.W. & PATTERSON, S.H. 1961. Origin of Pennsylvanian underclay and related seat rocks. Bull.Geol.Soc.America. 72:1643-1660.

HUDSON, R.G.S. 1930. The Carboniferous of the Craven Reef Belt: The Namurian unconformity at Scalebar, near Settle. Proc.Geol.Assoc. 41:290-322.

HUDSON, R.G.S. 1933. The scenery and geology of north-west Yorkshire. In 'The Geology of the Yorkshire Dales' Proc.Geol.Assoc. 44:227-269.

HUDSON, R.G.S. 1938. In "The Geology of the country around Harrogate," Proc.Geol.Ass. 49: 293-352.

HUDSON, R.G.S. & DUNNINGTON, H.V. 1945. The Carboniferous rocks of the Swinden Anticline, Yorkshire. Proc.Geol.Assoc. 55:195-215.

HUDSON, R.G.S. & KING, W.B.R. 1933. Report of Summer Field Meeting (1933) to Yorkshire Dales. Proc.Geol.Assoc. 44:428-440.

HUSSEINI, S.I. & MATTHEWS, R.K. 1972. Distribution of High-Magnesium Calcite in Lime Muds of the Great Bahamas Bank: Diagenetic Implications. J.Sediment.Petrol. 42:179-182.

ILLING, L.V. 1954. Bahaman calcareous sands. Am.Assoc.Pet.Geol. 38: 1-95.

ILLING, L.V. 1959. Deposition and diagenesis of some Upper Paleozoic carbonate sediments in western Canada. 5th World Petrol.Congr. Proc.Paper. 2, Sect 1, 23-50.

IMBRIE, J. & BUCHANAN, H. 1965. Sedimentary structures in modern carbonate sands of the Bahamas. In MIDDLETON, G.V. ed. Primary Sedimentary Structures and Their Hydraulic Interpretation. Soc.Econ.Palaeontologists and Mineralogists Spec.Publ. 12: 149-172.

IMBRIE, J. & PURDY, E.G. 1962. Classification of modern Bahamian carbonate sediments. In HAM, W. E.ed. Classification of Carbonate Rocks. Am.Assoc.Pet.Geol.Mem. 2: 253-272.

INGRAM, R.L. 1954. Terminology for the thickness of stratification and parting units of sedimentary rocks. Bull.Geol.Soc.America. 65:937-938.

IRWIN, M. L. 1965. General theory of epeiric clear water sedimentation. Bull.Am.Assoc.Pet.Geol. 49:445-459.

JEFFERSON, D.P. 1980. Cyclic sedimentation in the Holkerian (Middle Visean) north of Settle, Yorkshire. Proc.York.Geol.Soc. 42:483-503.

JOHNS, C. 1908. Some undescribed faults in the Settle-Malham area. Proc.Yorks.Geol.Soc. 16: 393-402.

JOHNS, C. & VAUGHAN, A.1910. On the Carboniferous basement beds at Ingleton. Geol.Mag. 3:320-323.

JOHNSON, A.M 1970. Physical Processes in Geology Freeman, Cooper & Co. San Francisco. 577pp.

JOHNSON, D.W. 1919. Shore Processes and Shoreline Development John Wiley, New York. 584pp

JOHNSON, G.A.L. 1967. Basement control of Carboniferous sedimentation in northern England. Proc.Yorks.Geol.Soc. 36:175-194.

JOHNSON, G.A.L. & MARSHALL, A.E. 1971. Tournaisian beds in Ravenstonedale, Westmorland. Proc.Yorks.Geol.Soc. 38:261-280.

JOHNSON, H.D. 1978. Shallow siliciclastic seas. In READING, H.G.ed. Sedimentary Environments and Facies Blackwell. Oxford. p207-258.

JONGMANS, W. J., KOOPMANS, R.G. and ROOS, K.G. 1938. Compt. rend. 2e Congr.strat.geol.Carb. (Heerleen 1935)p 1733.

KENDALL, C.G. St. C. & SKIPWITH, P. A. D'E. 1969. Holocene shallow-water carbonate and evaporite sediments of Khor al Baxam, Abu Dhabi, southwest Persian Gulf. Am.Assoc.Pet.Geol.Bull. 53: 841-869.

KENDALL, P.F. 1911. Geology of the district around Settle and Harrogate. Proc.Geol.Assoc. 22:46.

KING, C.A.M. 1975. Introduction to Physical and Biological Oceanography. Edward-Arnold, London, 372pp.

KING, W.B.R. & WILCOCKSON, W.H. 1934. The Lower Palaeozoic rocks of Austwick and Horton-in-Ribblesdale, Yorkshire. Quart.J.Geol.Soc.Lond. 90: 7-31.

KLEIN, G.de V. 1963. Analysis and review of sandstone classifications in the North American geological literature 1940-1960. Geol.Soc.America.Bull. 74: 555-576.

KLEIN, G. de. V. 1970. Depositional and dispersal dynamics of intertidal sand bars. J.Sediment.Petrol. 40:1095-1127.

KOBLUCK, D.R. & KAHLE, C.H.F. 1978. Geologic significance of boring and cavity-dwelling marine algae. Bull.Canadian.Pet.Geol. 26: 362-379.

KOBLUCK, D. R. & RISK, M.J. 1977. Micritization and carbonate-grain binding by endolithic algae. Am.Assoc.Pet.Geol.Bull. 61:1069-1082.

KORNICKER, L.S. & PURDY, E.G. 1957. A Bahamian faecal-pellet sediment. J.Sediment.Petrol. 27:126-128.

KREVELEN, D. W. Van. 1961. Coal. Elsevier, Amsterdam-London-NewYork. 514pp.

KRUMBEIN, W.C. & SLOSS, L.L. 1963. Stratigraphy and Sedimentation 2 ed. Freeman. San Francisco-London. 660pp.

KRYNINE, P.D. 1948. The megascopic study and field classification of sedimentary rocks. J.Geol. 56: 130-165.

KUMAR, N. & SANDERS, J.E. 1976. Characteristics of shoreface storm deposits: Modern and Ancient examples. J.Sediment.Petrol. 46: 145-162.

LAND, L.S. 1967. Diagenesis of skeletal carbonates. J.Sediment.Petrol. 37: 914-930.

LAND, L.S. 1970. Carbonate mud: Production by epibiont growth on Thalassia testudinum. J.Sediment.Petrol. 40.1361-1363.

LAPORTE, L.F. 1967. Carbonate deposition near mean sea-level and resultant facies mosaic: Manlius formation (Lower Devonian) of New York State. Bull.Am.Assoc.Pet.Geol 51: 73-101.

LAPORTE, L.F. 1968. Recent carbonate environments and their paleoecologic implications. In DRAKE, E.T. (ed). Evolution and Environment. Yale Univ. Press, New Haven, Conn, pp229-258.

LAPORTE, L.F. 1969. Recognition of a transgressive carbonate sequence within an epeiric sea. Helderberg Group (Lower Devonian) of New York State. Soc.Econ.Palaeontologists and Mineralogists Spec.Publ. 14: 98-119.

LAPORTE, L.F. 1971. Paleozoic carbonate facies of the central Appalachian shelf. J.Sediment.Petrol. 41: 724-740.

LAPORTE, L.F. 1975. Carbonate tidal-flat deposits of the Early Devonian Manlius Formation of New York State. In GINSBURG, R.N. ed. Tidal Deposits Springer-Verlag, New York. p233-250.

LEEDAL, G.P. & WALKER, G.P.L. 1950. A restudy of the Ingletonian Series of Yorkshire. Geol.Mag. 87: 57-66.

LEEDER, M.R. 1975. Lower Border Group Tournaisian stromatolites from the Northumberland Basin. Scott.J.Geol. 11:207-226.

LEIGHTON, M.W. & PENDEXTER, C. 1962. Carbonate rock types. In HAM, W.E.ed. Classification of Carbonate Rock: A symposium. Am.Assoc.Pet.Geol.Mem. 1:33-61.

LEES, A. 1975. Possible influence of salinity and temperature on modern shelf carbonate sedimentation. Marine Geol. 19:159-198.

LINDHOLM, R.C. & FINKELMAN, R.B. 1972. Calcite staining: Semiquantitative determination of ferrous iron. J.Sediment.Petrol. 42:239-242.

LOGAN, B.W., HOFFMAN, P. & GEBELEIN, C.D. 1974. Algal mats, cryptalgal fabrics and structures, Hamblin Pool, Western Australia. Am.Assoc.Pet.Geol.Mem. 22: 140-194.

LOGAN, B.W., HARDING, J.L., AHR, W.M., WILLIAMS, J.L. & SNEAD, R.G. 1969. Carbonate sediments and reefs, Yucatan shelf, Mexico. Am.Assoc.Pet.Geol.Mem. 11:1-198.

LOGAN, B.W., REZAK, R. & GINSBURG, R.N. 1964. Classification and environmental significance of algal stromatolites. J. Geol 72:68-83.

LOREAU, J.P. 1970. Ultrastructure de la phase carbonate des oolithes marines actuelles. Compt. Rend. Ser. D., 271,816-819.

LOWENSTAM, H., & EPSTEIN, S. 1957. On the origin of sedimentary aragonite needles of the Great Bahama Bank. J.Geol. 65:364-375.

LUCIA, F.J. 1972. Recognition of evaporite-carbonate shoreline sedimentation. Soc. Econ. Palaeontologists and Mineralogists Spec. Publ. 16, 160-191.

McCABE, P.J. 1972. The Wenlock and Lower Ludlow strata of the Austwick and Horton-in-Ribblesdale inlier of north-west Yorkshire. Proc. Yorks. Geol. Soc. 39, 167-174.

McCABE, P. J. & WAUGH, B. 1973. Wenlock and Ludlow sedimentation in the Austwick and Horton-in-Riblesdale inlier, north-west Yorkshire. Proc.Yorks.Geol.Soc. 39: 445-450.

MARR, J. E. 1881. On some sections in Lower Palaeozoic rocks of the Craven District. Proc.Yorks.Geol.Soc. 7:397.

MARR, J. E. 1887. The Lower Palaeozoic rocks near Settle. Geol.Mag. 1887: 35-38.

MARR, J. E. 1899. On the limestone knolls in the Craven district of Yorkshire and elsewhere. Quart.J.Geol.Soc.Lond. 55: 327-358.

MARR, J. E. 1921. On the rigidity of north-west Yorkshire. Naturalist 1921: 63-72.

MATTHEWS, R.K. 1966. Genesis of Recent lime mud in southern British Honduras. J.Sediment.Petrol. 36:428-454.

MIDDLETON, G.V. & HAMPTON, M.A. 1973. Sediment gravity flows: Mechanics of flow and deposition. Soc.Econ.Palaeontologists and Mineralogists. Pac. Sect., Short Course, p1-38.

MILLER, A.A. & TURNER, J.S. 1931. The Lower Carboniferous succession along the Dent Fault and the Yoredale beds of the Shap district. Proc.Geol.Assoc. 42: 1-28.

MILLER, J. & GRAYSON, R. F. 1982. The regional context of Waulsortian facies in northern England. In Symposium on the Palaeoenvironmental Setting and Distribution of Waulsortian Facies. El Paso Geol.Soc., Univ. of Texas p. 17-32.

MILLIMAN, J.D. 1974. Marine Carbonates. Springer, Berling, 375 pp.

MITCHELL, M. 1972. The base of the Visean in south-west and north-west England. Proc.Yorks.Geol.Soc. 39: 151-160.

MITCHELL, M. 1978. Dinantian. In MOSELEY, F.ed. The Geology of the Lake District. Yorks.Geol.Soc. Occas. Publ. No.3.

MONTY, C.L.V. 1972. Recent algal stromatolitic deposits, Andros Island, Bahamas. Preliminary report. Geol.Rundschau 61: 742-783.

MONTY, C.L.V. 1976. The origin and development of cryptalgal fabrics. In WALTER, M. R. ed. Stromatolites. Developments in Sedimentology, Elsevier, New York, p193-249.

MONTY, C.L.V. 1977. Evolving Concepts on the Nature and the Ecological Significance of Stromatolites. In FLUGEL, E., ed. Fossil Algae: Recent Results and Developments. Springer-Verlag, Berlin - Heidelberg - New York :15-35.

MOORE, L. R. 1968. Some sediments closely associated with coal seams. In MURCHISON, D. & WESTOLL, T.S. eds. Coal and Coal-Bearing Strata Oliver & Boyd. Edinburgh & London, p 105-123.

MOSELEY, F. 1972. A tectonic history of northwest England. J.Geol.Soc. Lond. 128, 561-598.

MOSELEY, F. & AHMED, S.M.1967. Carboniferous joints in the north of England and their relation to earlier and later structures Proc. Yorks.Geol.Soc. 36:61-90

MOUNTJOY, E. W. 1975. Intertidal and supratidal deposits within isolated Devonian buildups, Alberta. In GINSBURG. R.N.ed. Tidal Deposits Springer-Verlag, New York p387-395.

MUNDY, D.J.C. & ARTHURTON, R.S. 1980. Field Meeting: Settle and Flasby. Proc. Yorks. Geol. Soc. 43: 32-36.

MURRAY, J. W., GRUNDMANIS, V. & SMETHIE, W.M.1978. Interstitial water chemistry in the sediments of Saanich Inlet. Geochim. et Cosmochim. Acta 42: 1011-1026.

MYERS, J.O. & WARDELL, J. 1967. The gravity anomalies of the Askrigg Block south of Wensleydale. Proc. Yorks. Geol. Soc. 36: 169-173.

NEUMANN, A.C., GEBELEIN, C.D. & SCOFFIN, T.P. 1970. The composition, structure and erodability of subtidal mats, Abaco, Bahamas. J. Sediment. Petrol. 40: 274-297.

NEUMANN, A.C. & LAND, L.S. 1975. Lime mud deposition and calcareous algae in the Bight of Abaco, Bahamas: a budget. J. Sediment. Petrol. 45:763-786.

NEWELL, N.D., IMBRIE, J., PURDY, E.G. & THURBER, D.L. 1959. Organism communities and bottom facies, Great Bahama Bank. Bull. Am. Museum. Nat. Hist. 117:177-228.

NEWELL, N.D., PURDY, E.G. & IMBRIE, J. 1960. Bahamian oolitic sand. J.Geol. 68:481-497.

NEWELL, N.D. & RIGBY, J. K. 1957. Geological studies on the Great Bahama Bank. In LE BLANC, R.H. & BREEDING, J.G., eds. Regional Aspects of Carbonate Deposition. Soc.Econ. Palaeontologists and Mineralogists Spec. Publ. 5:15-72.

NEWELL, N.D., RIGBY, J.K., WHITEMAN, A.I. & BRADLEY, J.S. 1951. Shoal-water geology and environments, eastern Andros Island, Bahamas. Bull. Am. Mus. Nat. Hist. 97: 1-29.

NICHOLAS, C. 1968. The stratigraphy and sedimentary petrology of the Lower Carboniferous rocks southwest of the Lake District. Unpublished Ph.D. Thesis, University of London.

NICHOLSON, H. A. 1869. Notes on the green slates and porphyries of the neighbourhood of Ingleton. Geol.Mag. 6:213.

NOVAK, I.D., 1978. Beach gravels. In FAIRBRIDGE, R.W. & BOURGEOIS, J., eds Encyclopedia of Sedimentology, p 43-44. Encyclopedia of Earth Sciences Series vol. 6. Dowden, Hutchinson & Ross, Stroudsberg.

NUDDS, J. R. 1981. Discovery of the Carboniferous coral Dorlodotia in Northern England. Proc.Yorks.Geol.Soc., 43: 331-340.

O'CONNOR, J. 1964. The Geology of the Area around Malham Tarn, Yorkshire. Field Studies. 2:53-82.

OFF, T. 1963. Rhythmic linear sand bodies caused by tidal currents. Am.Assoc.Pet.Geol.Bull. 47: 324-341.

OKADA, H. 1971. Classification of sandstone: analysis and proposal. J.Geol. 79: 509-525.

OLDERSHAW, A.E. & SCOFFIN, T. P. 1967. The source of ferroan and non-ferroan calcite cements in the Halkin and Wenlock Limestone. Geol J. 5:309-319.

O'NIONS, R.K., OXBURGH, E.R., HAWKESWORTH, C.J. & MACINTYRE, R.M. 1973. New isotopic and stratigraphical evidence on the age of the Ingletonian: probable Cambrian of northern England. J.Geol.Soc.Lond. 129:445-452.

PERKINS, R.D. & HALSEY, S.D. 1971. Geologic significance of micro-boring fungi and algae in Carolina shelf sediments. J.Sediment.Petrol. 41:843-853.

PETTIJOHN, F.J. 1957. Sedimentary Rocks. Harper, New York, 718pp.

PETTIJOHN, F.J. & POTTER, P.N. 1964. Atlas and Glossary of Primary Sedimentary Structures. Springer-Verlag. Berlin-Heidelberg-New York. 370pp.

PHILLIPS, J. 1829. On a group of slate rocks ranging ESE between the Rivers Lune and Wharfe, from near Kirby Lonsdale to near Malham; and on the attendant phenomena. Trans.Geol.Soc.London. 3, 1-19.

PHILLIPS, J. 1836. Illustrations of the geology of Yorkshire. Part.II. The Mountain Limestone District. John Murray, London, 253 pp.

PLAYFAIR, J. 1802. Illustrations of the Huttonian Theory. London.

PURDY, E.G. 1963a. Recent calcium carbonate facies of the Great Bahama Bank. 1. Petrography and Reaction Groups. J.Geol. 71:334-355.

PURDY, E.G. 1963b. Recent calcium carbonate facies of the Great Bahama Bank. 2. Sedimentatry facies. J.Geol. 71: 472-497.

PURDY, E.G.1968. Carbonate diagenesis: Am environmental survey. Geol.Romana. 7:183-228.

RAISTRICK, A. & MARSHALL, C.E. 1939. The Nature and Origin of Coal and Coal Seams. English Universities Press Ltd. London. 282 pp.

RAMSBOTTOM, W.H.C. & MITCHELL,M. 1968. Report of the Palaeontological Department. Institute of the Geological Sciences Ann. Rep. 1968/1969, p97.

RAMSBOTTOM, W.H.C. 1973. Transgressions and Regressions in the Dinantian: A new Synthesis of British Dinantian Stratigraphy. Proc.Yorks.Geol.Soc. 39:567-607.

RAMSBOTTOM, W.H.C. 1974. Dinantian. In RAYNER, D.H. & HEMINGWAY, J.E., eds. The Geology and Mineral Resources of Yorkshire. Yorks.Geol.Soc. 47-73.

RAMSBOTTOM, W.H.C. 1977. Major cycles of Transgression and Regression (Mesothems) in the Namurian. Proc.Yorks.Geol.Soc. 41:261-291.

RAMSBOTTOM, W.H.C. 1981. Eustacy, sea level and local tectonism, with examples from the British Carboniferous. Proc.Yorks.Geol.Soc. 43: 473-482.

RASTALL, R.H. 1906. The Ingletonian Series of west Yorkshire. Proc.Yorks.Geol.Soc 16: 87-100.

RAYNER, D.H. 1953. The Lower Carboniferous rocks in the north of England. Proc.Yorks.Geol.Soc. 28: 231-315.

RAYNER, D.H. 1957. A problematical structure from the Ingletonian rocks, Yorkshire. Trans.Leeds Geol.Ass. 7: 34-42.

READ, J.F. 1975. Tidal-flat facies in carbonate cycles, Pillara Formation (Devonian), Canning Basin, Western Australia. In GINSBURG, R.N.ed. Tidal Deposits. Springer-Verlag. New York. p251-258.

READ, J.F. & GROVER, G.A. Jr. 1977. Scalloped and planar erosion surfaces, Middle Ordovician Limestones, Virginia. J.Sediment.Petrol 47: 956-972.

READING, H. E. ed., 1978. Sedimentary Environments and Facies. Blackwell. Oxford. 567 pp.

REINECK, H.E. & SINGH, I.B. 1973. Depositional Sedimentary Environments. Springer-Verlag. Berlin-Heidelberg-New York. 439 pp.

RICHTER, D.K. 1980. Former magnesian-calcite ooids in Paleozoic to Recent sediments. Int.Assoc.Sedimentol.1st.Eur.Meet.Abstr. p215-218.

RICHTER, D.K. 1983. Calcareous ooids: a synopsis. In PERYT, T, ed. Coated Grains. Springer-Verlag. Berlin-Heidelberg. p71-99.

RICHTER, D.K. & FUCHTBAÜER, H. 1978. Ferroan calcite replacement indicates former magnesian calcite skeletons. Sedimentology 25: 843-860.

RICKETTS, C. 1869. The geology of the neighbourhood of Ingleborough. Proc.Liv.Geol.Soc.Sess. 10:34.

RIDING, R. 1975. Girvanella and other algae as depth indicators. Lethaia 8:173-179.

ROONEY, W.S. & PERKINS, R.D. 1972.. Distribution and geologic significance of microboring organisms within sediments of the Arlington Reef Complex, Australia. Bull.Geol.Soc.America. 83: 1139-1150.

ROSE, W.C.C. & DUNHAM, K.C. 1978. Geology and haematite deposits of south Cumbria. Mem.Geol.Surv.G.B. 171 pp.

SCHOLLE, P.A. 1978. A color illustrated guide to carbonate rocks constituents, textures, cements and porosities. Am.Assoc.Pet.Geol.Mem. 27, 241pp.

SCHOLLE, P.A. & KLING, S.A. 1972. Southern British Honduras; Lagoonal coccolith ooze. J.Sediment.Petrol. 42: 195-204.

SCHWARZACHER, W. 1958. The stratification of the Great Scar Limestone in the Settle district of Yorkshire. Lpool Manchr.Geol.J. 2: 124-142.

SCOFFIN, T.P. 1970. The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini Lagoon, Bahamas. J.Sediment.Petrol. 40: 249-273.

SEDGWICK, A. 1835. Description of a series of longitudinal and transverse sections through a portion of the Carboniferous Chain between Penigent and Kirby Stephen. Trans.Geol.Soc.Lond. (2), 4:69-101.

SEDGWICK, J.M. 1983a. The Geology of an area north of Austwick, Yorkshire. Undergraduate mapping project. University of Southampton, 33p

SEDGWICK, J.M. 1983b. The Red Hill Limestone at Nappa Scars, Yorkshire. Undergraduate project. University of Southampton, 42pp.

SELWOOD, B.W. 1978. Shallow-water Carbonate Environments. In READING, H.G., ed. Sedimentary Environments and Facies: 259-313

SEYLER, 1954. Letter to the Nomenclature Sub-committee, International Committee for Coal Petrology.

SHAW, A.B. 1964. Time in Stratigraphy. McGraw-Hill, New York, 353pp.

SHELLEY, A.E. 1967. Analyses of two coals from the Great Scar Limestone near Ingleton, Yorkshire. Proc. Yorks. Geol. Soc.. 36: 51-56.

SHINN, E. A. 1968. Practical significance of birdseye structures in carbonate rocks. J.Sediment.Petrol. 38: 215-223.

SHINN, E.A. 1983a. Birdseyes, fenestrae, shrinkage pores and loferites: A re-evaluation. J.Sediment.Petrol. 53: 619-628.

SHINN, E. A. 1983b. Tidal Flat. In SCHOLLE, P.A. BEBOUT, D.G. & MOORE, C.H. eds. Carbonate Depositional Environments. Am. Assoc. Pet. Geol Mem. 33: 171-210.

SHINN, E.A. & ROBBIN, D.M.1983. Mechanical and chemical compaction in fine grained shallow-water limestones. J.Sediment.Petrol. 53: 595-618.

SOMERVILLE, I.D. 1979. A sedimentary cyclicity in early Asbian (lower D1) limestones in the Llangollen district of North Wales. Proc.Yorks. Geol.Soc. 42: 397-404.

STEEL, R.J. 1974. New York Sandstone floodplain and piedmont sedimentation in the Hebridean Province. J.Sediment.Petrol. 44: 336-357.

STIEGLITZ, R.D. 1972. Scanning electron microscopy of the fine fraction of Recent carbonate sediments from Bimini, Bahamas. J.Sediment. Petrol. 42: 211-226.

STIEGLITZ, R.D. 1973. Carbonate needles: additional organic sources, Bull.Geol.Soc. America. 84: 927-930.

STOCKMAN, K. W., GINSBURG, R.N. & SHINN, E.A. 1967. The production of lime mud by algae in south Florida. J.Sediment.Petrol. 37: 633-648.

STOPES, M.C. 1935. On the petrology of banded bituminous coals. London. Fuel, 14: 4-13.

STRATTEN, T. 1974. Notes on the applicability of shape parameters to differentiate between beach and river deposits in southern Africa. Trans.Geol.Soc.S.Africa. 77: 59-64.

STRICKLIN, F. L. & SMITH, C.I. 1973. Environmental reconstruction of a carbonate beach complex: Cow Creek (Lower Cretaceous) Formation of central Texas. Geol.Soc.America.Bull. 84: 1349-1368.

SWEETING, M. M. 1950. Erosive cycles and limestone caverns in the Ingleborough district. Georgl.J. 115; 63-78.

SWINCHATT, J. P. 1969. Algal boring: a possible depth indicator in carbonate rocks and sediments. Bull.Geol.Soc.America. 80: 1391-1396.

TEBUTT, G.E., CONLEY, C.D. & BOYD, D.W. 1965. Lithogenesis of a carbonate rock fabric. Contrib.Geol. 4: 1-13.

TELLAM, J. H. 1977. Sedimentology of the Dry Gill section, Yorkshire. Unpublished undergraduate project, University of Southampton.

THOMPSON, A.F. & THOMASSON, M.R. 1969. Shallow to deep water facies development in the Dimple limestone (Lower Pensylvanian), Marathon Region, Texas. In FRIEDMAN, G. M., ed. Depositional Environments in Carbonate Rocks. Soc.Econ.Palaeontologists and Mineralogists Spec. Publ. 14: 57-78.

TIDDEMANN, R.H. 1889. On concurrent faulting and deposition in Carboniferous times in Craven, Yorkshire, with a note on Carboniferous reef. Rep. Br. Ass. (Newcastle): 600-603.

TIDDEMANN, R.H. 1894. On the occurrence of a limestone-conglomerate on the north side of the Craven Faults. Proc.Yorks.Geol.Soc. 12: 437-440.

TIDDEMANN, R.H. 1901. On the formation of reef knolls. Geol.Mag. 8: 20-23.

TOOMEY, D.F. 1974. Algally coated grains from the Leavenworth Limestone (U. Pennsylv., Midcontinent Region, U.S.A.). N.Jb.Geol.Palaont.Mh. 1974: 175-191.

TROTTER, F.M. & HOLLINGWORTH, S.E. 1928. The Alston Block Geol.Mag. 65: 433-448.

TURMEL, R. J. & SWANSON, R.G. 1976. The development of Rodriguez Bank, a Holocene Mudbank in the Florida Reef Tract. J.Sediment.Petrol. 46: 497-518.

TURNER, J.S. 1927. The Lower Carboniferous succession in the Westmorland Pennines and its relations to the Pennine and Dent Faults. Proc.Geol.Ass. 38: 339-350.

TURNER, J.S. 1949. The deeper structure of central and northern England. Proc.Yorks.Geol.Soc. 27: 280-297.

TURNER, J.S. 1950. Notes on the Carboniferous Limestone of Ravenstonedale, Westmorland. Trans.Leeds.Geol.Ass. 6: 124-134.

TURNER, J.S. 1959. Pinskey Gill Beds in the Lune Valley, Westmorland, and the Ashfell Sandstone in Garsdale, Yorkshire. Trans.Leeds.Geol.Ass. 7, 78-87.

TURNER, P. 1980. Continental Red Beds. Developments in Sedimentology 29. Elsevier. Amsterdam. 562pp.

TYLER, J. H. 1969. Genesis and environmental energy of a Devonian lagoonal bank near Alpena, Michigan. J.Sediment.Petrol. 39: 509-520.

VALET, G. 1979. Approche paleoecologique du monde des Dasycladales a patir de l'ecologie des forms actuelles. Bull.Centre Rech.Explor-Prof.Elf-Aquitaine. 3: 857-866.

VAUGHAN, A. 1905. The palaeontological sequence in the Carboniferous Limestone of the Bristol area. Quart.J.Geol.Soc.Lond. 61:181-307.

VAUGHAN, A. 1906. The Avonian of the Avon Gorge. Proc.Bristol Nat.Soc. series 4: 1:74-168.

VAUGHAN, A. 1916. The knoll region of Clitheroe, Bowland and Craven. Proc.Yorks.Geol Soc. 19: 41-50.

VAUGHAN, T.W. 1914. Preliminary remarks on the geology of the Bahamas: origin of oolite. Carnegie Inst.Wash.Publ. 182: 47-54.

WAGER, L. R. 1931. Jointing in the Great Scar Limestone of Craven and its relation to the tectonics of the area. Quart.J.Geol.Soc.Lond. 87: 392-424.

WALKDEN, G.M. 1972. The mineralogy and origin of interbedded clay wayboards in the Carboniferous Limestone of the Derbyshire Dome. Geol.J. 8: 143-160.

WALKER, R.G. 1975. Conglomerate: sedimentary structures and facies models. Soc.Econ.Palaeontologists and Mineralogists Short Course 2: 133-161.

WALTHAM, A.C. 1971. Shale units in the Great Scar Limestone of the southern Askrigg Block. Proc.Yorks.Geol.Soc. 38: 285-292.

WALTHAM, A.C. 1974, ed. The Limestones and Caves of North-West England. David & Charles - Br.Cave Res.Assoc. Newton Abbott, 477pp.

WALTHAM, A.C. 1976. Excursion report: Ingleton and Ingleborough. Mercian Geologist. 6: 67-75.

WEYL, P.K. 1967. The solution behaviour of carbonate materials in sea water. Studies in Tropical Oceanogr. Univ.Miami. 5: 178-228.

WHETTON, J T., MYERS, J. O. and BURKE, K.B.S. 1961. Tracing the boundary of the concealed coalfield of Yorkshire using the gravity method. Min.Engr. 120: 657-674.

WHETTON, J. T., MEYER, J. O. & WATSON, I. J. 1956. A gravimeter survey in the Craven district of north-west Yorkshire. Proc.Yorks.Geol.Soc. 30: 259-287.

WILCOCKSON, W.H. 1927. The pre-Carboniferous topography near Austwick and Horton-in-Ribblesdale. Proc.Yorks.Geol.Soc. 21: 17-23.

WILMORE, A. 1910. On the Carboniferous Limestone south of the Craven Fault (Grassington-Hellifield district). Quart.J.Geol.Soc.Lond. 66: 539-585.

WILSON, A.A. & CORNWELL, J. D. 1982. The Institute of Geological Sciences Borehole at Beckermonds Scar, North Yorkshire. Proc.Yorks.Geol.Soc. 44:59-88.

WILSON, J. L. 1974. Characteristics of carbonate platform margins. Am.Assoc.Petrol.Geol.Bull. 58: 810-824.

WILSON, J. L. 1975. Carbonate Facies in Geologic History, Springer-Verlag, Berlin - Heidelberg - New York, 471 pp.

WILSON, M .J. 1965. The origin and geological significance of the South Wales underclays. J.Sediment.Petrol. 35: 91-99.

WINLAND, H. D. 1968. The role of high Mg calcite in the preservation of micrite envelopes and textural features of aragonitic sediments. J.Sediment.Petrol. 38: 1320-1325.

WINLAND, H. D. & MATTHEWS, R.K. 1974. The origin and significance of grapestone, Bahama Islands. J.Sediment.Petrol. 44: 921-927.

WOLF, K. H. 1965. "Grain-diminuition" of algal colonies to micrite. J.Sediment.Petrol. 35: 420-427.

WOOD, A. 1941a. The algal nature of the genus Koninckopora Lee; its occurrence in Canada and Western Europe. Quart.J.Geol.Soc.Lond. 98: 205-222.

WOOD, A. 1941b. The Lower Carboniferous calcareous algae Mitcheldeania Wethered and Garwoodia n.gen. Proc.Geol.Ass. 52: 216-226.

WOOD, A. 1941c. "Algal dust" and the finer-grained varieties of Carboniferous limestones. Geol.Mag. 78: 192-200.

WRAY, J. L. 1972. Environmental distribution of Calcareous Algae in Upper Devonian Reef Complexes. Geol.Rundsch. 61: 578-584.

WRAY, J. L. 1977. Calcareous algae. Developments in Paleontology and Stratigraphy. 4, Elsevier, Amsterdam, 185 pp.

ZAMARRENO, I. 1975. Peritidal origin of Cambrian carbonates in Northwest Spain. In GINSBURG, R.N., ed. Tidal Deposits. Springer - Verlag. New York. p 289-298.

PLATES

Plates 1 to 11	Field Photographs
Plates 12 to 24	Hand Specimen Photographs and Photomicrographs.

ERRATUM

During the course of this study two of the formation names were changed. The Red Hill Limestone (RHL) and Dalton Formation (DF) have become the Thornton Force Formation and Raven Ray Formation respectively.

Consequently, in Plate 6a read RHL as the Thornton Force Formation. and in Plates 5a, 6a and 6d read DF as the Raven Ray Formation.

PLATE 1

1a. Unconformable contact between the Great Scar Group and underlying Lower Palaeozoic rocks, Moughton Scars (SD788699), above Austwick Road. The irregular relief on the unconformity (1-3metres) has resulted from weathering and erosion of inclined Silurian rocks.

1b. Unconformable contact between the Great Scar Group and the underlying Horton Formation siltstones, Moughton Scars (SD798697), above Combs Quarry, Ribblesdale. There is very little relief over most of the exposed length of the unconformity; it is a wave cut platform.

1c. Unconformable contact between the Great Scar Group and the underlying Lower Palaeozoic rocks, northern end of Combs Quarry (SD799699), Ribblesdale. Microrelief on this part of the unconformity is 1-3 metres. (height of supervisor: 1.80m).

1d. Unconformable contact between the Great Scar Group and the underlying Lower Palaeozoic rocks, western side of Crummack Dale (SD767708-771714).

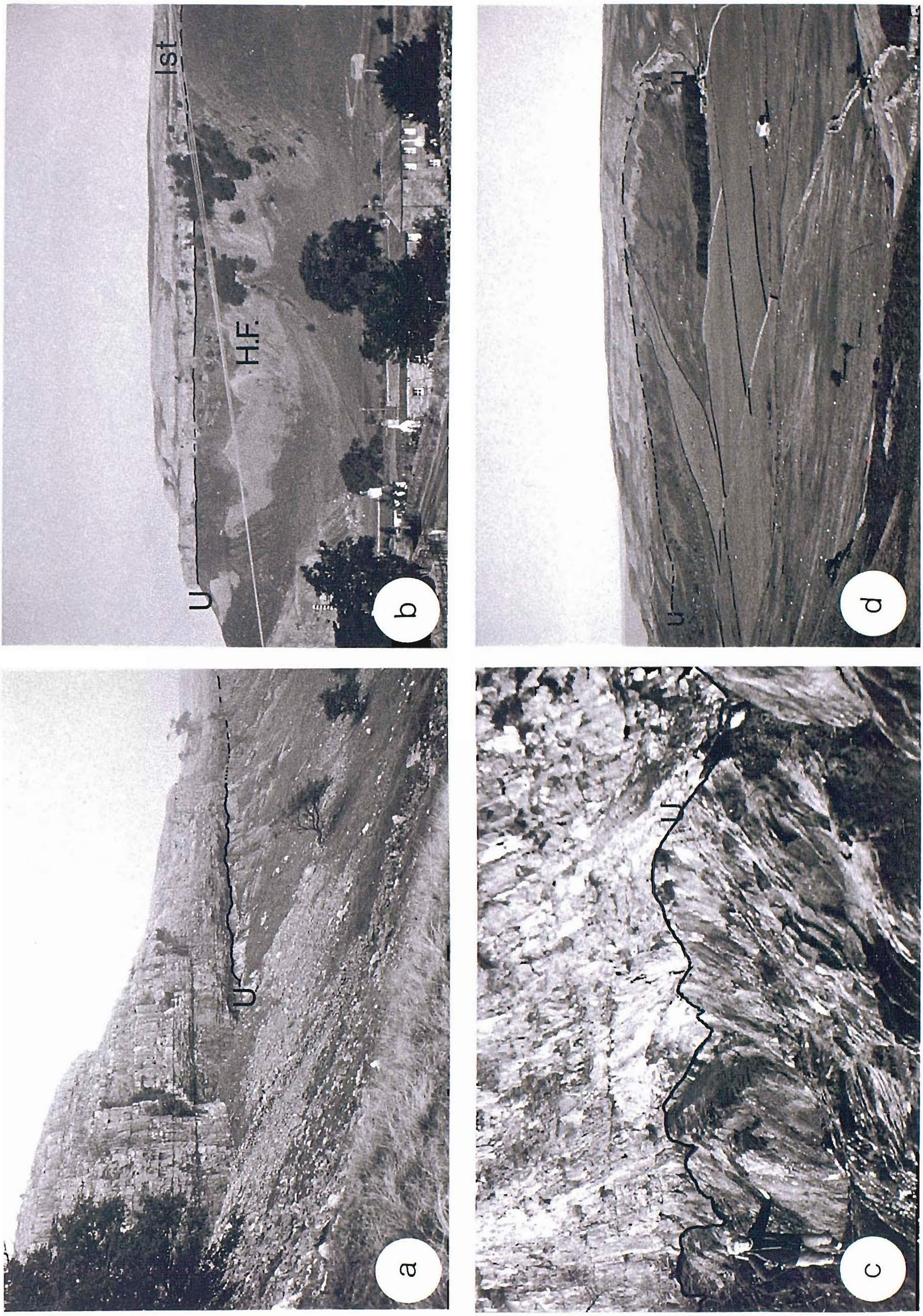


Plate 1.

PLATE 2

2a. Thornton Force Formation, Thorton Force (SD695753), Kingsdale
The type of section of the Thorton Force Formation on the Askrigg Block overlies vertical slates of the Ordovician Ingleton Group. There are 16.45m of variably lithoclastic, well bedded, pale grey limestone disconformably overlain by the Raven Ray Formation (not seen).

2b. Thornton Force Formation, old Ingleton reservoir springs (SD714747), Chapel-le-Dale.
The microrelief on the unconformity (U) at this locality is at least 1.60m. Vertical slate beds (sl) occur beneath the hammer handle and up to 1.60m above (centre top) projecting through beds of calcarenite. (Hammer length: 0.40m).

2c. Thornton Force Formation, Twisleton Scars (SD718759), Chapel-le-Dale. A lens of pebble and cobble-size, subrounded lithoclasts and boulder-size bioclasts (Lithostrotion colonies) occurs in a sequence of pale grey calcarenites. The lens, 0.55m thick, is laterally impersistent. (Hammer length: 0.40m).

2d. Thornton Force Formation, Thornton Force (SD695753), Kingsdale.
There is very gently relief of 0.60m on the unconformity which is overlain by a rudite up to 0.85m thick. The rudite comprises rounded pebbles, cobbles and boulders of slate, graywacke, vein quartz and sparse limestone capped by a boulder monolayer. The largest boulders are 530mm in length (centre-right).

Plate 2.

PLATE 3.

3a Thornton Force Formation, Twisleton Scars (SD712755), Chapel-le-Dale. The rudite at the base of the Formation unconformably overlies overturned slates of the Ordovician Ingleton Group. Beds of slate are incorporated in the base of the rudite, a debris flow, above the hammer head and far right. Clasts of rudite are poorly imbricated and aligned.
(Hammer length: 40cm).

3b. Thornton Force Formation, Skirwith Quarry (SD709738), Chapel-le-Dale. Herring-bone cross-lamination in the coarse grained calcarenite is most clearly defined in those beds which contain laminae of quartz sand or granule lithoclasts. Lamina cosets are 20-30cm thick.
(Hammer length: 30cm).

3c Thornton Force Formation, Twisleton Scars (SD719759), Chapel-le-Dale. Stranded pebbles and cobbles of graywacke and slate occur in erosional hollows on top of beds of the Thorton Force Formation. Clusters of large lithoclasts are very local features.
(Hammer length: 40cm).

3d. Thornton Force Formation, Springcote Pasture (SD721761), Chapel-le-Dale. An isolated, stranded, incomplete graywacke boulder occurs between two beds of coarse grained, crinoidal calcarenite. The boulder is at least 900mm in length.
(Hammer length: 40cm).

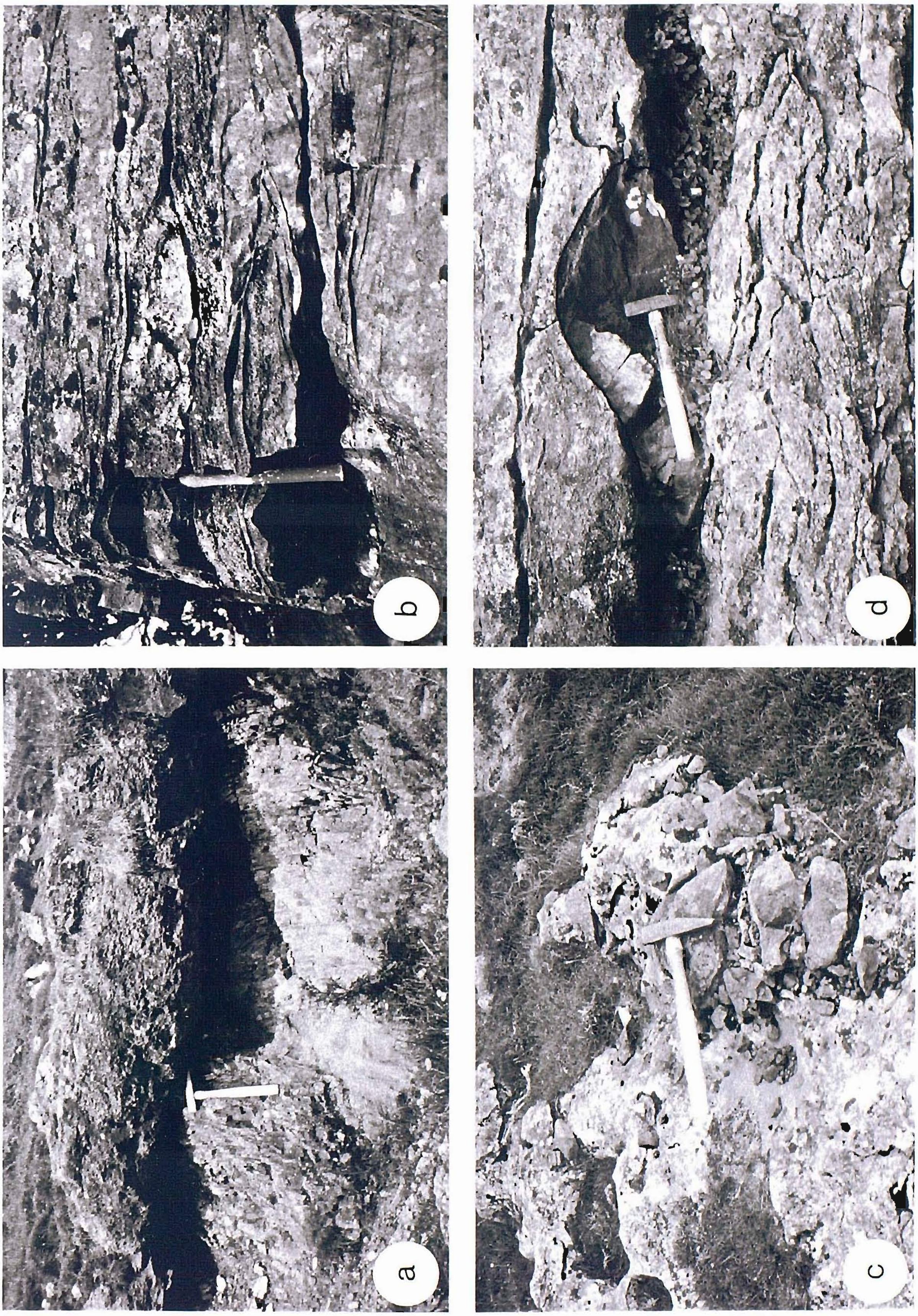


Plate 3.

PLATE 4

4a. Thornton Force Formation, Nappa Scars (SD768697), Crummack Dale. The granule arenite contains variable amounts of calcarenite matrix. There is some grading of granules, although most are extremely well sorted (2-4 mm in size). Cross-laminae can be seen most clearly in the more calcareous parts. Calcarenite intraclasts occur at the base of the photograph.
(Hammer length in photograph: 45cm).

4b. Thornton Force Formation, Nappa Scars (SD768697), Crummack Dale. The erosive contact between the granule arenite and the underlying lithoclast-free calcarenite is simple and only slightly undulose over most of its length. However, below the hammer head, a wedge of calcarenite is almost completely enclosed by granule arenite. Large intraclasts may be produced by this mechanism.
(Hammer length: 40cm).

4c. Thornton Force Formation, Nappa Scars (SD769698), Crummack Dale. Rounded slate (sl) and graywacke (gk) boulder-size lithoclasts occur in a wedge of rudite with a lithoclastic calcarenite matrix. The wedge, here 1.50-2.00m thick, decreases rapidly in thickness to the southwest. The largest boulders are 2050 x 1950 mm.
(Hammer length: 40cm).

4d. Thornton Force Formation, Nappa Scars (SD768697), Crummack Dale. Pebble-sized intraclasts occur in calcarenites above the lithoclastic beds of the Formation. The intraclasts are very variable in size and boulder-size calcarenite intraclasts have been observed. In the picture, intraclasts average 50mm in diameter.
(Length of hammer head: 20cm).

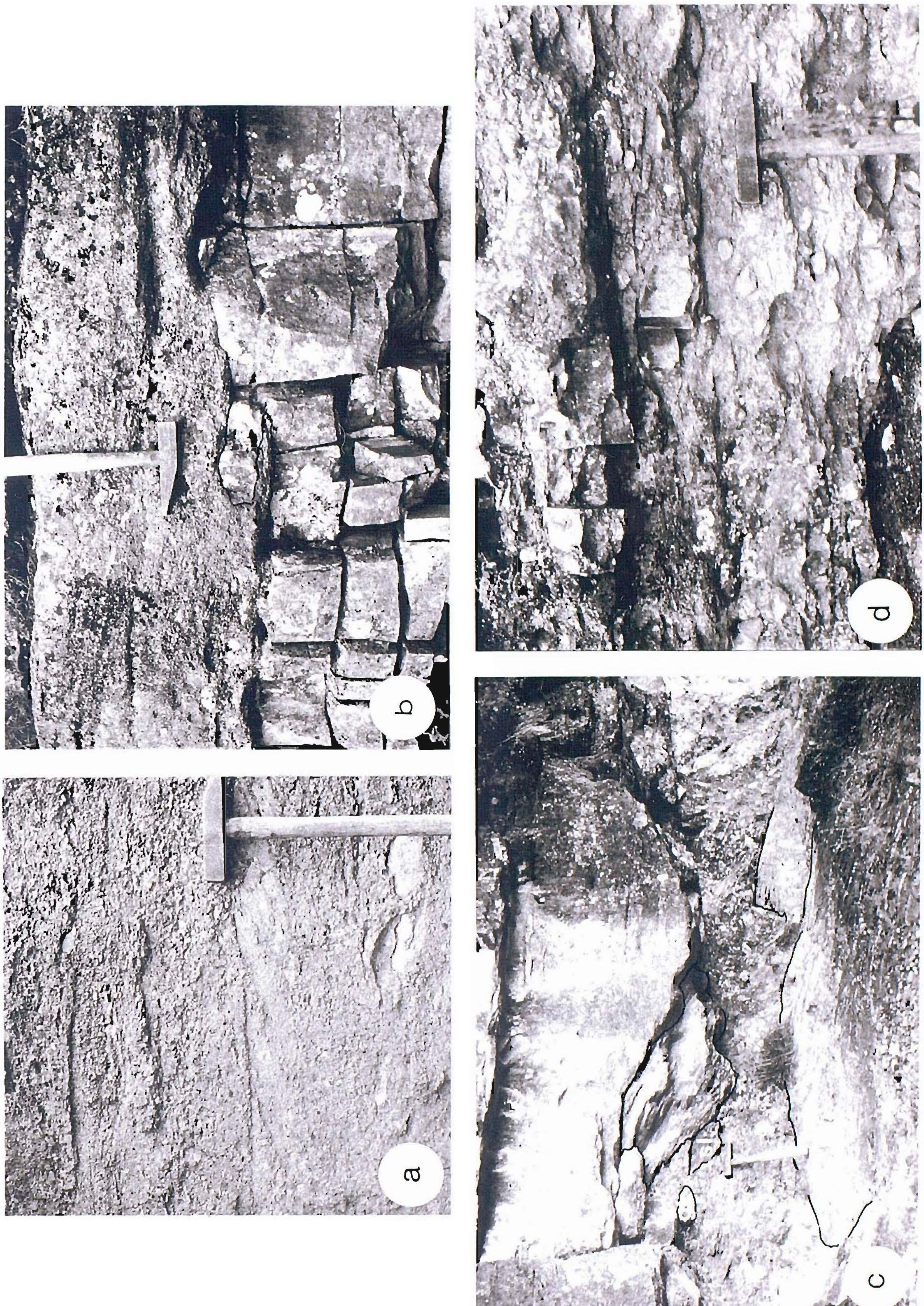


Plate 4.

PLATE 5

5a Douk Gill Formation, Douk Gill (SD816725), Ribblesdale.
At this, the type-section of the Douk Gill Formation, the upper part of the Formation comprises interbedded thin calcarenites, calcilutites and shale partings. Most of the shales have weathered back and are recognised by deep slots in the outcrop. The shale occurring at the contact with the overlying Raven Ray Formation is only 0.08m thick at this locality.
(Thickness of bed DFG : 0.30m).

5b Douk Gill Formation, Douk Gill (SD816725), Ribblesdale.
A sequence of shale, shale with coal fragments, black shiny coal (12cm thick), and shale, together 0.25 thick, is present at the top of the Formation. The coal contains much vitrinite and vitrinite fragments occur in both overlying and underlying shales. The limestone above represents the base of the Raven Ray Formation.
(Length of straight edge of tape box: 5cm).

5c Douk Gill Formation, Dub Cote Gill (SD819718), Ribblesdale.
A wedge of lithified rounded, graywacke pebble-cobble rudite with a sand matrix overlies weathered slate pebble rudite with a shale matrix. Alternating wedges of lithified graywacke rudite and shaly slate rudite comprise the basal sequence of the Formation.
(Visible length of hammer handle: 20cm).

5d Douk Gill Formation, Raven Ray Formation and Horton Limestone, Gillet Brae (SD800719), Ribblesdale.
The lower part of the Douk Gill Formation (DGF) comprises thin, interbedded grey shales and sandstones overlain by 0.45m of rudite (foreground). In the background, the upper part of the Douk Gill Formation is overlain by the Raven Ray Formation which is succeeded by the Horton Limestone.
(Height of supervisor, when standing: 1:80m).

Plate 5.

PLATE 6

6a. Thornton Force Formation-Raven Ray Formation, Thornton Force (SD695753), Kingsdale.
Mounds up to 0.50m high are present on the disconformable contact between the pale grey Thornton Force Formation and overlying dark grey, shaly Raven Ray Formation. The lowermost shales and limestones of the Raven Ray Formation fill the hollows and drape over the steep-sided ridges.
(Hammer length: 40cm).

6b. Raven Ray Formation, above Thornton Force (SD695753), Kingsdale.
The type-section of this Formation comprises thin-medium beds of dark grey, foetid calcarenite and calcisiltite interbedded with calcareous mudstones Occasional mudstones split and incorporate lenses of calcisiltite (centre).
(Hammer length: 40cm).

6c. Raven Ray Formation, Raven Ray (SD695754), Kingsdale.
The Formation crops out well in the bluff but the exposure deteriorates rapidly as the angle of slope decreases. Irregular and rubbly thin beds of calcarenite and calcisiltite crop out at the beck sides and form the beck floor.

6d. Raven Ray Formation-Horton Limestone, Raven Ray (SD694755), Kingsdale.
Medium bedded calcarenites interbedded with calcareous shales occur at the top of the Raven Ray Formation. The contact with the overlying Horton Limestone is located at the position of the highest shale. Above the limestones are much paler grey, non-foetid, thick bedded and shale-free.
(Hammer length: 30cm).

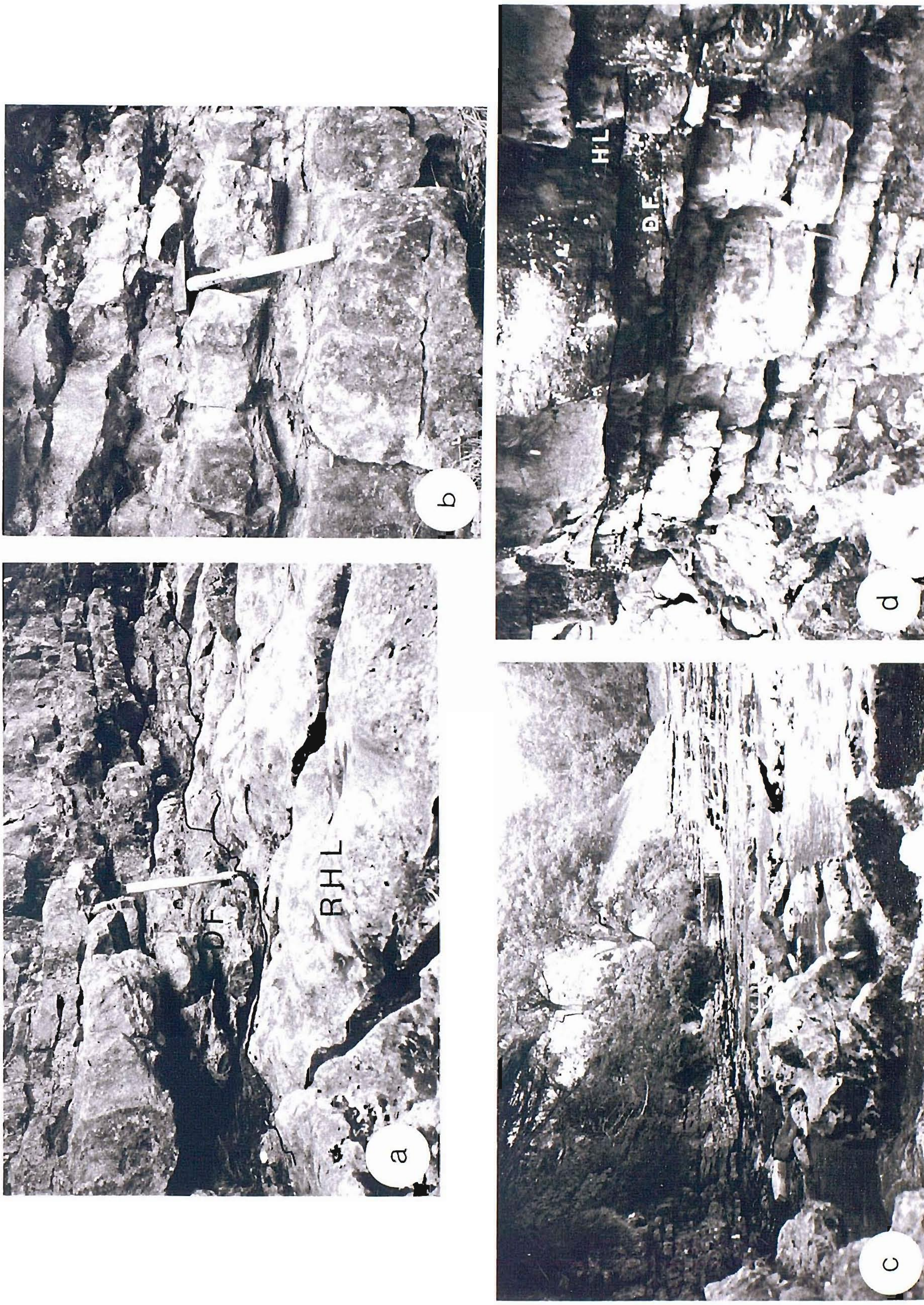


Plate 6.

PLATE 7

7a. Raven Ray Formation, Twisleton Scars (SD714756), Chapel-le-Dale. Intermittent exposure of mid grey, rubbly weathering beds of foetid limestone is typical of the Raven Ray Formation (foreground). Above are blocky, poorly bedded, pale grey limestones of the Horton Limestone overlain by well-bedded and excellently exposed Kingsdale Limestone.

7b. Raven Ray Formation, Twisleton Scars (SD717759), Chapel-le-Dale. Cross-laminated, rubbly, thin bedded, coarse grained bioclastic calcarenites crop out only 1.20m above Lower Palaeozoic rocks. There is no underlying Thorton Force Formation which has wedged out against the graywacke mound. The coarse grained, cross-laminated limestones of the Raven Ray Formation occur only above graywacke mounds.
(Hammer length: 40cm).

7c. Raven Ray Formation, Newby Cote Quarry (SD733707), Newby. Most of the Raven Ray Formation comprises medium-thick beds of dark grey, slightly foetid calcarenite and calcisiltite at this locality. However, limestones are interbedded with thin shales, thick shales (sh) and quartz arenites (sst) in the upper part of the Formation. Two pyritised and partially dolomitised, rubbly limestone beds (R) occur just below the Formation top. The lower rubbly bed is 0.45m thick. The overlying Horton Limestone is not exposed.

7d. Raven Ray Formation, Gillet Brae (SD800719), Ribblesdale. The Formation comprises thin-medium beds of dark grey, slightly foetid calcarenite. There is a pronounced wedge of calcarenite 0-0.90m thick (centre) which overlies a bed of irregular thickness. The overlying bed thins rapidly over the wedging bed to only 0.15m thick.
(Visible height of notebook (shaded) : 12cm).

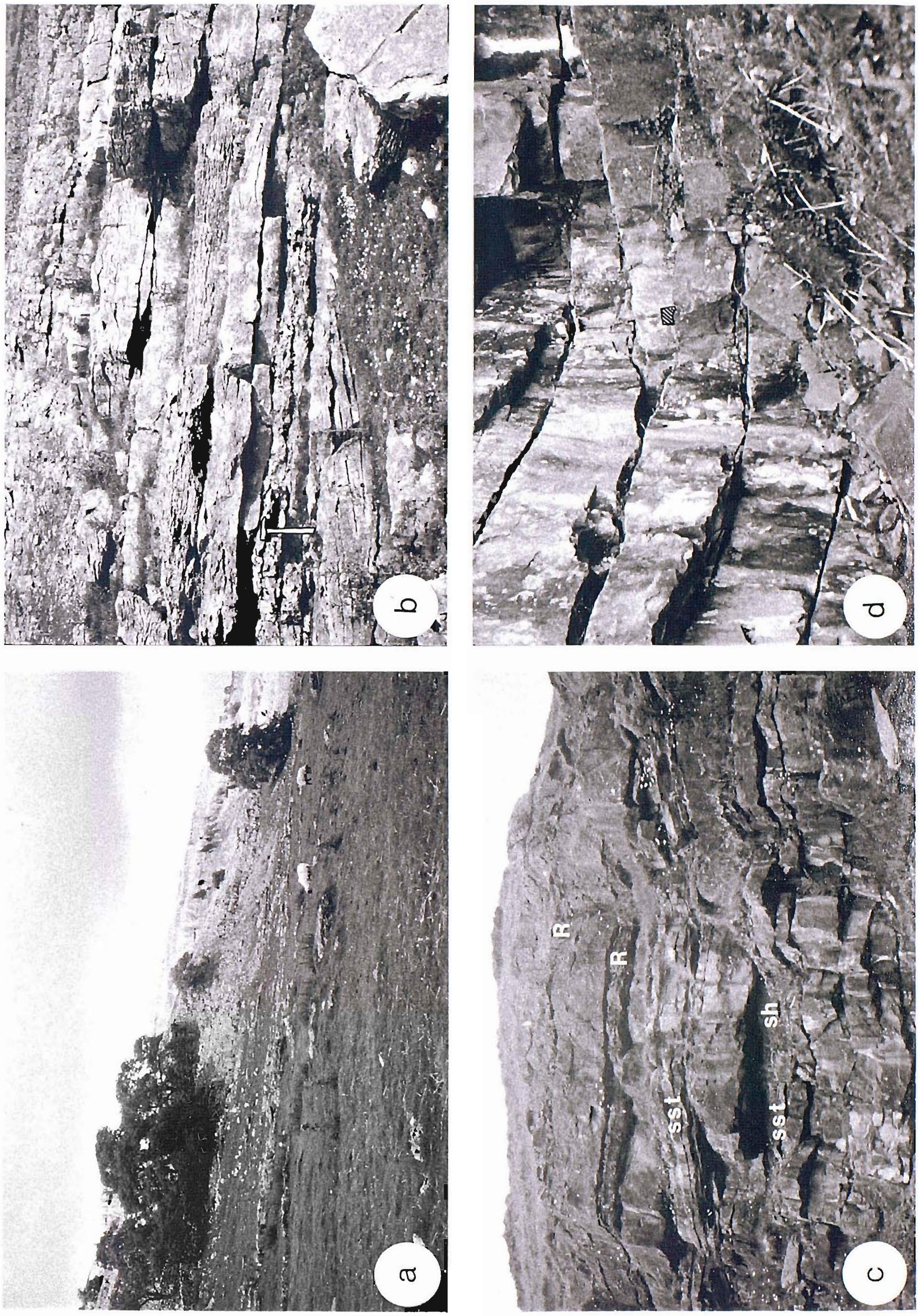


Plate 7.

PLATE 8

8a. Raven Ray Formation-Horton Limestone, Yew Cogar Scar (SD919707), Cow Side Beck.
The Raven Ray Formation (lowest bed) is abruptly and conformably overlain by mid grey limestone of the Horton Limestone. The upper and lower bounding surfaces of the lowest bed of Horton Limestone are mounded (relief 0.15m) and the two bedding contacts appear to be erosional.
(Hammer length: 70cm - lower right).

8b. Raven Ray Formation-Horton Limestone, Kilnsey Crag (SD974684), Wharfedale.
The lower beds of dark grey Raven Ray Formation limestone are disconformably overlain by mid grey calcarenites of the Horton Limestone. There are erosional contacts between the two Formations and the lower two beds of Horton Limestone. There is a maximum of 0.20m relief on each surface. The exposure is very similar to that of Yew Cogar Scar.

8c. Horton Limestone, Horton Quarry (SD797722), Ribblesdale.
Mid grey limestones of the middle part of the Horton Limestone grade up into pale grey calcarenites (top of face) through a series of interbedded dark grey, mid grey and pale grey calcarenites.
(Face height: approximately 20m).

8d. Horton Limestone, Horton Quarry (SD797722), Ribblesdale.
Loose, slightly weathered blocks of calcarenite reveal the low angle cross-lamination not seen at outcrop. Lamina cosets are 10-20cm thick.
(Tape measure, inches on left, centimetres on right).

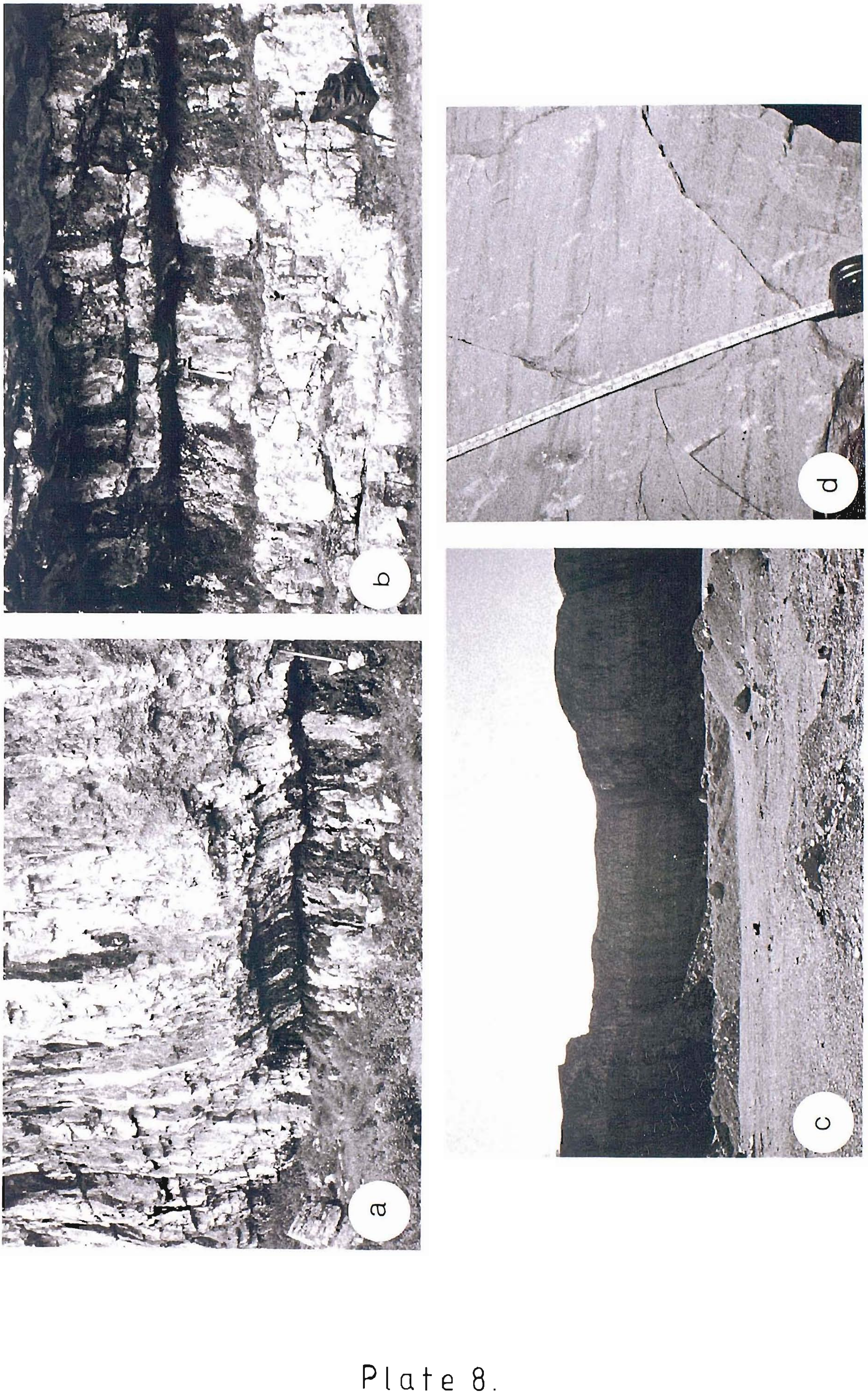


Plate 8.

PLATE 9

9a. Raven Ray Formation?, western Crummack Dale (SD768704).
The exposure occurs at the top of a steep slope from which partially exposed graywacke boulders protrude. Sparse large graywacke boulders (maximum 2600x2000x1800mm) occur in a pale grey, bioclastic and lithoclastic calcarenite 1.40m thick.
(Hammer length: 40cm).

9b. Horton Limestone, western Crummack Dale (SD767710).
Partially rounded boulders of Silurian graywacke occur in a matrix of crushed, angular pebble- and cobble - size lithoclasts near the base of the Horton Limestone. The boulder-rudite is usually poorly exposed and the matrix rarely visible.
(Height of supervisor: 1.80m).

9c. Horton Limestone, Studrigg Quarry (SD781708), eastern Crummack Dale.
Broken and partially rounded graywacke cobbles and small boulders occur in a matrix of lithoclastic calcarenite near the base of the Horton Limestone where it unconformably overlies Lower Palaeozoic siltstones. No boulders larger than 650mm were observed in the lithoclastic lenses.
(Hammer length: 40cm).

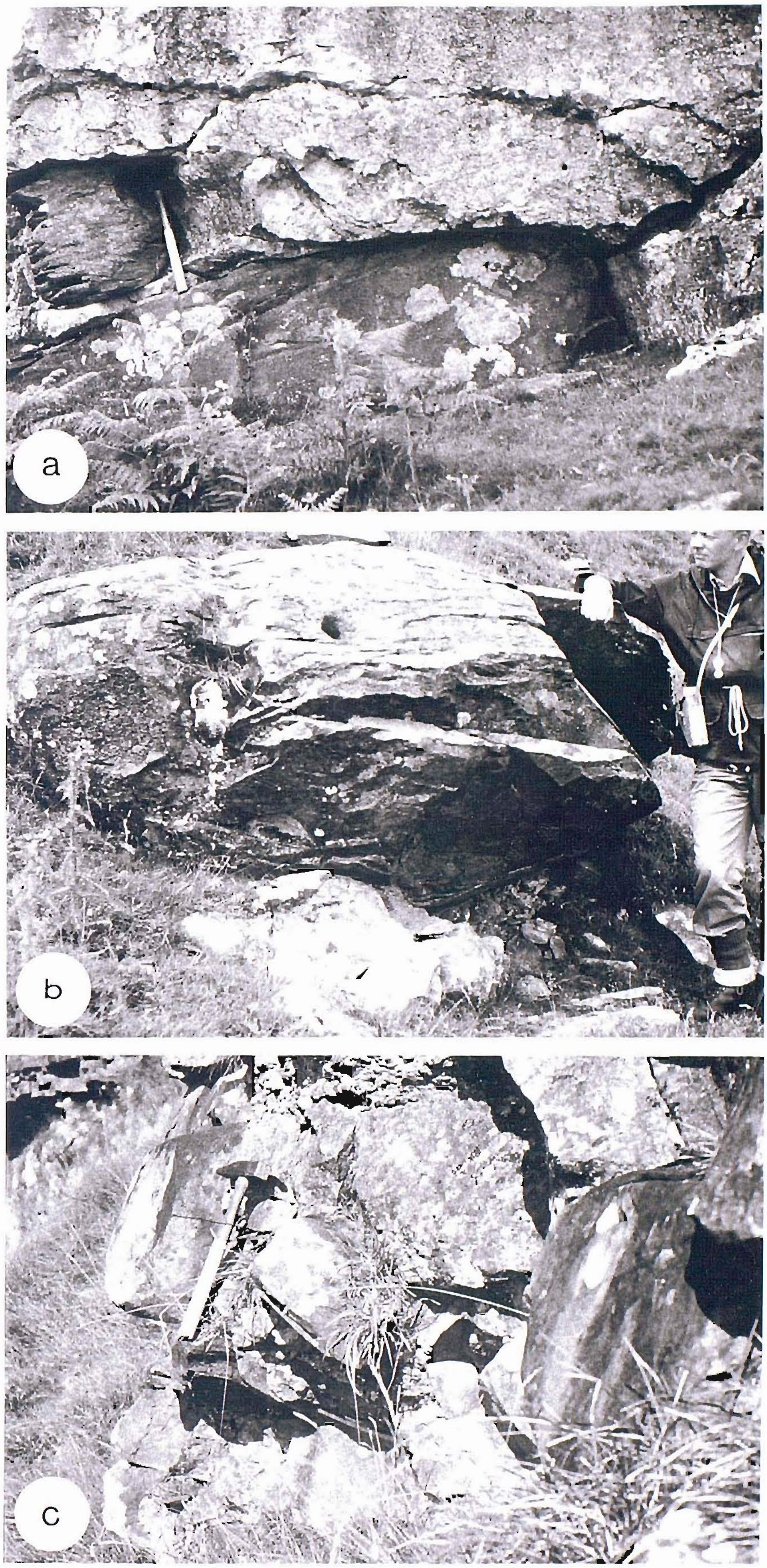


Plate 9.

PLATE 10

10a. Horton Limestone, Moughton Scars above Capple Bank (SD783719), Crummack Dale.
General view of the Horton Limestone in Crummack Dale. The mid grey and pale grey calcarenites of the Formation are only 32 metres thick above Capple Bank (centre and left). The thin, white beds of the Moughton Calcilutite Member (m) can be seen near the top of Moughton Scar.

10b. Moughton Calcilutite Member, Moughton Scars (SD783720), Crummack Dale.
Two medium beds of calcilutite (m) separated by fine grained, cross-laminated, pale grey calcarenite crop out through till and scree above Moughton Whetstone Hole. The upper bed is thicker, better exposed and laterally more persistent. Lowermost beds of the Kingsdale Limestone can be seen in the top right of the picture.
(Height of supervisor: 1.80m).

10c. Moughton Calcilutite Member, Long Scar (SD772717), Crummack Dale.
A lens of pale grey calcilutite, 0.15m thick, is overlain by low-angle cross-laminated, fine grained, pale grey calcarenite. The contact between the two rock-types is stylolitic.
(Hammer length: 40cm).

10d. Moughton Calcilutite Member, Selside (SD785763), Upper Ribblesdale.
A thick bed of dark grey calcilutite (lowermost bed) is overlain by a wedge of cross-laminated dark grey calcarenite which has slumped in its thinnest part towards the north (right). It is overlain by a wedge of fissile shale which thickens to the north as the calcarenite below thins.
(Length of straight edge of tape box: 5cm).

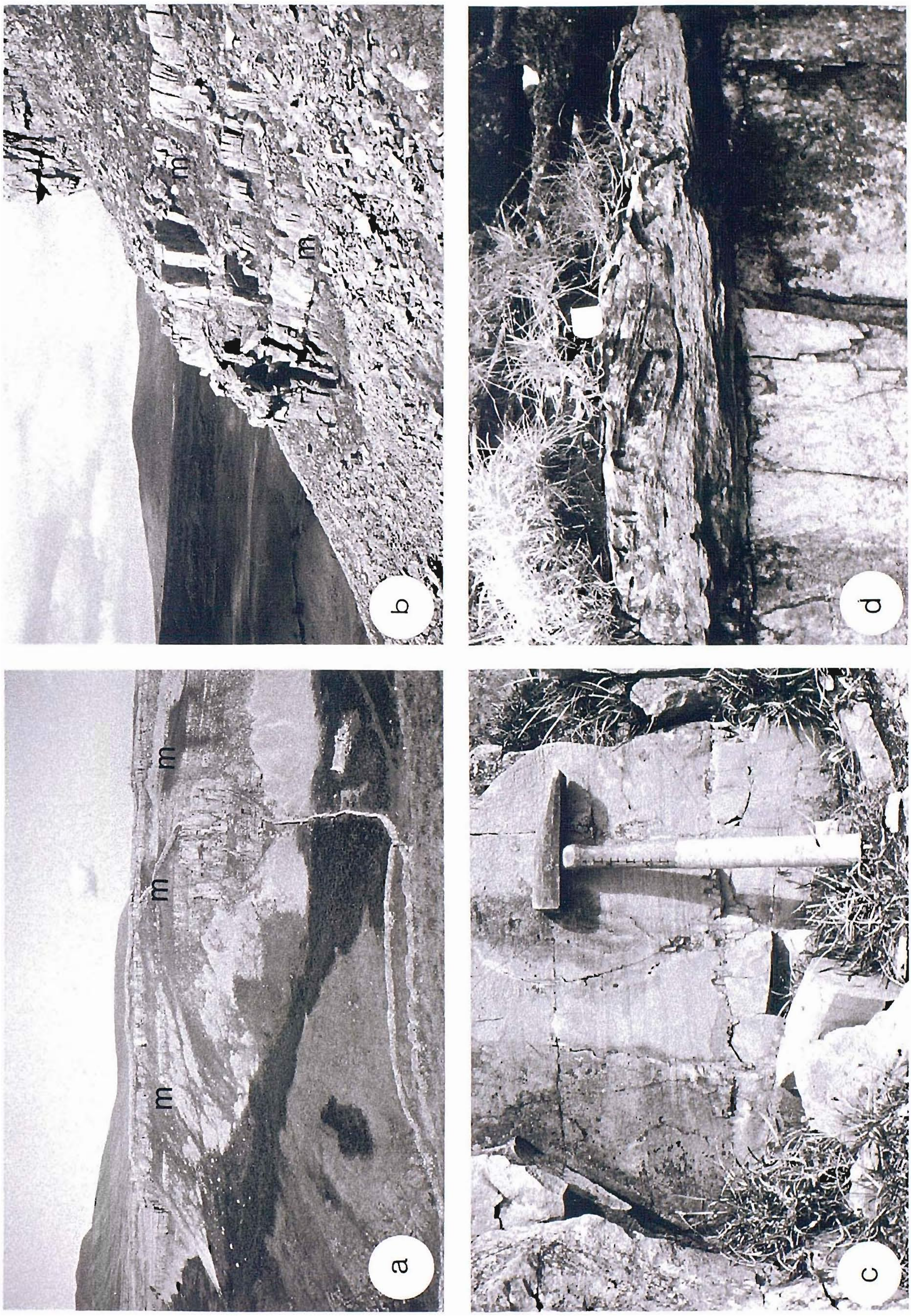


Plate 10.

PLATE 11

11a. Horton Limestone-Kingsdale Limestone, Meal Bank Quarry (SD698735), Chapel-le-Dale.
Inclined beds of the Horton Limestone (HL) are unconformably overlain by well bedded Kingsdale Limestone (KL). The angular discordance is approximately 4^{o}. A thick shale and overlying coal infill a solution hollow which formed at the contact prior to deposition of the Kingsdale Limestone. A second phase of tilting occurred at a later date, resulting in the present configuration.

11b. Horton Limestone-Kingsdale Limestone, Meal Bank Quarry (SD698735), Chapel-le-Dale.
A solution hollow with an irregular base, and a maximum depth of 1.90m, formed on the gently inclined top of the Horton Limestone. It is infilled with up to 1.90m of shale with rootlets, overlain by 0.10-0.24m of coal. The contact with the overlying Kingsdale Limestone is abrupt.
(Height of geologists: approximately 1.80m).

11c. Meal Bank Shale, Meal Bank Quarry (SD698735), Chapel-le-Dale.
The shale, at least 1.90m thick, is a seat earth. It is bioturbated by numerous black carbonised and pyritised rootlets. Occasionally larger root-like bodies, stigmaria (centre of picture) composed of fusinite, can be seen. Gypsum, jarosite and limonite are common weathering products of pyrite, which occurs in both the shale (centre right) and underlying limestone.
(Length of straight edge of tape box: 5cm).

11d. Horton Limestone, Malham Cove (SD898641).
Closely jointed and poorly but thickly bedded, pale grey limestones of the Horton Limestone (HL) are conformably overlain by well bedded limestones of the Kingsdale Limestone (KL). There are approximately 81 metres of Horton Limestone at this exposure.

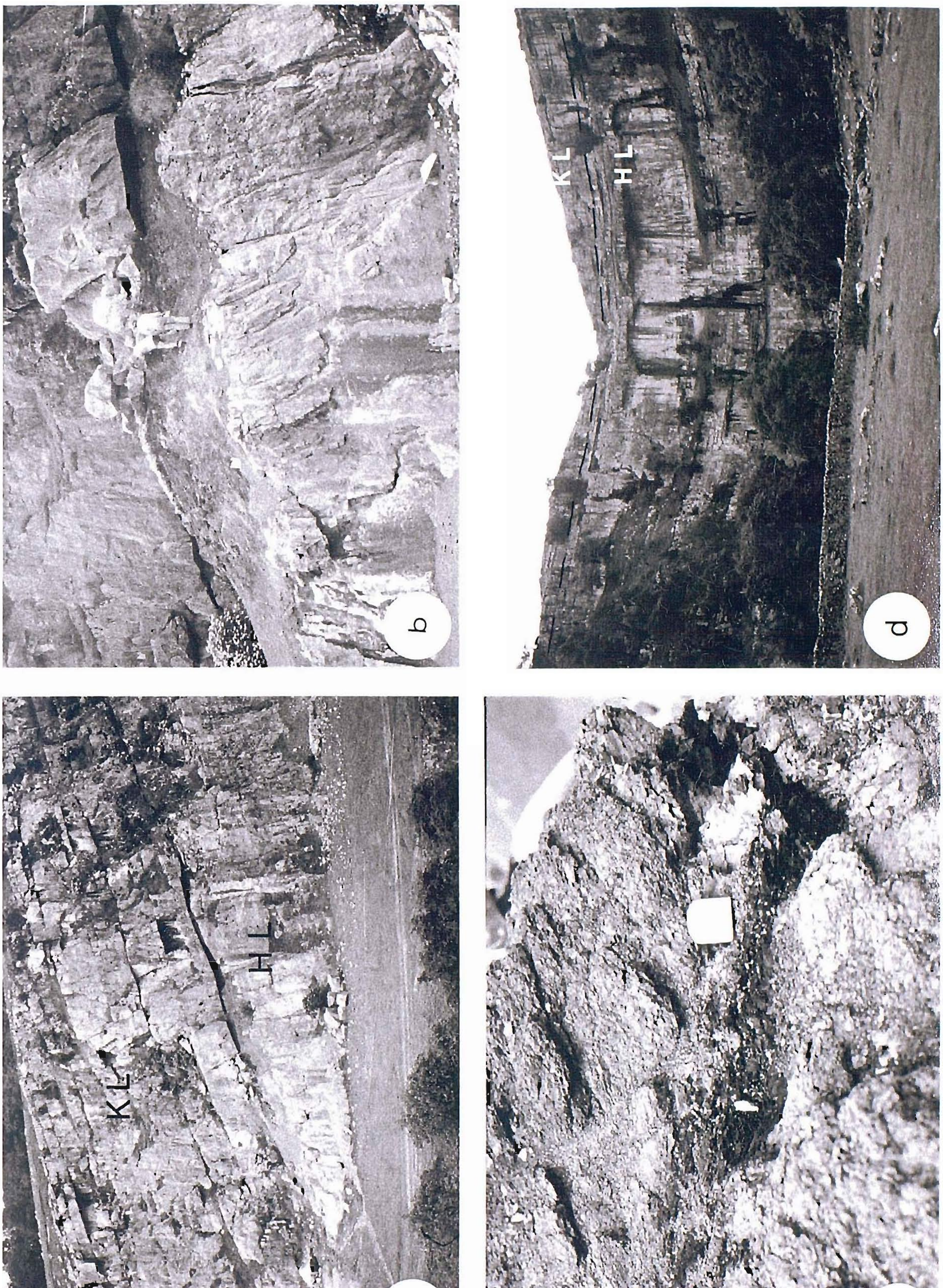


Plate 11.

PLATE 12

12a. The contact between fenestral calcilutite and overlying fine grained calcarenite is sharp yet burrowed and bioturbated. Large calcarenite-filled burrows are up to 10mm in length. Tubular fenestrae 1mm wide and 5mm long, infilled with spar, occur throughout the calcilutite.
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

12b. Pale grey fenestral and laminated calcilutite is abruptly overlain by dark grey, sparsely bioclastic, very fine grained calcarenite. The contact is stylolitic. Fine tubular fenestrae occur in the upper part of the calcilutite and below there is faint, impersistent lamination.
Moughton Calcilutite Member, south of Horton Quarry (SD797715), Ribblesdale.

12c. The sharp contact between fenestral calcilutite and overlying mid grey, fine grained calcarenite is partially stylolitic. Many small burrows, 1mm wide and only 5mm deep, occur along the contact. Small tubular and irregular spar-filled fenestrae, mostly less than 4mm in diameter, are cross-cut by a second phase of much larger sediment-filled fenestrae up to 15mm in diameter. Mottles, consisting of bleached cream-coloured halos, occur particularly around small fenestrae.
Moughton Calcilutite Member, Raven Scar (SD728746), Chapel-le-Dale.

12d. Small and large randomly orientated fenestrae occur in bioclastic calcilutite (large ferroan calcite shell fragment occurs 2cm below scale bar). The smaller fenestrae, 0.25-1.0mm in size, appear to be completely infilled with carbonate silt whereas the larger are partially silt-filled or entirely silt-free. All fenestrae have mottled rims.
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

12e. Two stages of fenestra-development can be recognised in the specimen. Small, spar-filled laminoid and irregular fenestrae (1-2mm in length) with cream-coloured halos occur throughout the sample. Much larger, sediment-and spar-filled fenestrae (10-30mm long and 15mm deep) cross-cut all earlier structures. These later fenestrae also have mottled rims. Large complex sediment-filled fenestrae are present (bottom-left and centre-right).
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

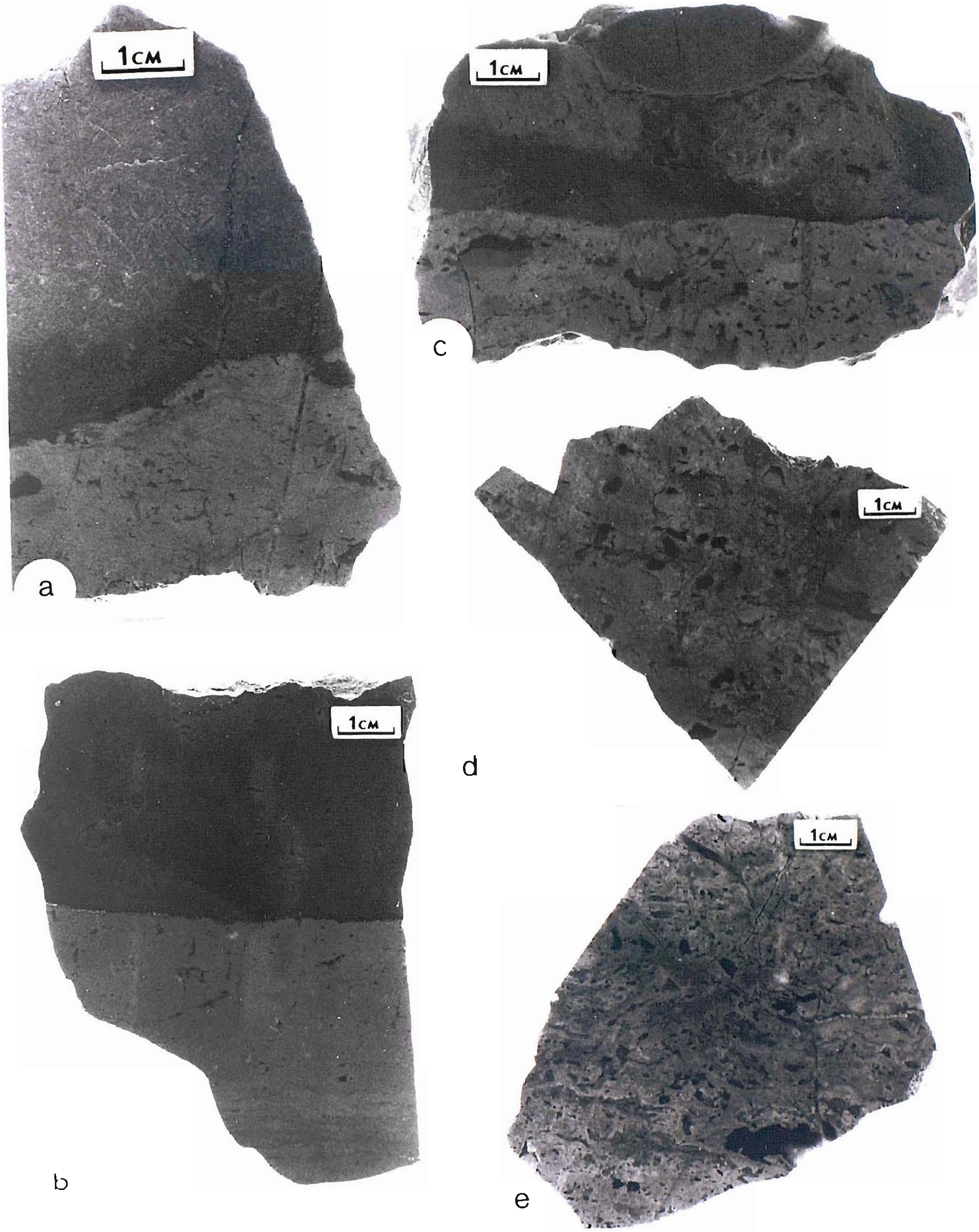


Plate 12

PLATE 13

13a. Fenestral calcilutite. Large spar and sediment-filled fenestrae (centre and bottom) occur in a fenestral micrite whose matrix has been recrystallised to microspar (N.E. $_{2-3}$). The earlier, small fenestrae (<1.0mm) rarely contain any silt. The larger stromatactis-like fenestrae (>20mm in length) have a complex history; they cross-cut all earlier structures and incorporate some of the smaller spar-filled cavities at their edges. An initial non-ferroan dolomite silt forms a geopetal sediment on which an isopachous crust of bladed dolomite crystals (P.B.$_5$ C.) formed prior to precipitation of coarse crystals of ferroan calcite. The final filling was of non-ferroan calcite (P.E.$_{5-7}$).
(stained thin section, ppl).
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

13b. Sparsely fenestral intrasparite. Intraclasts, mostly unidentifiable micritised clasts averaging 0.4mm in diameter, are cemented by fine grained equant sparite (P.E. $_4$). A fine fringing isopachous cement (P.E.$_3$) surrounds all clasts. Sporadic, large stromatactic fenestrae, at least 20mm in length and with a complex history of infilling, occur. The initial fill consists of bladed non-ferroan calcite crystals (P.B.$_5$ C.) which formed a thicker layer at the base of the void.Non-ferroan dolomite silt overlies this and forms a geopetal sediment. The final infill consists of variably ferroan calcite (P.E.$_6$).
(stained thin section, ppl).
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

13c. Fenestral calcilutite. Large fenestrae with geopetal sediments (top right and bottom) occur in a calcisphere-bearing micrite whose matrix has undergone patchy recrystallisation to microspar (N.E.$_{2-3}$). Most of the fenestrae are filled with non-ferroan calcite silt containing bioclasts (serpulid worms?). Some fenestrae have an initial fringe of fibrous calcite (P.F. $_4$ C.). The final infill is large equant crystals of non-ferroan calcite (P.E.$_{4-5}$). The smaller fenestrae are completely filled with non-ferroan calcite spar and appear to have been involved in only the last stage of void-filling.
(stained thin section, ppl).
Moughton Calcilutite Member, White Scars (SD728746). Chapel-le-Dale.

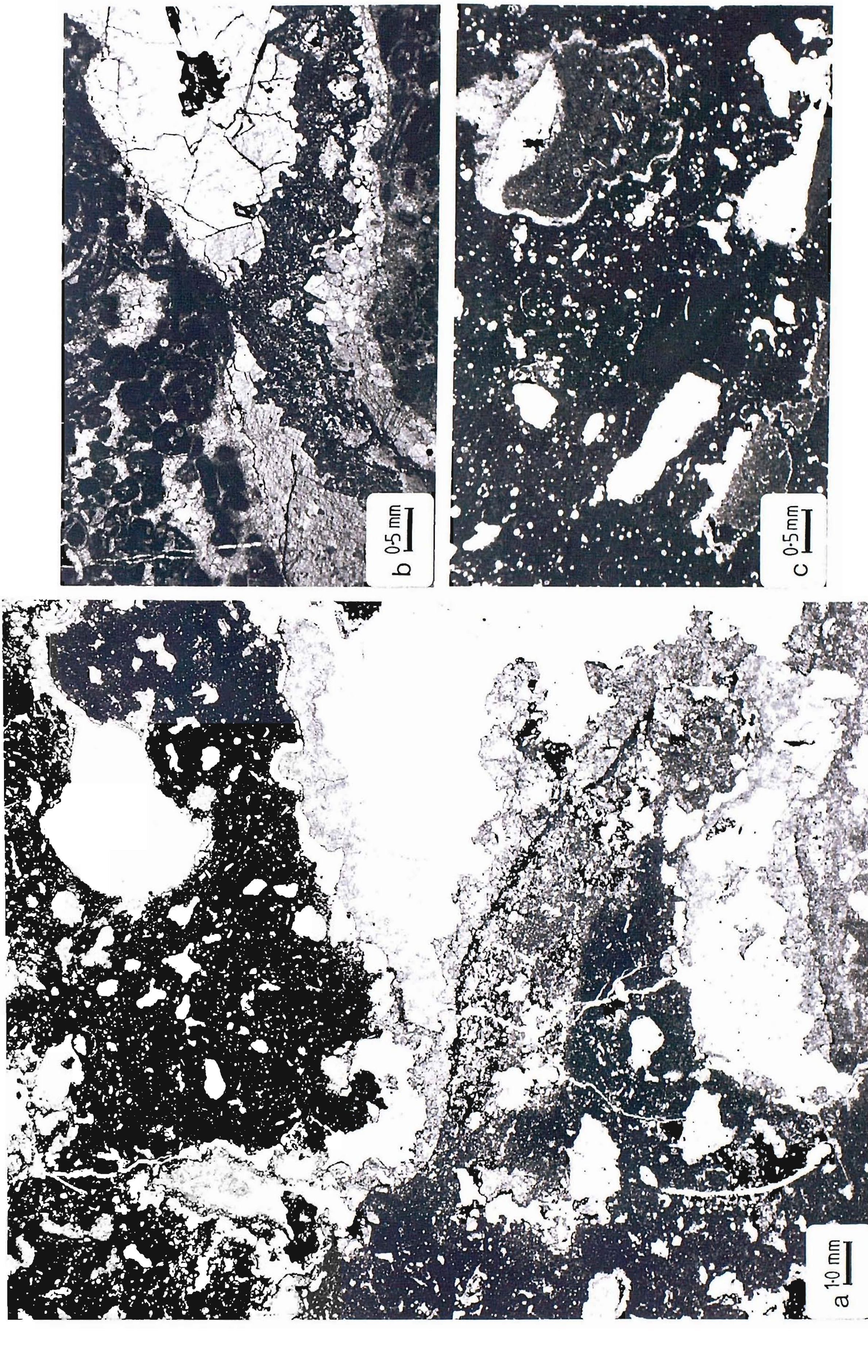


Plate 13

PLATE 14

14a. Bioclastic calcilutite. Thin shelled ostracods, calcareous foraminifera and calcispheres occur in a recrystallised matrix of non-ferroan calcite microspar (N.E. $_{2-3}$). Voids within bioclasts are infilled with equant calcite spar (P.E. $_{3-4}$).
(stained thin section, ppl).
Moughton Calcilutite Member, Selside (SD785763)), Upper Ribblesdale.

14b. Bioclastic calcilutite. Coiled calcareous foraminifera, sparse calcispheres and ostracod valves occur in a partially recrystallised micrite matrix (P.E.$_{1-2}$ and N.E.$_{2-3}$). The partial recrystallisation has resulted in a clotted texture.
(stained thin section, ppl).
Moughton Calcilutite Member, Brows Pasture (SD731763) Chapel-le-Dale.

14c. Calcisphere calcilutite. Calcispheres with complex double walls, single micrite walls or no apparent walls, all less than 0.125mm in diameter, occur in a micrite matrix which has recrystallised to microspar (N.E. $_{2-3}$). The larger and most of the smaller calcispheres are infilled with non-ferroan calcite spar (P.E.$_{3-4}$). Some small calcispheres contain calcite silt. Sparse spar-filled fenestrae occur throughout.
(stained thin section, ppl).
Moughton Calcilutite Member, Brows Pasture (SD731763), Chapel-le-Dale.

14d. Abrupt contact between calcilutite and overlying calcisiltite. The calcilutite has been burrowed and pelsparite bioturbated down into it by at least two different types of organism. This has resulted in narrow burrows (centre-left) and wide, deep burrows (centre). The cohesion of the overhanging wall of calcilutite (centre-right) suggests that it was at least firm during the phase of burrowing.
(stained thin section, ppl).
Moughton Calcilutite Member, south of Horton Quarry (SD797715), Ribblesdale.

14e. Authigenic quartz in sparsely bioclastic and fenestral calcilutite. Large, semi-parallel, elongate fenestrae traverse sparsely bioclastic micrite. Lumps of micrite (up to 0.3mm) occur in calcite silt at the base of some fenestrae. The remaining voids are infilled with non-ferroan calcite drusy mosaic (P.E. $_{4}$). The micrite matrix has partially recrystallised to microspar (N.E.$_{2-3}$) and it contains well formed authigenic quartz crystals up to 0.25mm in length. The quartz crystals are randomly orientated and there are no obvious nucleation sites.
(stained thin section, ppl).
Moughton Calcilutite Members, Old Cote Low Moor (SD927728), Littondale.

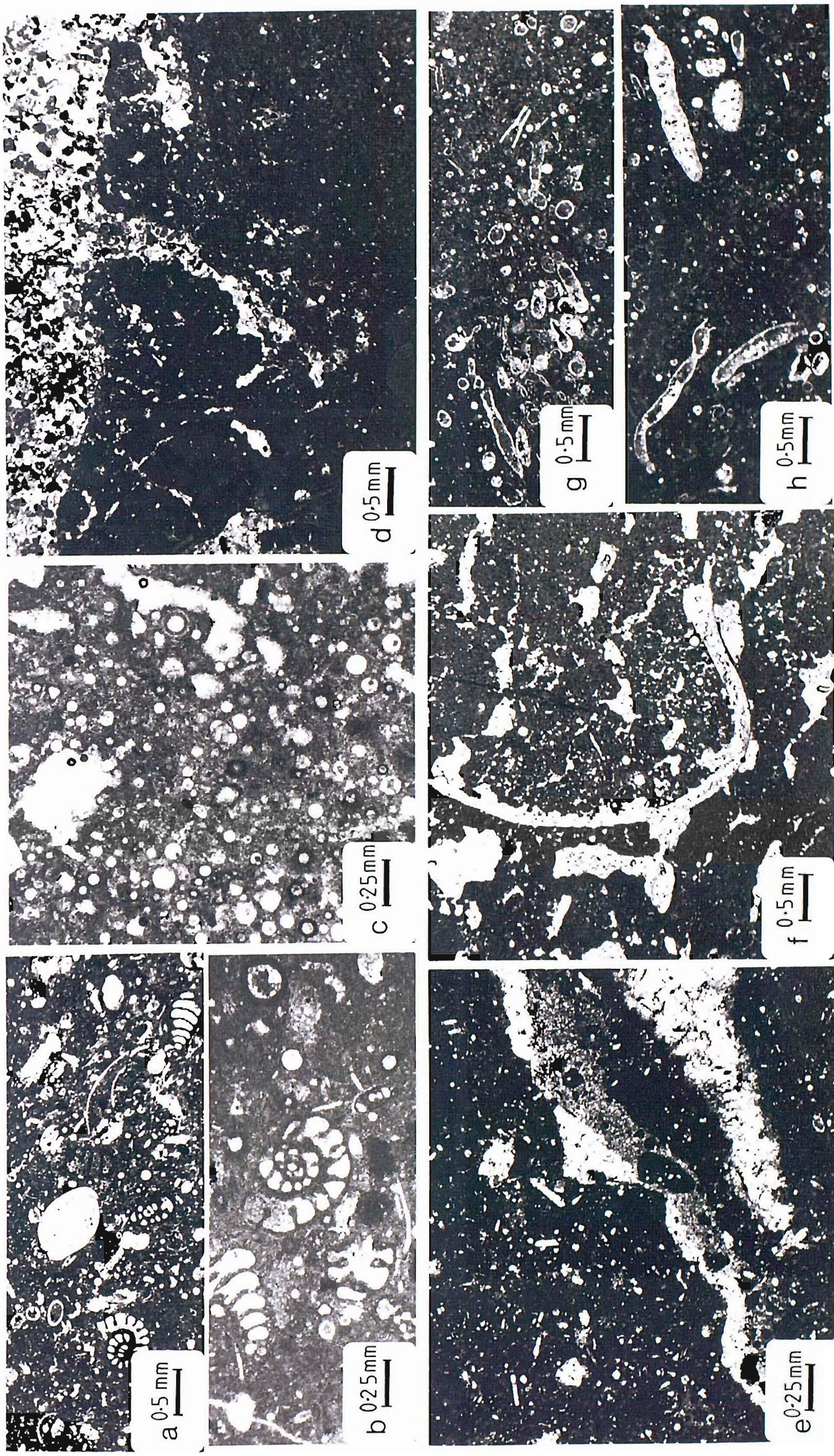


Plate 14

14f. Fenestral pelmicrite. Small irregular fenestrae transect the pelmicrite. Much of the micrite matrix in the vicinity of the large mollusc fragment has recrystallised to pseudospar (N.E.$_{3-4}$) giving the impression of pelsparite. Many of the larger fenestrae are intimately associated with this mollusc. Dissolution of the mollusc shell and infilling by neomorphic spar appear to be related to the formation of cavities and their infilling.
(stained thin section, ppl).
Moughton Calcilutite Member, Selside (SD785763), Upper Ribblesdale.

14g.&14h. Bioclastic calcilutite. Numerous examples of an irregular tube-like biota, associated with sparse ostracod valves and calcispheres, occur in a micrite matrix which has partially recrystallised to microspar (N.E.$_{2-3}$) resulting in a clotted texture. The tube-like animals could be serpulid worms. Similar tubes have been observed in most calcilutite samples but not in such abundance.
(stained thin section, ppl).
Moughton Calcilutite Member, Old Cote Low Moor (SD927728), Littondale.

PLATE 15

15a. Intramicrite. Large and small intraclasts composed of micrite occur in a micrite matrix which has recrystallised to microspar (N.E.$_{2-3}$). The largest intraclasts are themselves composed of smaller intraclasts 0.4-0.7mm in diameter, thus forming grapestone; many of the small intraclasts appear to be coated. It is possible that the coating and aggregation is of algal origin, and the grains oncoliths. (stained thin section, ppl).
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

15b. Intramicrite. Coated intraclasts (possibly oncoliths) occur in a recrystallised microspar matrix (N.E.$_{2-3}$). The coatings are very poorly defined and many have recrystallised. The largest clast (centre-top) appears to have a clotted algal coating of irregular thickness. The clast, itself is composed of many smaller loosely packed intraclasts internally cemented by medium and coarse spar (P.E.$_{5-6}$).
(stained thin section, ppl).
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

15c. Intramicrite. Lamina-coated clasts,oncoliths, 0.3-1.2mm in diameter are present in microspar. Local patches of spar between the grains probably are associated with the late-stage calcite veining. Oncolith nuclei are sparsely bioclastic micrite lumps with tiny (0.1-0.2mm) fenestrae.
(stained thin section, ppl).
Moughton Calcilutite Member, Horton Quarry (SD795724), Ribblesdale.

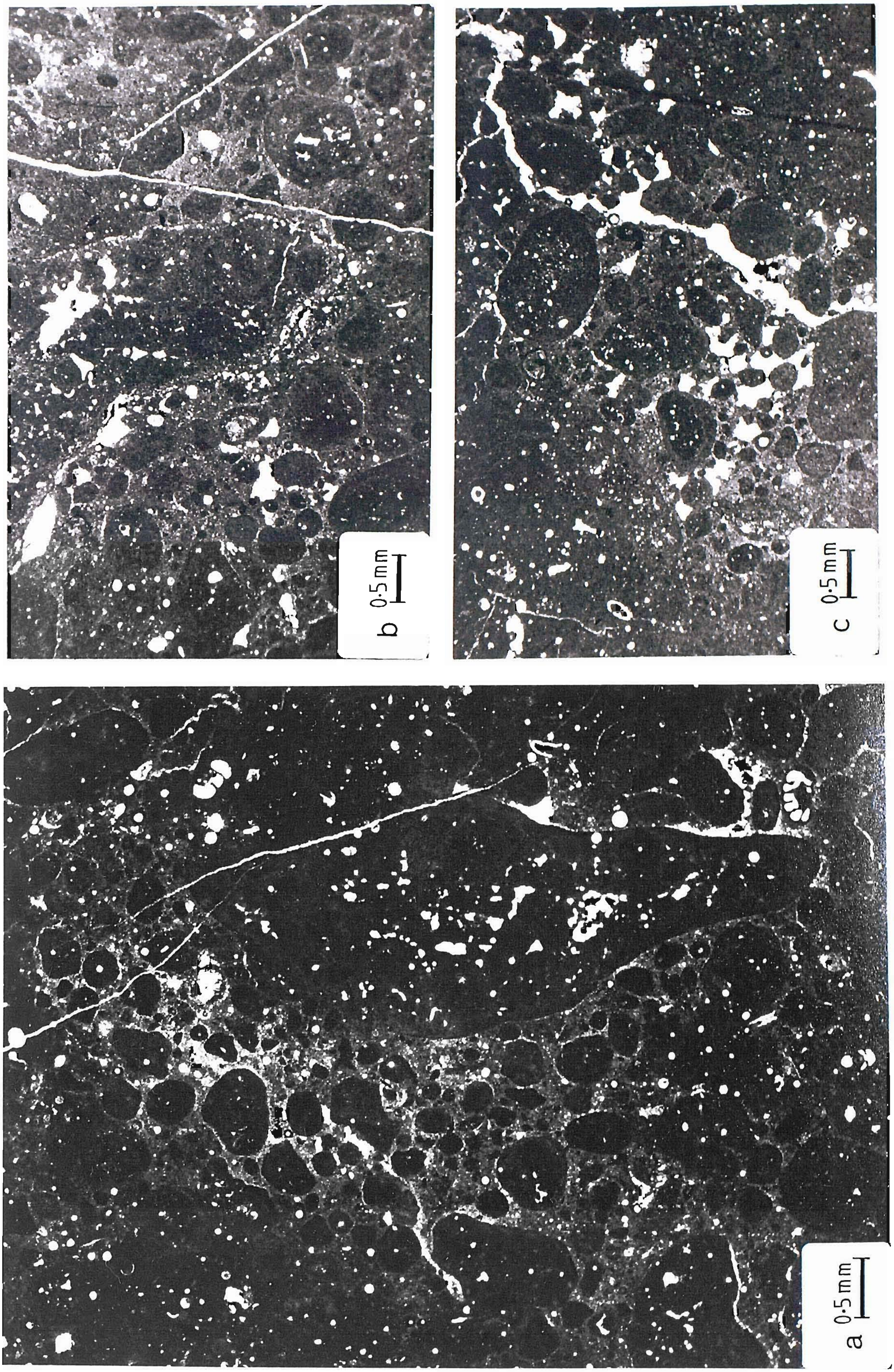


Plate 15

PLATE 16

16a. Intrasparite. Large micrite-coated bioclasts and intraclasts occur in a dusty sparite cement (P.E. $_{3-4}$). Many of the intraclasts appear to be totally micritised bioclasts (centre-right, top-right). Recrystallised mollusc fragments with thick micrite envelopes and micritised pores are common (centre and top-left), and micrite-coated crinoid fragments can be seen. In the centre and at the top of the picture, laminated crusts coat clasts and partially infill voids whose final fill is non-ferroan calcite (P.E.$_5$). Clotted micrite-microspar occurs adjacent to the laminated crusts.
(stained thin section, ppl).
Top of the Thornton Force Formation, Skirwith Quarry (SD709738), Chapel-le-Dale.

16b. Algal crusts. Dark, laminated and clotted algal crusts coat grains and bind them together around voids. The algal crusts are restricted to small areas and occur irregularly throughout the bed. The coarse spar (P.E.$_4$) is non-ferroan calcite.
(stained thin section, ppl).
Top of the Thornton Force Formation, Thornton Force (SD695753), Kingsdale.

16c. Algal laminated and clotted crusts. Dark algal laminated micrite crusts bind together grains around voids. Dark clotted micrite occurs between adjacent laminated voids, filling interstitial spaces between clasts. No algal filaments were observed. The coats are similar to oncolitic coats.
(stained thin section, ppl).
Top of the Thornton Force Formation, Skirwith Quarry (SD709738), Chapel-le-Dale.

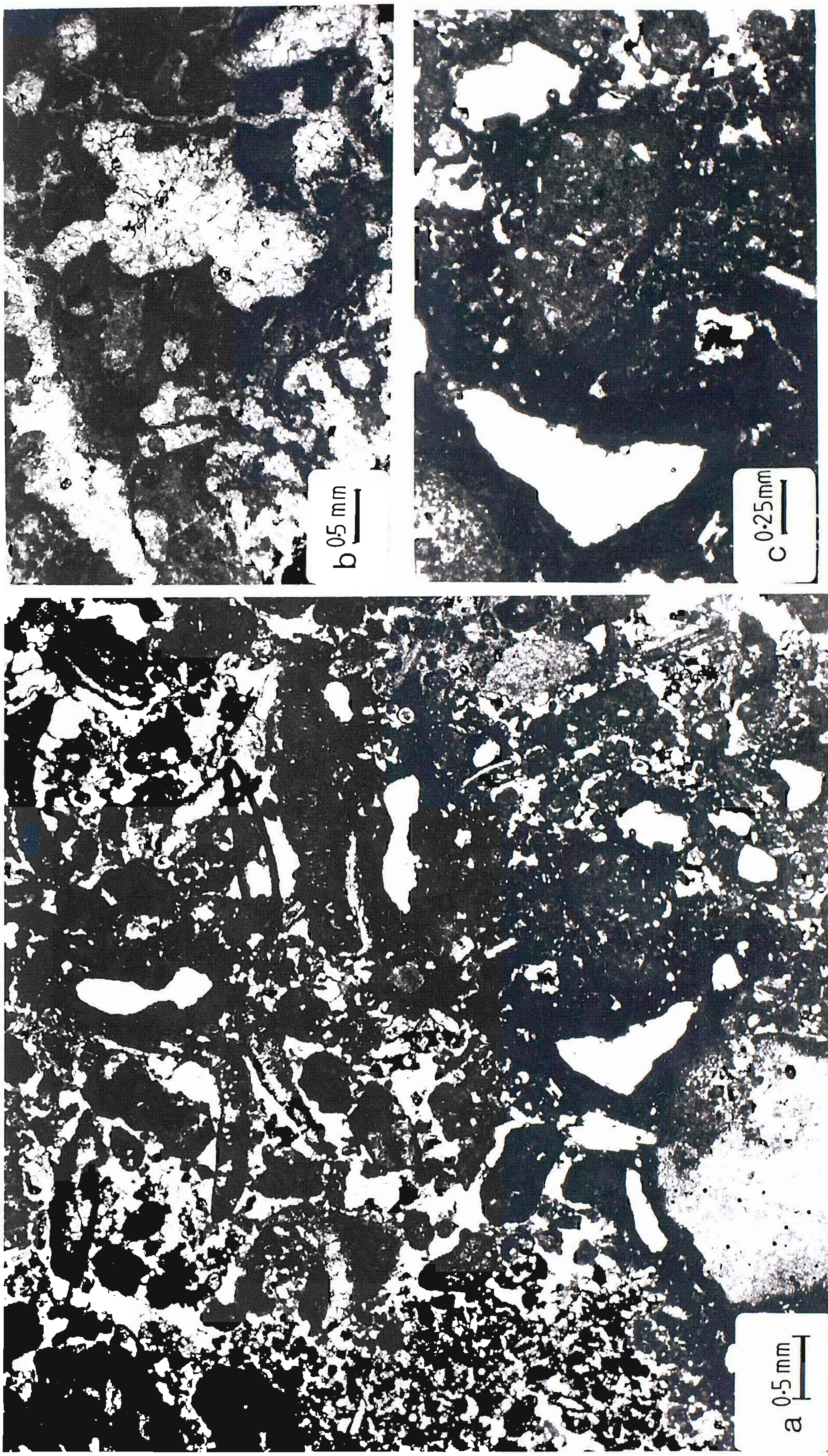


Plate 16

PLATE 17

17a Biosparite. Large longitudinal fragments of the dasycladacean alga Koninckopora occur in association with micritised bioclasts, crinoid fragments, intraclasts and pelletoids in a coarse calcite drusy mosaic
($P.E._5$). The walls of the alga have been extensively micritised.
(stained thin section, ppl).
Thornton Force Formation, Dry Gill (SD719759), Chapel-le-Dale.

17b Algal nodule in intrasparite. A nodule of the alga Garwoodia sp. occurs associated with micritised bioclasts and intraclasts in a coarse grained intrasparite. The alga shows the typical right-angle bend and branching of cell filaments 0.1mm in diameter. There is some micritisation of the outer surface of the nodule.
(stained thin section,ppl).
Thornton Force Formation, Dry Gill (SD719759), Chapel-le-Dale.

17c Biosparite. Fragments of crinoids, dasycladacean algae, mollusc shells, foraminifera and brachiopods are cemented with fine, non-ferroan calcite ($P.E._{4-5}$). There has been much micritisation of the bioclasts, especially the crinoids, molluscs and algae. Grain size is variable; the rock is poorly sorted but better sorted within individual laminae.
There has been minor compaction, but as very few bioclasts are fractured compaction probably occurred post-cementation, and hence limited to the quite extensive pressure-solution seen. Micro-stylolitic contacts have developed between those clasts lacking micrite envelopes.
(stained thin section, ppl).
Horton Limestone, Kilnsey Crag (SD974684), Wharfedale.

17d Encrusting alga. The alga Solenopora, seen here encrusting a single crinoid ossicle, occurs infrequently. This colony is at least 2.25 x 1.0mm in size. The contact between the colony and the ossicle is unusually straight.
(stained thin section, ppl).
Thornton Force Formation, old Ingleton reservoir springs (SD714747), Chapel-le-Dale.

17e Fenestrate bryozoan. Longitudinal section through a particularly well preserved fenestrate bryozoan colony which, at 2.5mm in length, is unusually large. The presence of pelletoids between the septa indicates that the organic matter had decayed, allowing infiltration.
(stained thin section, ppl).
Raven Ray Formation, Ten Pound Gill (SD719750), Chapel-le-Dale.

17f Fenestrate bryozoan with crinoid ossicle substrate. This is very unusual, and the only example to be observed. There has been micritisation of the outer perimeter of the bryozoan and the crinoid ossicle where it is not coated, but the lunule is unaffected. Septa can be seen in the bryozoan (bottom right).
(stained thin section, ppl).
Raven Ray Formation, Ten pound Gill (SD719750), Chapel-le-Dale.

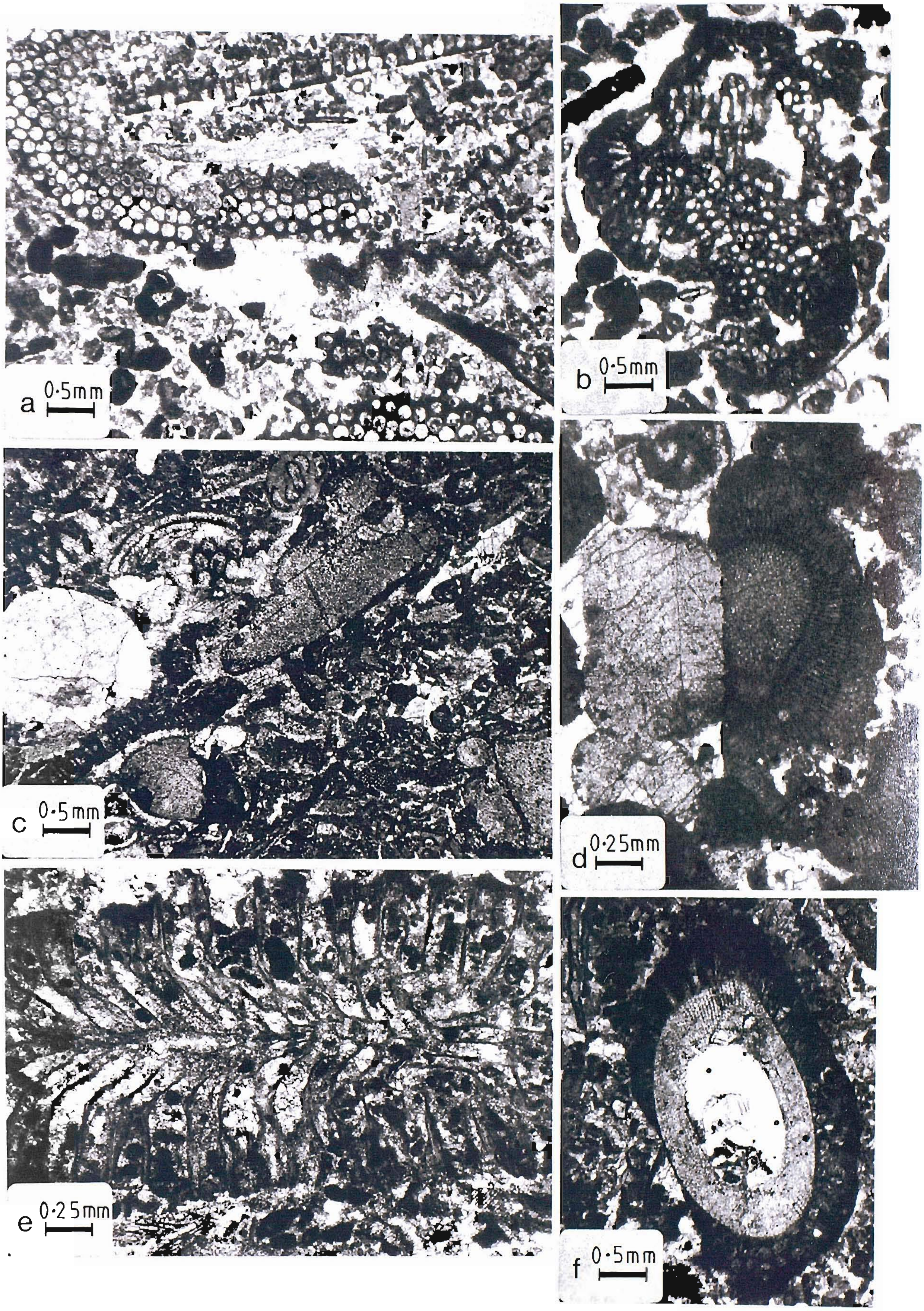


Plate 17

PLATE 18

18a Large intraclasts (maximum length 6cm) of fine grained calcarenite are present in a matrix of granule arenite (Plate 23b). The intraclasts vary considerably in shape and size; most are rounded and between 10mm and 60mm in length.
Thornton Force Formation, Nappa Scars (SD768697), Crummack Dale.

18b Intrasparite. Micrite intraclasts and complex intraclasts (grapestone) occur with pelletoids (probably small intraclasts) and micritised bioclasts, cemented with pore-filling coarse-fine non-ferroan calcite numerous (P.E.$_{3-5}$). The larger grapestones are sparse. They are composed of pelletoids, small intraclasts and micritised bioclasts loosely packed and cemented with dusty spar (P.E. $_3$) Micritised rinds are common on grapestones.
(stained thin section, ppl).
Thornton Force Formation, Skirwith Quarry (SD709738), Chapel-le-Dale.

18c Intrasparite. Micritised, rounded intraclasts of echinodermal, algal and brachiopod origin occur in a fine, equant, calcite cement (P.E.$_{3-4}$). Algal intraclasts are the most common. Where echinoderm fragments are incompletely enveloped by micrite, syntaxial overgrowth (P.E. $_5$ 0_m) has developed (centre-bottom). Micritised brachiopod fragments (centre-left) are uncommon. Sparse partially micritised mollusc ghosts and graywacke lithoclasts of the same size range (0.4-0.6mm) also occur.
(stained thin section, ppl).
Horton Limestone, Studrigg Quarry (SD781709), Crummack Dale.

18d Bioclastic intrasparite. Variably micritised bioclasts and intraclasts 0.2-1.0mm in diameter are cemented with fine, non-ferroan calcite drusy mosaic (P.E. $_{3-4}$). Almost all echinoderm fragments (both ossicles and plates) are micrite coated and overgrowths have not developed. Recrystallised archaediscid foraminifera are poorly preserved and molluscs are represented by spar-filled moulds with micrite envelopes. Intraclasts comprise greater than 40% of the rock. Most have some structure remaining suggesting a bioclastic origin.
(stained thin section, ppl).
Horton Limestone, Coniston Gorge (SD985676), Wharfedale.

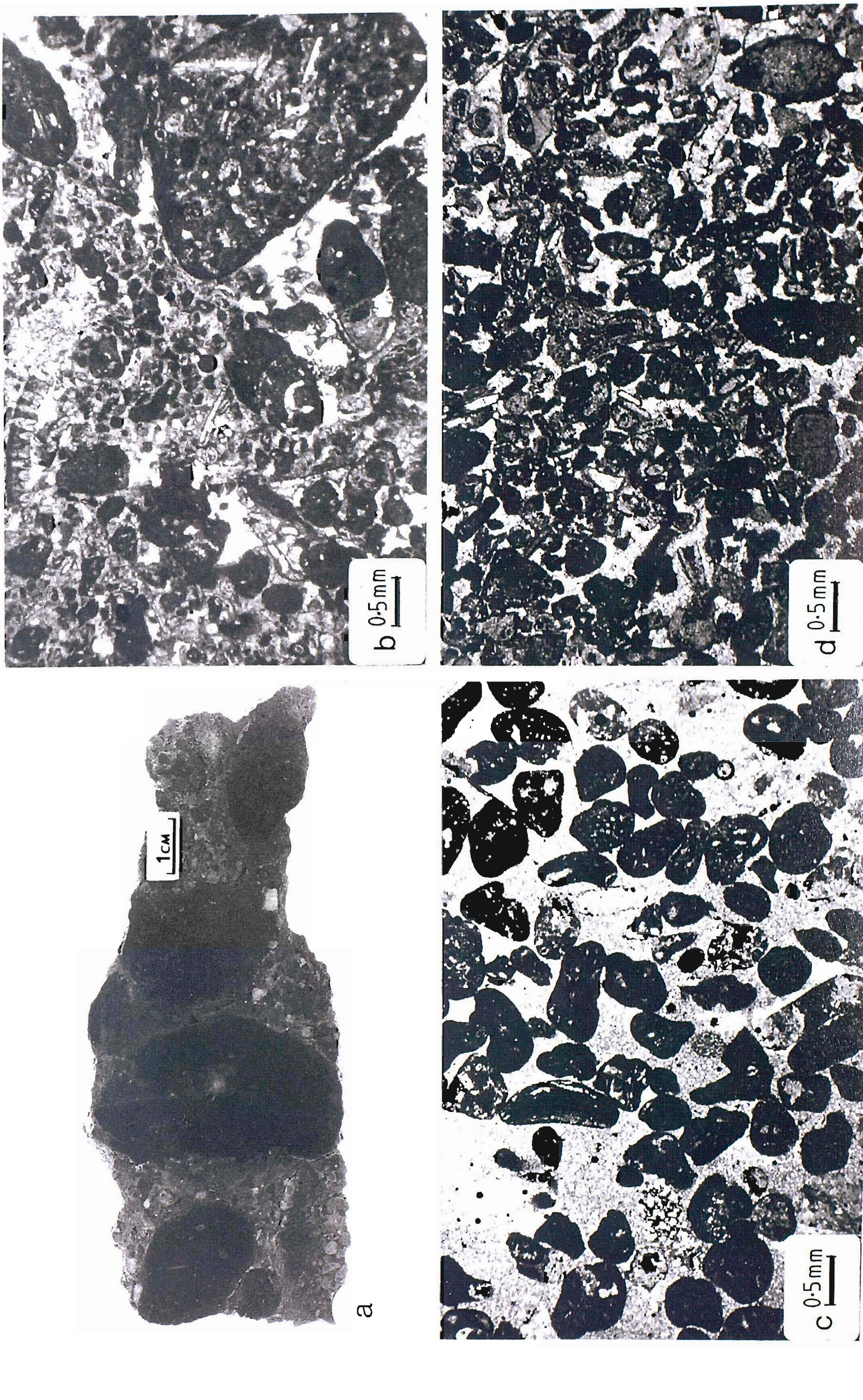


Plate 18

PLATE 19

19a Oosparite. Ooliths and superficial ooliths 0.2-0.35mm in diameter occur with minor amounts of intraclasts and quartz grains. A maximum of four oolitic coats can be indentified. Most of the nuclei appear to be degraded or micritised crinoid fragments. The non-ferroan calcite pore-filling cement formed early and there is no compaction.
(stained thin section, ppl).
Thornton Force Formation, Skirwith Quarry (SD709738), Chapel-le-Dale.

19b Oosparite. Well formed ooliths and superficial ooliths (0.2-0.25mm in size) dominate the mixed assemblage of clasts. Ghosts of molluscs with micrite envelopes, crinoids, pelletoids and angular quartz grains also occur, deposited as hydraulic equivalents. Almost all the ooliths are composed of ferroan calcite, some laminae being more ferroan than others. The fine, pore-filling cement is non-ferroan calcite.
(stained thin section, ppl).
Douk Gill Formation, Brackenbottom Farm (SD817721), Ribblesdale.

19c Oolitic and bioclastic pelsparite. Sparse 0.2-0.4mm size ooliths with bioclastic nuclei and one or two ferroan calcite laminae occur with numerous pelletoids, some recrystallised mollusc fragments and lithoclasts. The non-ferroan calcite pore-filling cement is early and there is no compaction.
(stained thin section, ppl).
Douk Gill Formation, Brackenbottom Farm (SD817721), Ribblesdale.

19d Intraclast-bearing pelsparite. Sparse large intraclasts (top-right) at least 6mm in length, occur in a ground mass of pelletoids, micritised bioclasts, graywacke lithoclasts and very sparse, mostly superficial, ooliths. Ooliths, superficial and well-formed, occur in the large intraclasts where they are cemented with dusty calcite spar and a micrite envelope. The non-ferroan calcite cement of the groundmass formed early and there is no compaction.
(stained thin section, ppl)
Douk Gill Formation, Brackenbottom Farm (SD817721), Ribblesdale.

19e Oosparite. Micritised superficial ooliths 0.3-0.4mm in diameter dominate an assemblage of intraclasts, sparse micritised bioclasts, crinoid fragments and occasional lithoclasts (bottom-right). Almost all the ooliths have been micritised and in many only one oolitic lamina can be recognised. The coarse, pore-filling calcite cement is early and there is no compaction. Large syntaxial overgrowths ($\mathrm{P.E.}_{5}\mathrm{O}_{m}$) have developed on crinoid fragments (centre and top-right).
(stained thin section, ppl).
Thornton Force Formation, Nappa Scars (SD768697), Crummack Dale.

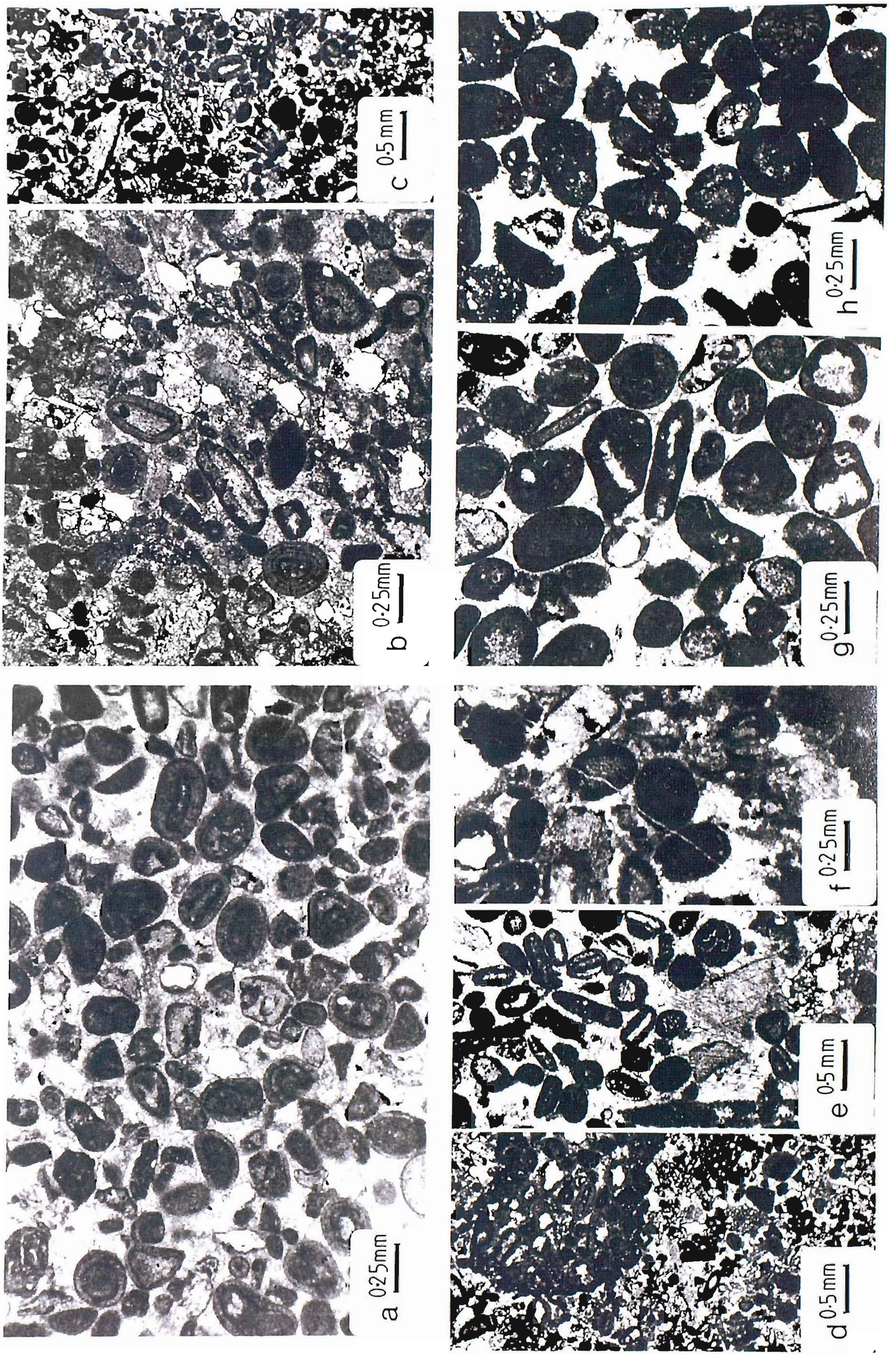


Plate 19

19f Reworked micritised ooliths in intrasparite. Sparse, reworked, intensely micritised superficial ooliths 0.2-0.3mm in size occur in small clusters in a sparsely bioclastic intrasparite. Most ooliths have only one or two identifiable coats and the nuclei are echinoderm fragments or micrite intraclasts. The cement is very variable, from patches of coarse spar (possibly neomorphic), through dusty spar (P.E.$_3$) to localised patches of microspar (N.E.$_{2-3}$ or P.E.$_{2-3}$). There is no compaction.
(stained thin section, ppl).
Raven Ray Formation, High Howeth (SD719751),
Chapel-le-Dale.

19g Bioclastic oosparite. Numerous micritised superficial ooliths (0.2-0.3mm in diameter) occur with similar sized, rounded, micritised bioclasts, especially crinoid fragments. Most oolith nuclei are unidentifiable and ooliths have only one or two coats. The non-ferroan calcite drusy cement (P.E. $_{3-4}$) is early and there is no compaction.
(stained thin section, ppl).
Thornton Force Formation, Raven Scar (SD716747),
Chapel-le-Dale.

19h Oolitic intrasparite. Intensely micritised, possibly reworked, superficial and well-formed ooliths (0.25-0.4mm in diameter) occur with rounded intraclasts and micritised bioclasts. The oolith nuclei are echinoderm fragments and endothyrid foraminifera. The pore-filling calcite cement (P.E. $_{4-5}$) is early and there is no compaction. Very sparse lithoclasts (top-left) are present.
(stained thin section, ppl).
Horton Limestone, Horton Quarry (SD795724), Ribblesdale.

PLATE 20

20a Foraminiferal intrasparite. Numerous endothyrid foraminifera 0.2-0.7mm in diameter occur with rounded intraclasts and abraded, micritised bioclasts. The foraminifera are a typical Holkerian assemblage. The larger foraminifera, containing air-filled chambers, were deposited as hydraulic size-equivalents of the smaller, denser bioclasts and intraclasts. All the pore-filling cement (P.E. $_{4-5}$) is non-ferroan calcite. Cementation was early because there is no compaction. (stained thin section, ppl).
Horton Limestone, Gate Cote Scar (SD963724), Wharfedale.

20b Bioclastic calcilutite. A restricted fauna of numerous ostracods (complete or single valves), endothyrid foraminifera and sparse calcispheres occur in a micrite matrix which has recrystallised to microspar (N.E. $_{2-3}$). Sparse mollusc moulds (gastropods?) and pelletoids are also present.
(stained thin section, ppl).
Douk Gill Formation, Gillet Brae (SD800719), Ribblesdale.

20c Foraminiferal biomicrite. A restricted assemblage of endothyrid foraminifera, calcispheres, sparse ostracods and very sparse serpulid worm tubes occurs in a matrix of micrite rich in organic matter. Sparse pelletoids are the only non-bioclastic carbonate grains. There has been some compaction with orientation of the bioclasts. Many clasts have interpenetrating microstylolitic contacts. Organic matter is particularly located along pressure solution contacts.
(stained thin section, ppl).
Moughton Calcilutite Member, Selside (SD785763), Upper Ribblesdale.

20d Bioclastic pelsparite. Numerous unidentifiable micrite clasts less than 0.2mm in diameter (pelletoids) are cemented with fine, pore-filling calcite (P.E.$_3$). Large mollusc moulds (1-2m min length, infilled with neomorphic calcite), and micritised crinoid ossicles (>2mm) occur with tiny bioclasts (<0.2mm) in the pelsparite groundmass. The cement is early and there is no compaction.
(stained thin section, ppl).
Horton Limestone, Twisleton Scar (SD723764), Chapel-le-Dale.

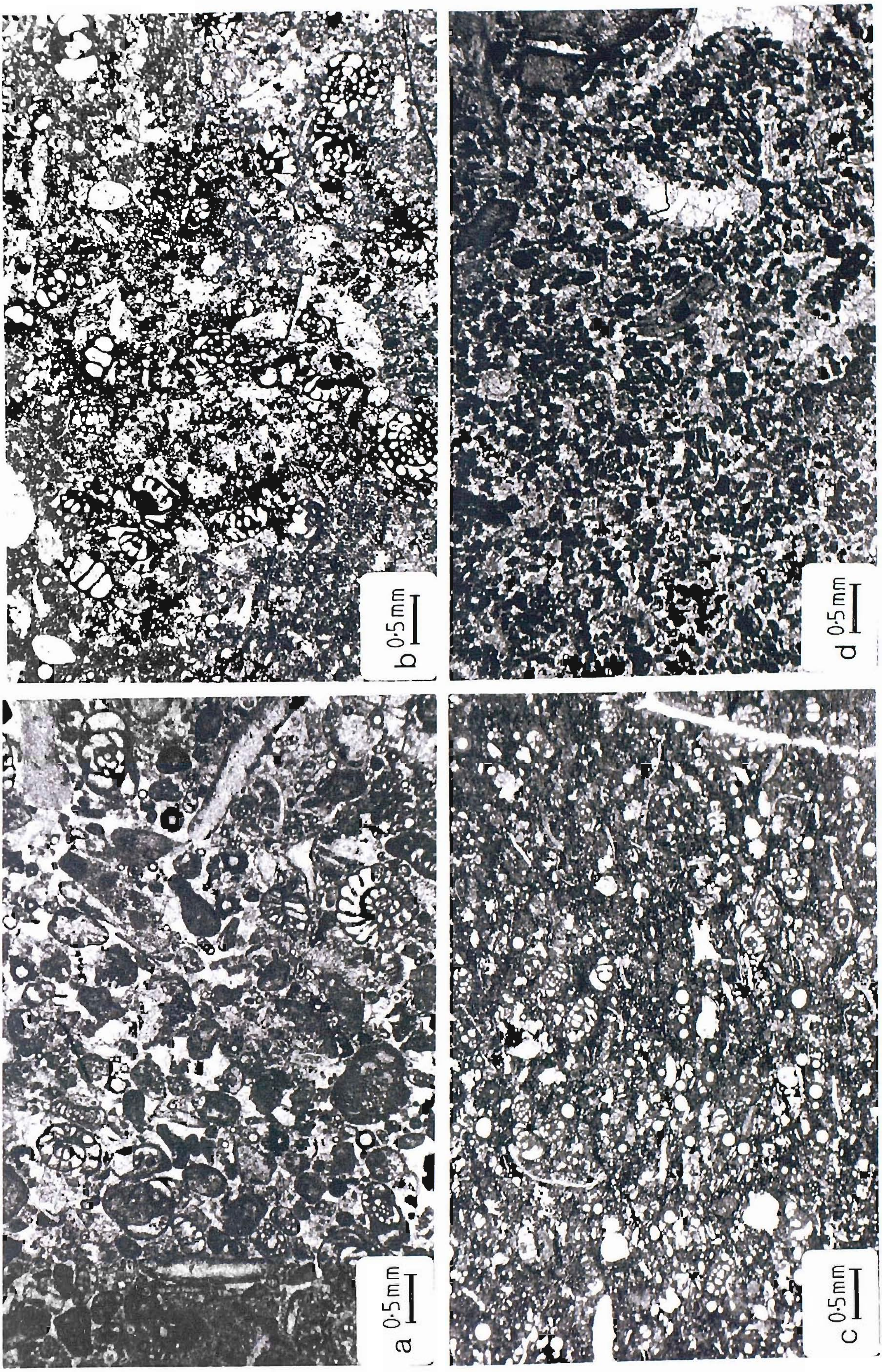


Plate 20

PLATE 21

21a Authigenic quartz. Large euhedra of authigenic quartz up to 0.7mm in length are present in bioclastic intrasparite. The cores of most quartz crystals are unreplaced calcite.
(stained thin section, ppl).
Raven Ray Formation, Springcote Pasture (SD721761), Chapel-le-Dale.

21b Authigenic quartz crystals. These crystals were extracted from an intrasparite by acid-digest. They vary between 0.25mm and 1.50mm in length and have cores of calcite. Most crystals are subhedral; the crystal terminations are not well developed.
(mounted crystals, xp).
Thornton Force Formation, Twisleton Scars (SD717759), Chapel-le-Dale.

21c Crinoid biosparite with quartz sand. During compaction of the sediment there was extensive pressure solution resulting in the dissolution of carbonate grains, particularly crinoid ossicles. The resistant quartz grains became embedded in the adjacent carbonate grains (top-left and centre). There is very little primary matrix, most has been lost during dissolution.
(stained thin section, ppl).
Raven Ray Formation?, God's Bridge (SD733763), Chapel-le-Dale.

21d Crinoidal biosparite. The original matrix or cement has been replaced by a non-ferroan dolomite pseudospar with which the calcite bioclasts are in disequilibrium. There has been some compaction with preferential dissolution of the calcite bioclasts. Irregular, microstylolitic contacts can clearly be seen.
(stained thin section, ppl).
Horton Limestone, Kilnsey Crag (SD974684), Wharfedale.

21e Dolomitised intrasparite. Micrite clasts and the primary non-ferroan calcite spar ($P.E._{4-5}$) are overgrown with scattered, millimetre-size dolomite rhombs. The cores of most rhombs contain some unaltered calcite and the rims contain numerous tiny pyrite inclusions.
(stained thin section, ppl).
Horton Limestone, old quarries (SD691756), Kingsdale.

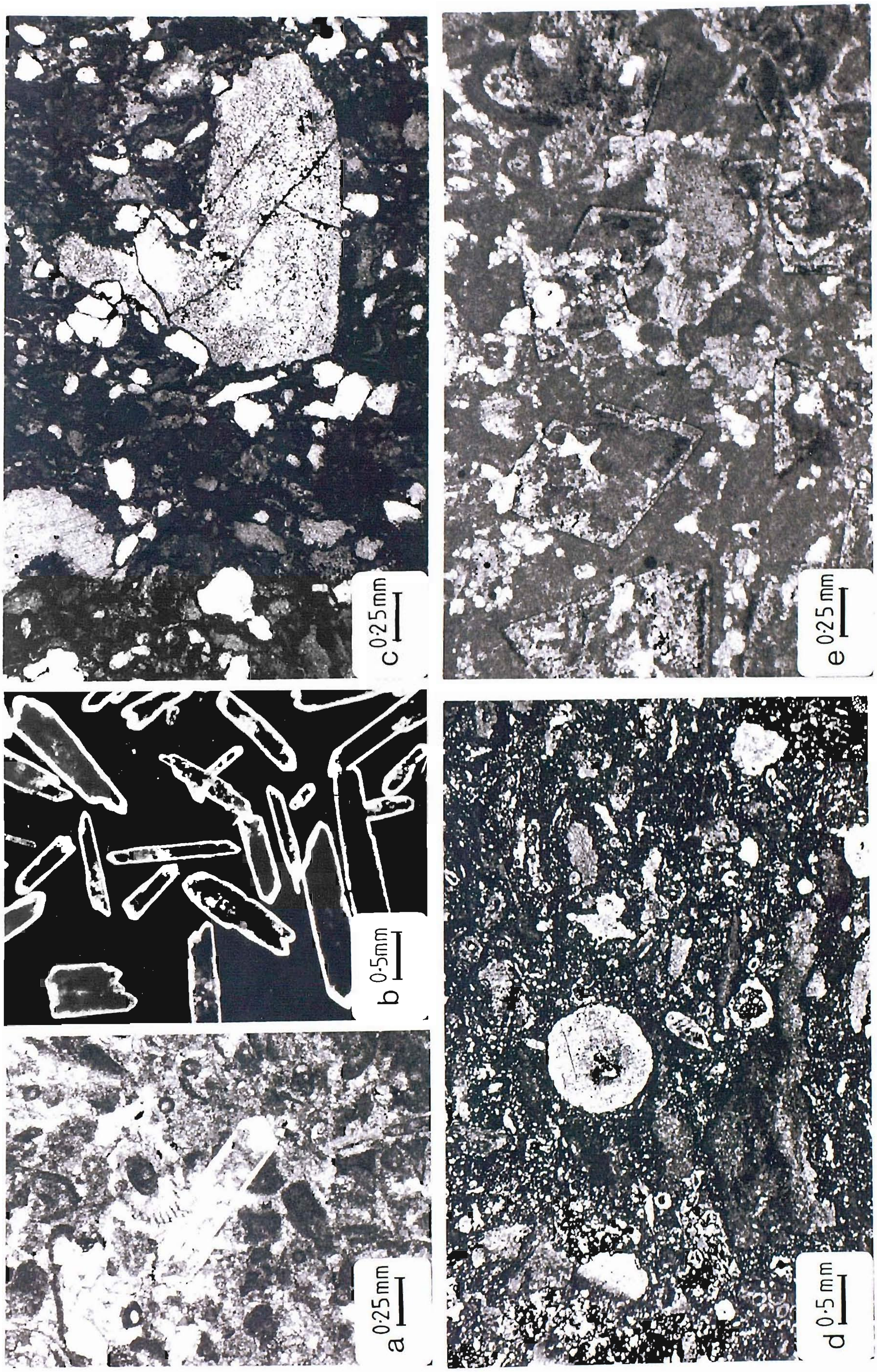


Plate 21

PLATE 22

22a A rudite lamina is abruptly overlain by mid grey, medium grained calcarenite. The rounded lithoclasts of slate, graywacke and vein quartz (2mm-20mm in length) occur in a matrix of medium grained, pale grey calcarenite. The elongate clasts are randomly orientated. Thornton Force Formation, Skirwith Quarry (SD709738), Chapel-le-Dale.

22b Rudite. Slate, graywacke and sparse vein quartz clasts are graded and reverse graded. The matrix comprises minute lithoclasts (<2mm) in fine grained calcarenite. Visible lithoclasts are angular-subangular, elongate and 1.5mm to 15mm in length. The smaller visible lithoclasts are randomly orientated and the larger mostly subparallel. There is no imbrication.
Thornton Force Formation, High Howeth (SD720752), Chapel-le-Dale.

22c Poorly graded, matrix-supported rudite. Large, semi-parallel fragments of slate, graywacke and vein quartz occur in a matrix of minute lithoclasts and clay minerals. The subangular-subrounded clasts are up to 25mm in length.
Thornton Force Formation, Twisleton Scars (SD713756), Chapel-le-Dale.

22d Graywacke clast-supported rudite. Rounded and subrounded parallel orientated clasts of coarse grained graywacke, fine grained graywacke and subsiduary quartz and slate all have extensive weathered rims. Many clasts smaller than 5mm must be weathered throughout. Small clasts are tightly packed between large clasts and there is no matrix. Carbonate cement (ferroan dolomite) is restricted to small pore spaces (top right).
Thornton Force Formation, Ten Pound Gill (SD719750), Chapel-le-Dale.

22e Graywacke cobble-framework rudite. Subrounded-subangular and broken graywacke cobbles and small boulders, in a matrix of lithoclastic, coarse grained calcarenite, occur as discrete lenses above the unconformable contact with Lower Palaeozoic rocks. The rudite is 1.35m thick at this locality and the lithoclasts average 600-700mm in length.
Horton Limestone, Studrigg Scars (SD781708), Crummack Dale.

22f Pebble-cobble rudite. Pebble and cobbles of Silurian graywacke with a matrix of lithoclastic, coarse grained calcarenite together form the matrix of some boulder rudites. The subrounded pebbles and cobbles are randomly arranged; there is no imbrication or clast orientation.
Horton Limestone, western Crummack Dale (SD767712).

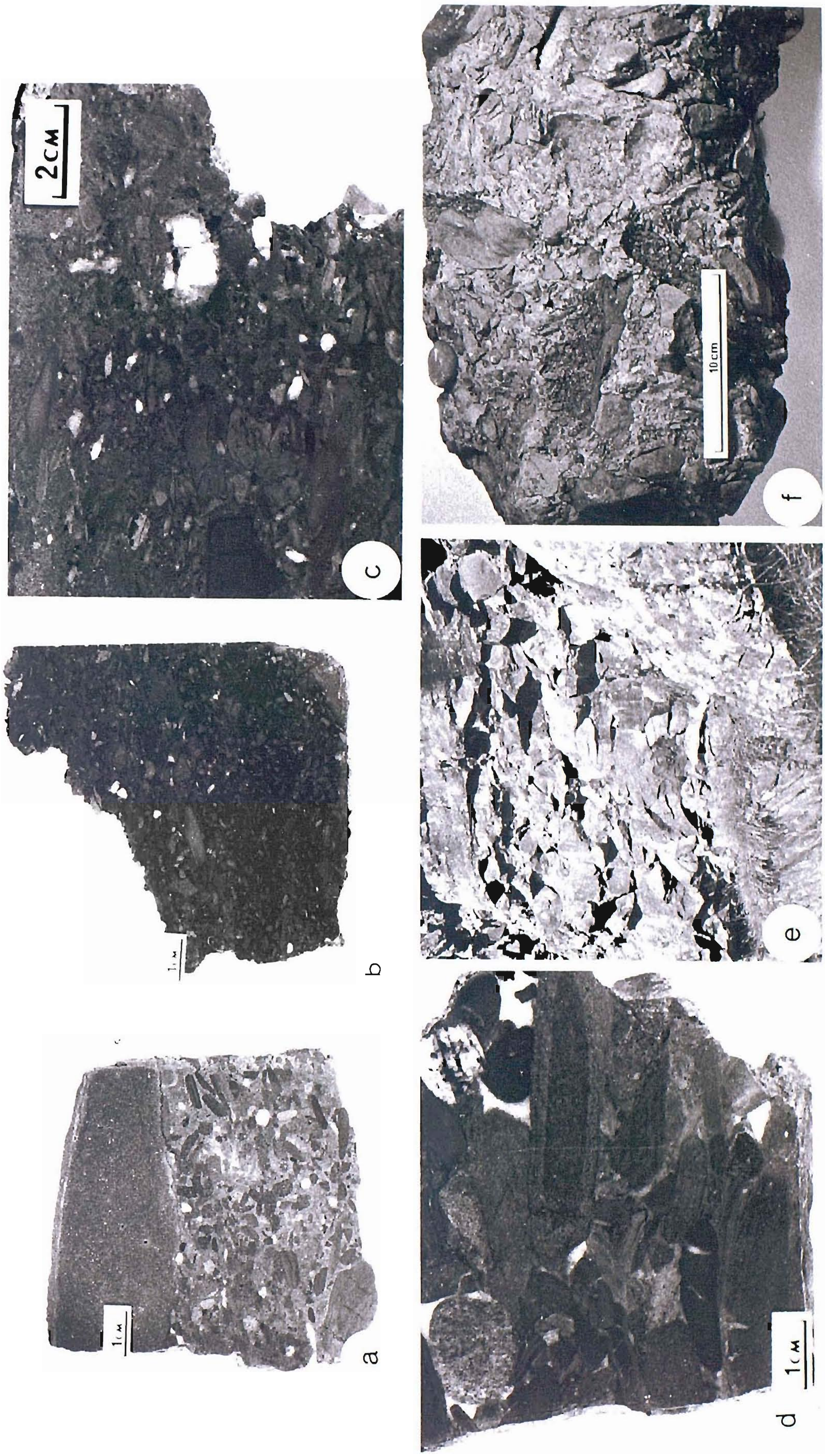
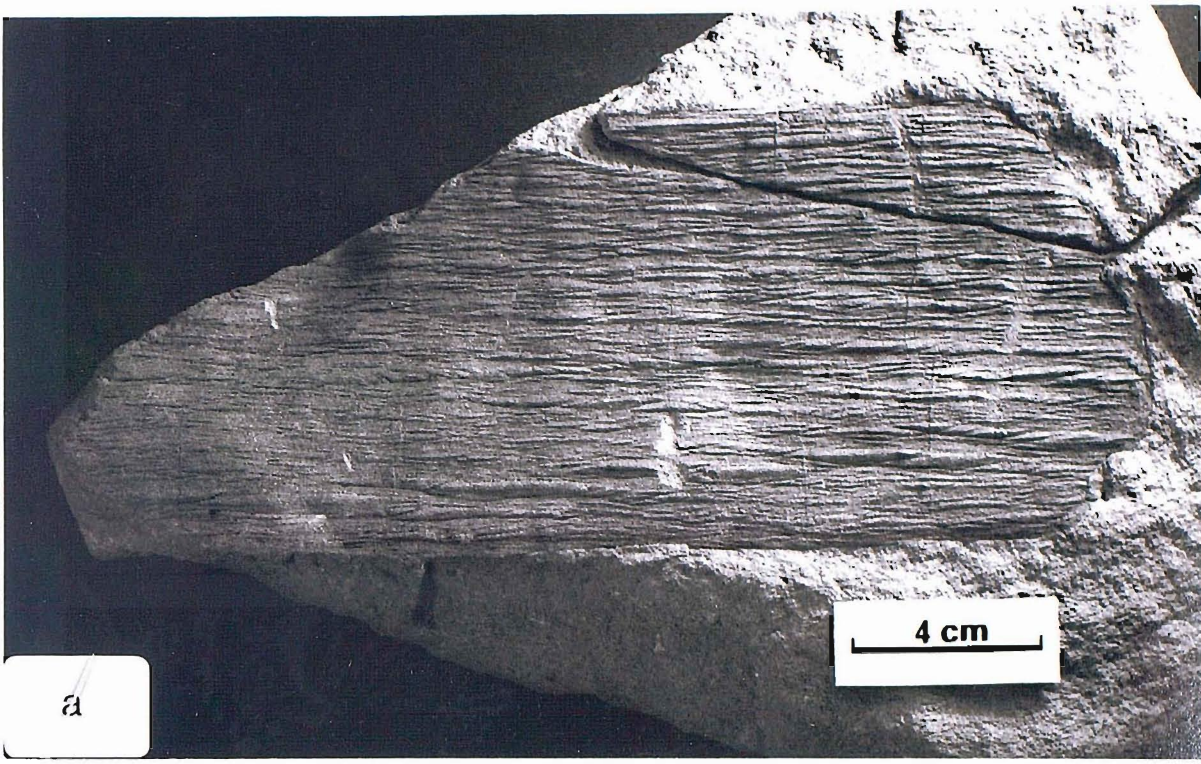


Plate 22

PLATE 23

23a Decorticated stem of "cf. Sublepidodendron". The fossil is a piece from an old stem showing no fusiform leaf cushions; these have probably been sloughed off (W.G. Chaloner, pers. comm.). The fossil is preserved in calcareous sandstone.
Thornton Force Formation, old Ingleton reservoir springs (SD714747), Chapel-le-Dale.

23b Granule arenite. Parallel, flat-lying lithoclasts of Silurian fine grained graywacke and siltstone occur in a calcarenite (intrasparite) matrix. All the lithoclasts are rounded and well sorted granules (2-4mm): larger and smaller lithoclasts are very uncommon. The sparse, abraded bioclasts are in the same size-range. The cement is non-ferroan calcite drusy mosaic.
(stained thin section, ppl).
Thornton Force Formation, Nappa Scars (SD769698), Crummack Dale.



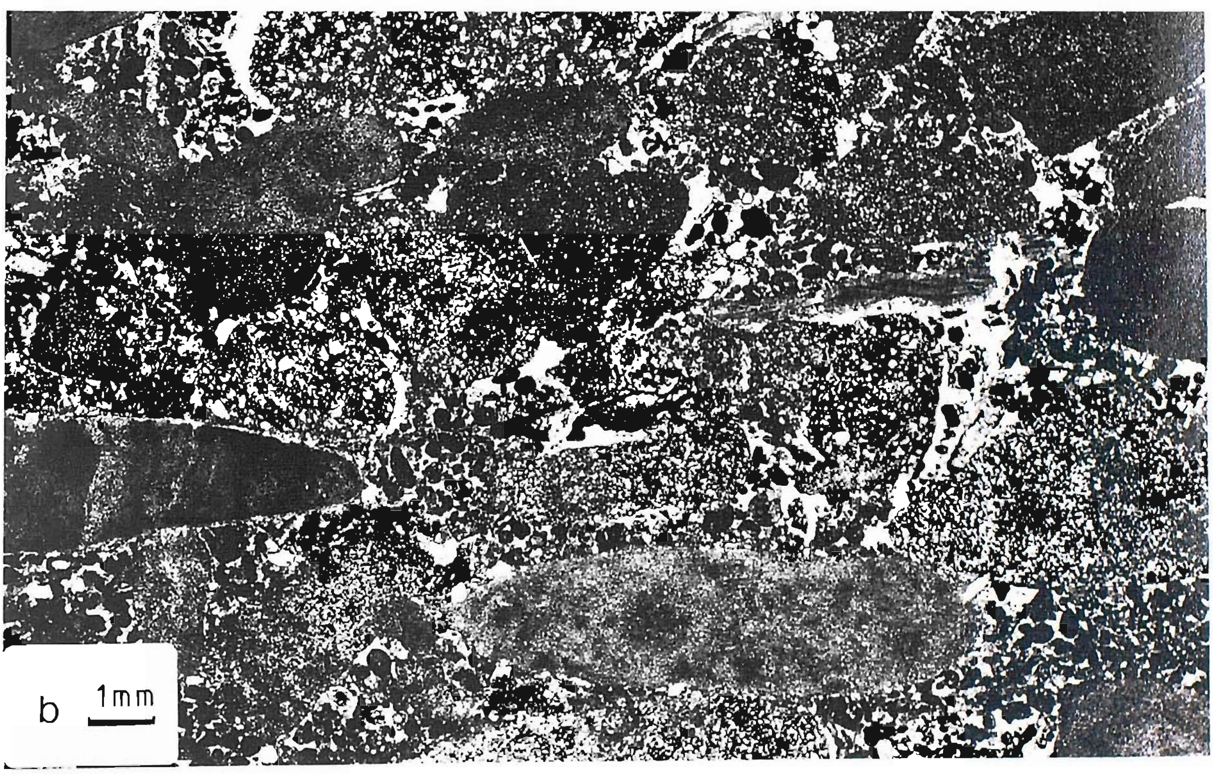


Plate 23

PLATE 24

24a Quartz arenite. Equant, well sorted, subrounded-subangular grains of quartz are cemented with non-ferroan and ferroan dolomite (P.E.$_3$). Calcite crinoid ossicles occur infrequently.
(stained thin section, ppl).
Raven Ray Formation, Newby. Cote Quarry (SD733707), Newby.

24b Quartz lithatenite. Moderately sorted, subangular quartz grains and sparse, poorly sorted lithoclasts occur in a matrix of quartz silt and clay minerals. Lithoclasts comprising fine quartz silt and clay minerals have very diffuse boundaries. No bioclasts were observed.
(thin section, xp).
Douk Gill Formation, Gillet Brae (SD800719), Ribblesdale.

24c Calcareous quartz arenite. Laminae rich in quartz grains and lithoclasts alternate with more bioclastic, quartz grain and lithoclast-poor laminae. The subangular-subrounded quartz clasts are very well sorted (0.2mm). Slate and graywacke clasts are slightly larger (0.3-0.35mm). All the lithoclasts and bioclasts (mostly crinoids) were deposited simultaneously and must have been hydraulic size-equivalents. Bioclasts, syntaxial overgrowth cements (P.E.$_{4-5}$ O_m) and drusy mosaic (P.E.$_{3-4}$) are all non-ferroan calcite.
(stained thin section, ppl).
Thornton Force Formation, Twisleton Scars (SD714756), Chapel-le-Dale.

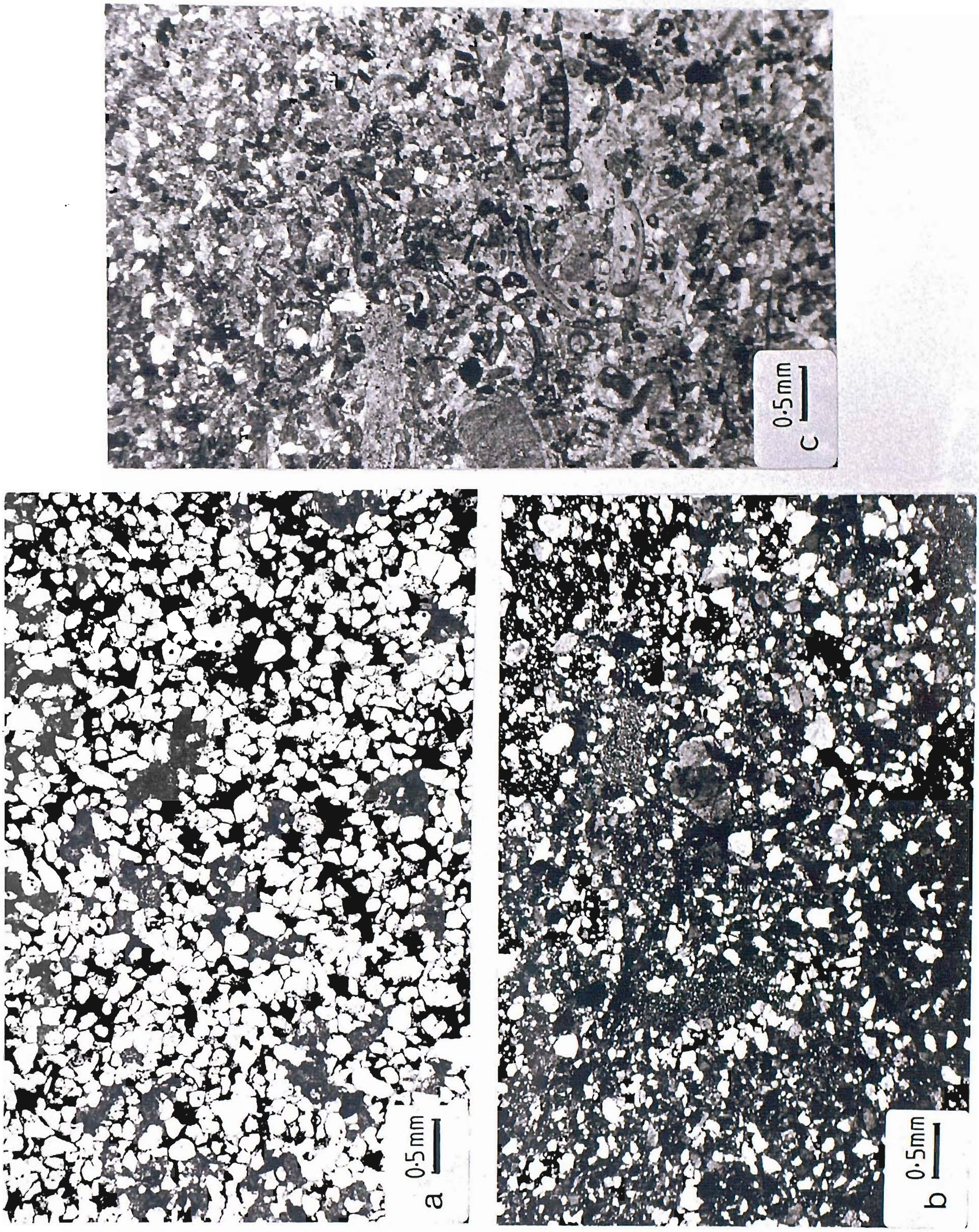


Plate 24