SEDIMENTOLOGY OF BAJOCIAN ROCKS FROM THE RAVENSCAR GROUP OF YORKSHIRE

by

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A thesis submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy

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January, 1981

ABSTRACT

There is a dramatic change in Jurassic sedimentary patterns in Yorkshire from shallow marine Liassic deposits to the mixed coastal plain/ marine sequences seen in the Middle Jurassic. The Middle Jurassic Ravenscar Group overlies Aalenian Dogger Formation shallow marine sediments. Facies analysis shows that the lower parts of the Ravenscar Group includes three non-marine horizons (the Saltwick Formation, the Sycarham Member and the Gristhorpe Member) interbedded with two marine sequences (the Eller Beck Formation and the Lebberston Member) and the section studied is terminated by thick offshore marine shales of the Scarborough Formation. Biostratigraphic evidence suggests a continuous period of coastal plain and marine sedimentation lasting approximately five million years for the sequence.

Three marine horizons, the upper parts of the Dogger Formation, the Eller Beck Formation and the basal member of the Scarborough Formation show coarsening-upward profiles indicative of coastline progradation following periods of sudden transgression. By comparison the lower part of the marine Lebberston Member resulted from a gradual relative sea level rise which reworked both underlying and exotic sediment into broad sand sheets. As the sea level stabilised carbonate sedimentation occurred as ooids formed in a shallow offshore marine environment, adjacent to a low energy coastline which lay to the north. The marine horizons demonstrate shallow water deposition under variable energy waves and micro- to mesotidal currents.

Rapid progradation of fluvial dominated coastal plains occurred at three horizons and the palaeocurrents from these non-marine beds show a strong southerly transport direction. Highly constructive river systems of variable magnitude deposited the majority of the clastic sediment seen in the Ravenscar Group, with large amounts of predominantly fine-grained material laid down in lacustrine, crevasse

splay, levee and alluvial floodplain environments. The rivers included high and ?low sinuosity forms. Some of the very large channel sand bodies were sites of complex deposition and erosion of sediment for long periods of time, and these rivers probably represent major distributary channels which dominated the coastal plains.

The upper parts of the coastal sections of the Lebberston Member indicate the rapid progradation of a wave-tide-fluvial delta front over offshore carbonate sediments. From the evidence of wave and tidal activity in the marine horizons this model is tentatively applied to the other non-marine deposits. The overall facies analysis of the sediments allows a description of the history of sedimentation of the Ravenscar Group to be made, including a summary of the depositional palaeogeographies.

Palaeocurrent, compositional and grain size evidence suggest that the non-marine horizons represent repeated periods of progradation of the same system, under the influence of tectonic activity (uplift?) in the hinterland, allied with delta abandonment within the outcrop area. Petrographic analyses combined with a consideration of the Mesosoic tectonic history of the North Sea area indicates a small scale sedimentary system deriving clastic detritus from dominantly Carboniferous outcrops in the region of the Mid-North Sea High. The sandstones are all sub-arkoses or quartz arenites.

Diagenetic studies of the sediments indicate widespread kaolinite formation but calcite cementation is restricted to the marine horizons. Clastic diagenesis in the Ravenscar Group shows similarities with other contemporaneous deposits in the North Sea region, with variable quartz redistribution and illite and illite/smectite formation. Illite is the dominant clay mineral present in the shales and mudstones, with kaolinite locally abundant in organic rich sediments. There is little difference between the clay mineral suites of the marine and non-marine mudrocks. The lower, carbonate bearing, parts of the Lebberston Member show evidence of syn-sedimentary lithification in submarine and beach environments prior to a sealing of the limestones by a coarse sparry calcite cement. This horizon is analagous in many respects to modern Bahaman environments.

ACKNOWLEDGEMENTS

Firstly I would like to thank Dr. M. R. Leeder for initiating this project and for his constant guidance and supervision throughout. The study was financed by the N.E.R.C. whose contribution is gratefully acknowledged.

Many people at Leeds University Dept. of Earth Sciences have provided assistance and advice and the author is indebted to Dr. E. Condliffe for help with the S.E.M. and microprobe analyses; to Dr. G. Hornung for assistance with the x-ray diffraction and Mr. A.Gray for teaching me how to use an X.R.F. analyser. Mr. T. F. Johnston patiently took many of the photomicrographs and helped with many of the laboratory studies. Special thanks are owed to A. R. Gardiner for providing the computer programmes used in the palaeocurrent and grain size analyses. The Dept. of Ceramics provided machine time on their diffractometer. Dr. A. Dickson and his colleagues at Nottingham University taught me how to use their cathodeluminescence equipment and skillfully took some of the photomicrographs in this thesis.

Several people have helped with field discussions including John Kantorowicz and Pete Ruxton, all those on the B.S.R.G. field trip in Dec. 1978 and everyone who attended the G.A. trip in May 1980. Dr. G. Gaunt at the I.G.S. took time to locate the Brown Moor borehole core for me and his help was much appreciated.

The staff at the Wellcome marine laboratory kindly lent me their cobble which was used to take cliff photographs and Mr. E. Daniels braved the North Sea to produce them. Mrs. J. Fall is thanked for typing the thesis and Jeff and Mary Bird provided accomodation during the field seasons. Finally I thank my parents for their constant support throughout this research.

CONTENTS

CHAPTER 1

INTRODUCTION

CHAPTER 1

1.1. Introduction

The Middle Jurassic Ravenscar Group outcrops over approximately 1300 square kilometres in north-east Yorkshire (Fig. 1.1). It consists of a mixed marine and non-marine sequence approaching 180m in thickness on the coast, and has been traced eastwards into the North Sea (Dingle, 1971). The Yorkshire Jurassic as a whole forms an upland area known as the North Yorkshire Moors with a maximum elevation of 454m. (Fig. 1.2). This National Park region is drained by a series of incised rivers which flow eastwards into Eskdale in the north and into the Vale of Pickering in the south (Fig. 1.2). The whole area has been heavily influenced by geomorphological processes associated with the last ice age (Penny, 1974). This region supports a heavy tourist trade, based at the two main towns, Whitby and Scarborough.

The structural geology of the area is relatively simple, and summarised in Fig. 1.3 after Kent (1980). The main feature is the Cleveland Dome which uplifts the Ravenscar Group to outcrop at the summit of the Moors. To the south of Eskdale the rocks dip gently under the Vale of Pickering and only outcrop on the coast and along a narrow strip to the west (Fig. 1.1). The region is cut by a series of faults thought to be Tertiary in age (Hemingway, 1974) including the major Howardian-Flamborough fault zone (Fig. 1.3). The maximum thickness of the Ravenscar Group is recorded in the region of the Cleveland Hills and it thins southwards on to the Market Weighton Block (Fig. 1.3). Here there is strong internal disconformity

FIG 1.1

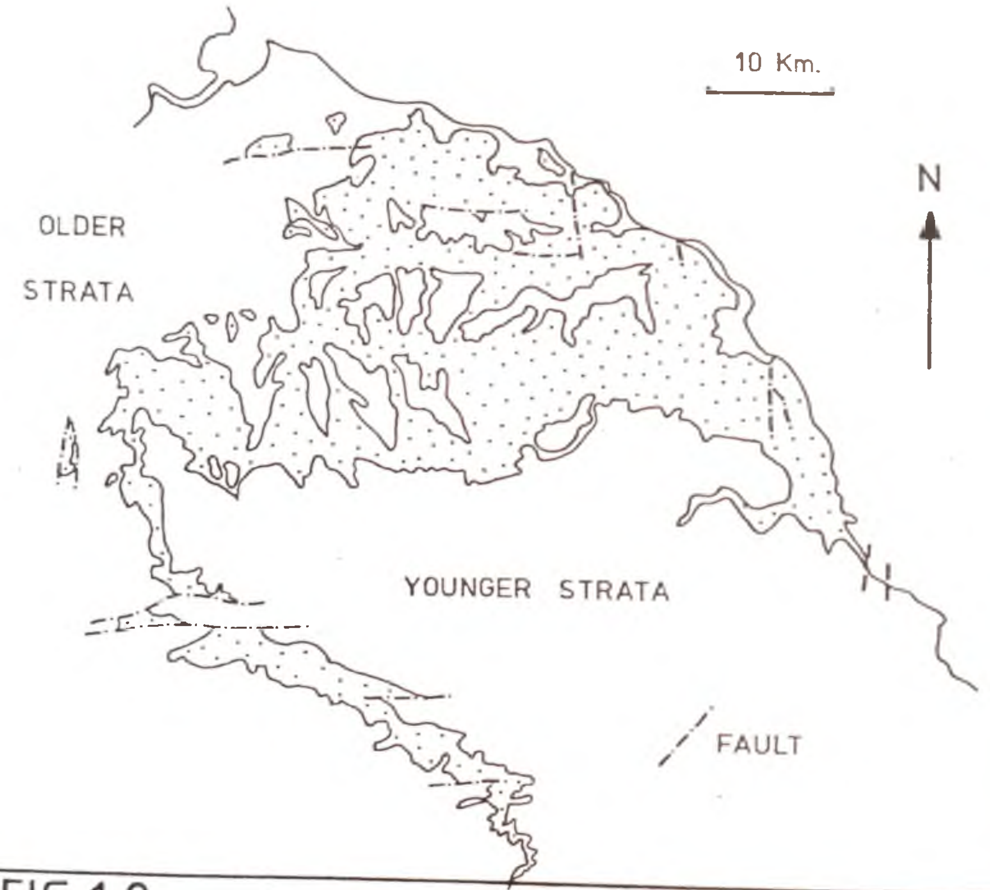

10 Km.
N
OLDER
STRATA
YOUNGER STRATA
FAULT

FIG 1.2


Redcar
TEESIDE
10 Km.
Whitby
N
329
ESKDALE
CLEVELAND HILLS
454
326
N. YORKSHIRE MOORS
299
HAMBLETON HILLS
Scarborough
VALE OF PICKERING
HOWARDIAN HILLS
VALE
OF
YORK
100 m.
WOLDS
Over 200 m.
100 m.

FIG 1.3

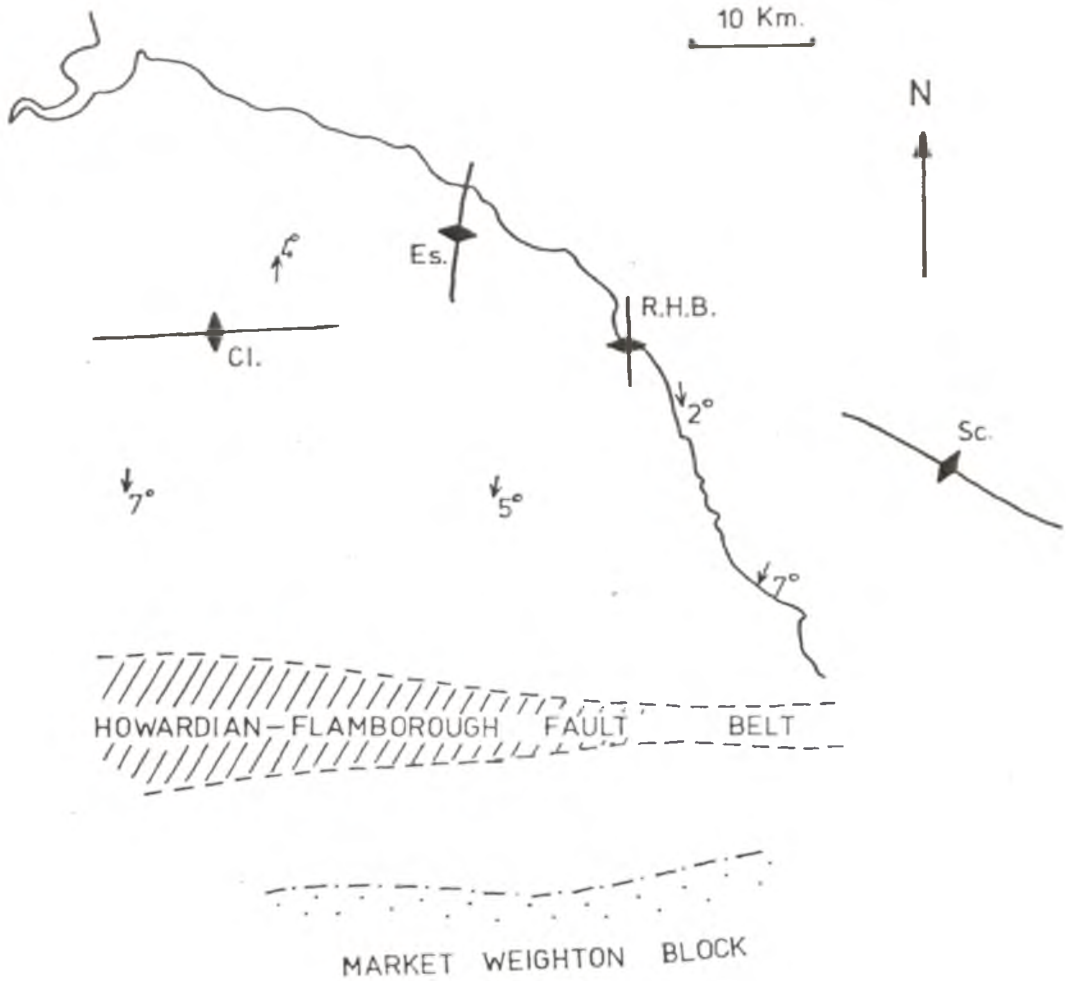


Fig. 1.1 Map showing the outcrop (stippled) of the Ravenscar Group in northeast Yorkshire.

Fig. 1.2 Topographic map of northeast Yorkshire with the major physiographic features indicated.

Fig. 1.3 Map showing the major structural features of the Jurassic in northeast Yorkshire (after Kent, 1980). Cl- Cleveland Dome, Es.- Eskdale anticline, R.H.B.- Robin Hoods Bay anticline and Sc.- Scarborough Dome.

and discontinuity with the Ravenscar Group completely absent over large areas. Recent geophysical work (Bott et al. 1978) postulates the existence of a granite at depth in this area, which was thought to have acted as a rigid block, severely restricting sediment deposition. This lateral thickness variation was noted by Fox-Strangways (1892) who introduced the term Yorkshire Basin to these sediments.

In the northern and eastern basin margins exposure occurs as crumbling cliff sections from near Redcar to the south of Scarborough. Inland the western limits of the Middle Jurassic basin is delimited by a sudden topographic feature overlooking the Vale of York. This feature extends from the Cleveland Hills in the north, through the Hambleton Hills to the Howardian Hills in the south (Fig. 1.2). The coastal cliff sections provide the best exposures, although in many cases they are either inaccessible or overgrown. Abandoned alum quarries cut into underlying Liassic strata enhance these natural exposures. Inland, deep fluvial incision following post glacial isostatic uplift gives a number of small exposures but much of the potential outcrop is hidden by soliflucted material. The western escarpment shows a variable degree of outcrop. The Cleveland Hills afford good natural sections but in the Hambleton and Howardian Hills forestation and a thicker boulder clay mantle restrict exposures to former building stone quarries, many of which have now been infilled. There is a strong bias towards coarser-grained sediment outcrop in the inland sections which gives an essentially two-dimensional study of much of the finer-grained deposits from the coastal ribbon exposure pattern.

1.2. History of Previous Research

One of the earliest workers in the region was Lister (1671) who made extensive fossil collections, but earnest research did not start until early in the nineteenth century. The famous British geologist William Smith travelled through Yorkshire in 1813 and paid particular attention to the Jurassic coals being worked in the area at this time (see Hemingway and Owen, 1975). In 1821 he published geological maps of Yorkshire and was influential in formulating early nomenclature of the strata. Many of the early workers during this period concentrated on attempting correlations with the better known Jurassic rocks of southern England. Young and Bird (1822), followed by Sedgwick (1826), provided systematic descriptions of the good coastal exposures. Phillips (1829) writing on what is now known as the Scarborough Formation, was the first person to describe marine rocks from the area. He correlated them with the Great or Middle Oolite of Bath. Murchison (1832) reported on the presence of fossil plants in growth position, which was the start of major interest into the palaeobotany of these rocks. Phillips (1858) continued to correlate erronously with southern England until Wright (1860) allied the Scarborough beds to the Inferior Oolite. Although Simpson was mostly interested in the Lias he wrote a useful guide to the coastal geology in 1868. Important information on the only oolitic limestones in the region was provided by Hudleston (1874). He traced this marine horizon from Malton into the Yorkshire Moors and named a younger carbonate series the Scarborough Limestones (now part of the Scarborough Formation).

A series of major advances were made by Geological Survey geologists at the end of the last century, culminating in a number of sheet memoirs (Fox-Strangways, 1880, 1892, Fox-Strangways and Barrow, 1885, Fox-Strangways, Reid and Barrow, 1885, Fox-Strangways, Cameron and Barrow, 1886, and Barrow, 1888). The maps these officers produced have stood without revision until this day. Fox-Strangways was the senior geologist and he formally introduced the term 'Estuarine Series' envisaging a similar depositional environment to laterally equivalent sediments in Lincolnshire. Kendal and Wroot (1924) however likened these deposits to those of the Coal Measures and suggested that they sourced from a land mass north of Scotland, including Scandinavia. They also suggested that large parts of the Pennines were covered with Jurassic sediments. Black (1928, 1929, 1934a and 1934b in Wilson et al.) strongly argued for a deltaic interpretation of these sediments, which was adopted by Arkell (1933) in his major volume on the British Jurassic system. Hemingway (1949) finally revised the terminology of Fox-Strangways subdividing the non-marine rocks into the Lower Middle and Upper Deltaic Series (see Fig. 1.4). Collecting and cataloguing of fossils from the marine horizons continued unabated throughout this period and Buckman (1909-1930) published a series of works on the ammonite faunas present. Richardson (1812) also published on the marine horizons, subdividing the Scarborough Beds into three lithological units.

Throughout the first half of this century Rastall maintained an interest in the lowest marine unit in the Middle Jurassic, known as the Dogger. Initially he worked on his own (Rastall, 1905) but later produced an extended series of papers with Hemingway (1939, 1940, 1941, 1943, 1949). The later papers discussed important contributions on this horizon by Tonks (1923), McMillan (1932) and Black (1934).

Rastall was also concerned with the petrography of the Middle Jurassic sediments (1932) and his work was followed by a major series of publications by Smithson (1934, 1937, 1941, 1942, 1943, 1954). His main concern was with the varied heavy mineral suites present, and he demonstrated how their distribution reflected the palaeogeography of the sediments. Around this time Harris (1942-1953, 1953) started his detailed analysis of the palaeobotany of the region which culminated in important systematic publications (1961-69). He was instrumental in demonstrating differences in flora between individual horizons in the Middle Jurassic, continuing the early work of Thomas (1915). Muir (1964) and Hill (1974) contributed to research into the palaeobotany of what was by then considered to be the classic area of Jurassic flora. Hill (1976) and Spicer and Hill (1979) have continued to publish the results of ongoing research.

Bate (1959) discussed the Yons Nab Beds and went on to produce work based on the ostracod faunas of the marine horizons in the Ravenscar Group, providing important correlations with stratigraphically equivalent rocks to the south (1964,1965 and 1967). His palaeogeographic work suffered from his habit of considering whole units rather than sedimentologically separate subdivisions. Farrow (1966) published a detailed study of palaeobathymetry based on trace fossils from the Scarborough Beds. The lateral extension of the Middle Jurassic into the North Sea was proved by Dingle (1971) based on an offshore geological survey.

More modern work by Knox (1969, 1970 and 1973) on the Lower Deltaic Series and the Eller Beck Bed was followed by a joint paper

(Hemingway and Knox, 1973) revising the nomenclature of the 'Deltaics' to accord with modern stratigraphic practice (see Fig. 1.4). They applied the term Ravenscar Group to the series and Hemingway (1974) provides a concise and useful summary of these sediments. Recent sedimentological work at Leeds University has concentrated on the upper part of the Ravenscar Group (Nami, 1976). Nami and Leeder (1978) and Leeder and Nami (1979) have written publications following this research. Parsons (1977) has improved the stratigraphic knowledge of the sediments, applying a humphriesianum age to parts of the Scarborough Formation, based on ammonite faunas. Kent (1980) and Bott et al. (1978) have added to the understanding of the structural evolution of the area and recent work by Hancock and Fisher (in press) has demonstrated the presence of marine microfauna in parts of the essentially non-marine sediments.

1.3. Lithostratigraphy and Nomenclature

Fox-Strangways (1892) produced the first complete and useful nomenclature of these sediments. Following later studies Hemingway (1949) renamed large parts of the Middle Jurassic and this was subsequently modified by Sylvester-Bradley (1949). A new set of terms were introduced by Hemingway and Knox (1973) and the correlation between these different terminologies is shown in Fig. 1.4. Fig. 1.5 gives a complete breakdown on the nomenclature used in this thesis and is taken from Hemingway and Knox's work. It can be seen from this figure that the Middle Jurassic consists of intercalated marine and non-marine strata. The lowest horizon, the Dogger Formation, is not considered to be part of the Ravenscar Group. The Saltwick Formation, the Eller Beck Formation and the Scarborough Formation can be traced

FIG. 1.4

	Fox Strangways 1892	Hemingway 1949	Hemingway-Knox 1973
U. JURASSIC	CORNBRASH		
MIDDLE JURASSIC	U. ESTUARINE SER.	U. DELTAIC SER.	SCALBY FN.
	GREY LST. SER.	GREY LST. SER.	SCARBOROUGH FN.
	M. ESTUARINE SER.	MIDDLE DELTAIC SERIES	CLOUGHTON FORMATION
	MILLEPORE SER.		
	MIDDLE ESTUARINE SERIES	ELLER BECK BED	ELLER BECK BED
		L. DELTAIC SER.	SALTWICK FN.
	DOGGER	DOGGER	DOGGER FN.
L. JURASSIC	LIAS		

FIG. 1.5

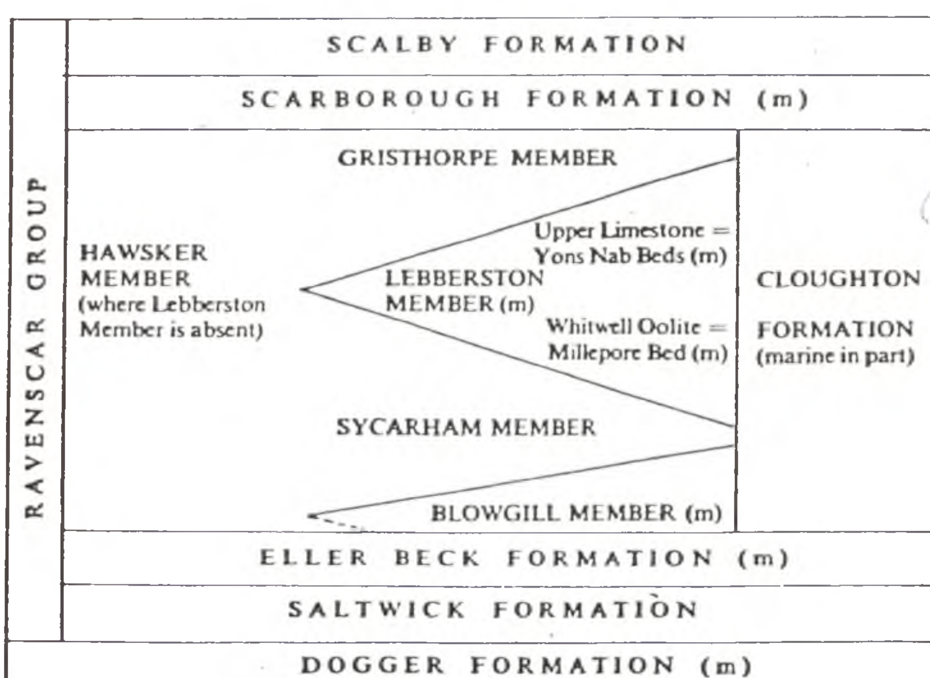


Fig. 1.4 Correlation of the nomenclature applied to the Middle Jurassic of Yorkshire (from Hemingway and Knox, 1973)

Fig. 1.5 Detailed nomenclature of the Ravenscar Group (from Hemingway and Knox, 1973). (m) indicates marine strata.

as relatively homogeneous units across the whole width of the outcrop. Complexities arise when considering the nomenclature of the mixed marine and non-marine Cloughton Formation. The basal (Blowgill) Member of this Formation is marine, but is only developed on the extreme south-west of the basin and its exact relationships with the other horizons are obscure (Hemingway and Knox, op. cit.). North of Ravenscar the Cloughton Formation is entirely non-marine and the term Hawsker Member is applied to the sediments in this region. To the south the Cloughton Formation includes a marine unit, the Lebberston Member, which in turn is subdivided into two parts (Fig. 1.5).Where the Lebberston Member is present two non-marine units are found as part of the Cloughton Formation, an older Sycarham Member, and a younger Gristhorpe Member.

This thesis concentrates on sediments from the Dogger Formation through to the basal parts of the Scarborough Formation.

1.4. Biostratigraphy

Only the Dogger Formation and the Scarborough Formation contain ammonites and the other horizons are devoid of zone fossils. The Dogger Formation is Aalenian in age (McMillan, 1932) and recent work by Parsons (1977) has shown that the Scarborough Formation is mainly of Bajocian (humphriesianum zone) age. Bate (1964, 1965 and 1967) correlated the marine horizons in the Ravenscar Group with laterally equivalent sediments from Lincolnshire and Humberside based on ostracod faunas. The Lebberston Member was correlated with the Middle and Upper Lincolnshire Limestone and Bate suggested that they were of discites age. Ashton (1980) found that the Lincolnshire Limestone spans two ammonite zones, laeviuscula and discites. Applying this work with Bates correlation gives results tabulated in Fig. 1.6.

Fig. 1.6 Biostratigraphy of the Ravenscar Group and correlation with laterally equivalent sediments in Lincolnshire and Humberside. The dates (156, 165 and 171 million years) are from van Hinte (1976) and the biostratigraphic column is after Hallam (1975). The age of the Scalby Formation is unknown (see Leeder and Nami, 1979). Discussion in text.

FIG. 1.6

YORKSHIRE	Stage	Substage	Zone	HUMBERSIDE	LINCOLNSHIRE
CORNBRASH	CALLOVIAN			CORNBRASH	
			macrocephalus		
SCALBY FN.			156		
	BATHONIAN	U.	discus		L. CORNBRASH
			aspidoides	BLISWORTH CLAY	
			retrocostatum		GT. OOLITE LST.
		M.	morrisi	UPPER ESTUARINE SERIES	
			subcontractus		
?		L.	progracilis	?	
			zigzag		
			165		
	BAJOCIAN	U.	parkinsoni		
			gargantiana		
			subfurcatum		
SCARBOROUGH FN.		L.	humphriesianum		
			sauzei		
LEBBERSTON MBR.			laeviuscula	CAVE OOLITE	M.&U. LINCOLNSHIRE
BLOWGILL MBR.-ELLER BECK FN.			discites	HYDRAULIC LST.	L. LST. FN.
			171	LOWER ESTUARINE SERIES	(GRANTHAM FN.)
	AALENIAN		concavum		
DOGGER FN.			murchisonae	DOGGER FN.?	NORTHAMPTON SAND FN.
			opalinum		

The Dogger Formation spans the murchisonae and opalinum zones of the Aalenian and the Saltwick Formation may be partly Aalenian as well. The Blowgill Member and the Eller Beck Formation bear resemblance to the Lower Lincolnshire Limestone on ostracod faunas, and are probably of discites age. The Lebberston Member would appear to be of laeviuscula age using the arguments stated above.

All the sediments analysed in this thesis are therefore Aalenian to Lower Bajocian in age and appear to span only a relatively short time range. Fig. 1.6 underlines the problem of the dating of the Scalby Formation discussed by Leeder and Nami (1979). The dates given in Fig. 1.6 are taken from van Hinte (1976) and the biostratigraphic column is after Hallam (1975).

1.5. Aims of present study

This study concentrates on the lower and middle sections (Bajocian) of the Ravenscar Group up to and including the basal parts of the Scarborough Formation. For the sake of completeness the youngest section of the Dogger Formation was also analysed. Fieldwork was used to elucidate depositional environments and palaeogeography while the petrography and diagenesis was studied from laboratory work. The fieldwork consisted of the careful measurement of well exposed stratigraphically delimited sections. A number of facies and facies associations were defined according to the total field aspect and pattern of the sediments themselves. The lithological, structural and organic characteristics were carefully noted to this end. Over 1400 palaeocurrent readings were taken to be used in the palaeogeographic analysis. Chapters 2 and 3 investigate the sedimentology of the marine units, including the Dogger Formation, and here facies and facies associations closely correspond to individual stratigraphic horizons. Chapter 4 considers the non-marine deposits as a whole, firstly discussing individual facies, and secondly in a stratigraphic context to show facies distributions. Chapter 5 draws all the previous information together as a facies synthesis to include palaeogeographic considerations.

Chapter 6 includes petrographic and diagenetic studies of the sediments based on an integrated laboratory analysis. This included a grain size study and a petrographic modal analysis of the sandstones. Their diagenetic history was studied using S.E.M. and X.R.D. techniques to include a detailed investigation of the clay mineral suites present. Fresh samples were available from the I.G.S. borehole at Brown Moor (Fig. 1.1). The one carbonate bearing horizon was microprobed and cathodeluminesced to study its diagenetic sequence of events. Both carbonate and siliciclastic diagenetic histories are discussed together in the conclusions of this chapter. Chapter 7 draws all the information together in conclusion and includes a brief regional synthesis and a discussion on provenance. The laboratory techniques used are outlined in the Appendices. A key to all the logs and a summary of the facies are included as inserts at the back of this thesis.

1.6. An explanation of the facies breakdown used in this thesis

Non-marine facies comprise 80% of the measured sections and present few problems of organisation and definition having been grouped together as associations of Facies 4 and 5. Although they share a common transgressional-regressional origin the thin marine horizons are quite distinct in detail. As such they are best considered as individual lithostratigraphic units and the following facies approach is adopted. All the laterally extensive clastic marine coarsening-upwards facies of coastal origin are grouped together in Chapter 2 as Facies 1a, 1b and 1c each representing different overall environments of deposition. Two separate marine sequences occur within one lithostratigraphic horizon, the Lebberston Member, which is the subject of Chapter 3. The carbonate bearing parts of the member are grouped together as Facies Association 2, whilst the dominantly marine clastic parts of the member are grouped together as Facies Association 3. From palaeoenvironmental considerations these two associations are quite separate.

This approach is somewhat unorthodox in that it closely follows lithostratigraphic units rather than pure facies analysis. The author believes that the above breakdown allows a clearer understanding of the sequences and enables the reader to follow the history of sedimentation and depositional palaeoenvironments discussed in Chapter 5.

CHAPTER 2

FACIES ANALYSIS OF COARSENING-UPWARDS MARINE UNITS

CHAPTER 2

FACIES ANALYSIS OF COARSENING-UPWARDS MARINE UNITS

2.1. Introduction

Three marine coarsening-upwards sequences occur in the section of the Ravenscar Group studied. They differ sufficiently in detail for them to be treated separately as Facies 1a, 1b and 1c. The palaeogeographies of these three facies and their relationships with other sediments are discussed in Chapter 5 on the environmental evolution of the area. A general key to all the logs is included as an insert in the back of this thesis.

2.2. Facies 1a. Coarsening-upwards, fining upwards unit The lower Scarborough Formation sandstone (here named the Blea Wyke Member)

This unit directly overlies non-marine Gristhorpe Member sediments and is found at the base of the thickest marine formation in the Ravenscar Group, (The Scarborough Formation, 32m. thick at Ravenscar, Fox-Strangways, 1892). Fox-Strangways recorded marine fossils from this unit at Cloughton Wyke (Fig. 2.1) but included it in the underlying 'deltaic' beds. Bate (1965) did not include it within his major ostracod work on the Scarborough Formation and also considered it part of the Middle Deltaic Series. Farrow (1966) recognised this basal sandstone at Ravenscar (Fig. 2.1) and recorded the trace fossil Arenicolites statheri (Diplocraterion), suggesting an intertidal origin. This was simply a re-iteration of Bather (1925).

Farrow's failure to recognise the almost identical sequence at Cloughton Wyke led him, and others (Hemingway, 1974) to suggest a steeply shelving gulf to the south.

Five complete logs were taken from the coastal exposures and one good inland section was also available. Inland exposure is poor however, and exact correlation difficult, but the geographical extent of this unit is limited due to primary deposition rather than subsequent erosion by overlying Scarborough Formation coarse clastic sediments (the Crinoid Grit and Brandsby roadstone Members). This erosion occurs over large areas of the Yorkshire Basin to the north and south-west.

2.2a. Description

The unit is thickest at Cloughton Wyke and Blea Wyke (approaching 7m, Fig. 2.2) and it thins northwards, westwards and southwards. These two exposures coarsen-upwards and then fine upwards in two parts, which suggests that subsidence must have occurred during deposition, resulting in further transgression. They contain a fully marine fauna, with abundant '_Ostrea_' and _Pleuromya_ as well as _Gryphea_ and _Astarte_ and numerous unrecognisable broken shells. '_Ostrea_' occurs as a lag deposit (dominantly concave-up) at Bloody Beck (Fig. 2.1), Blea Wyke and Cloughton Wyke, forming in shallow lenticular scour zones. Trace fossils are well preserved, occurring especially at the top of the unit, and include _Diplocraterion_, _Laevicyclus_, _Asterosoma_, _Thalassinoides_, straight horizontal grazing trails with spriete and

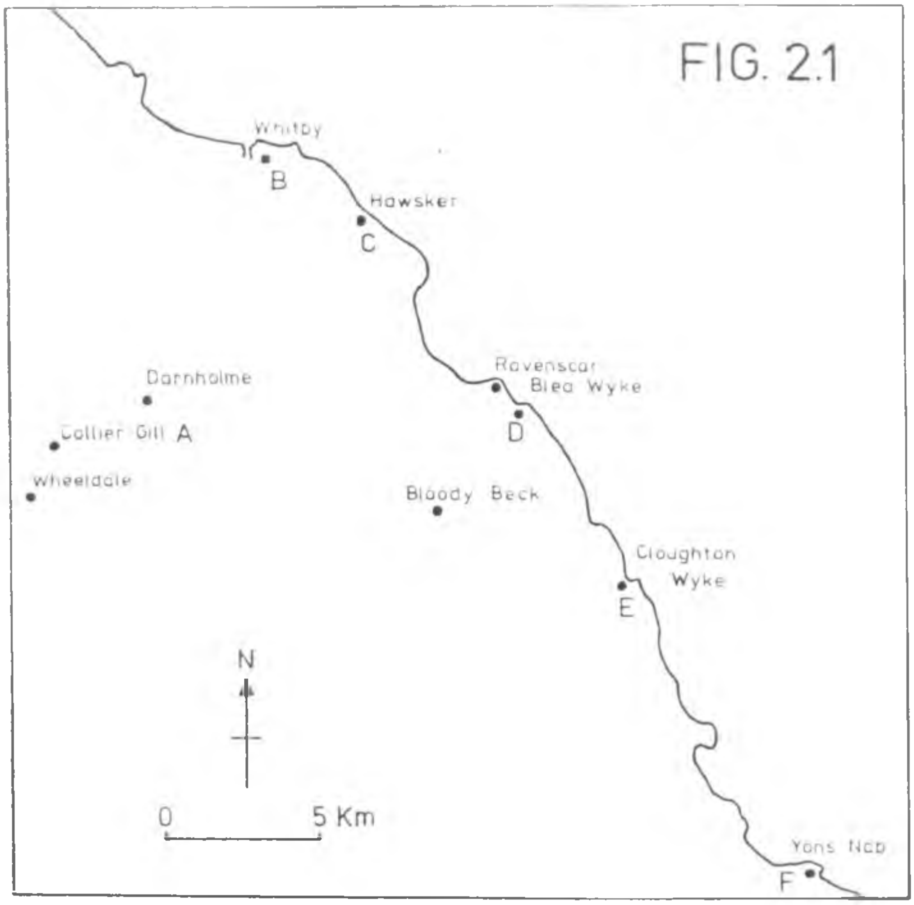
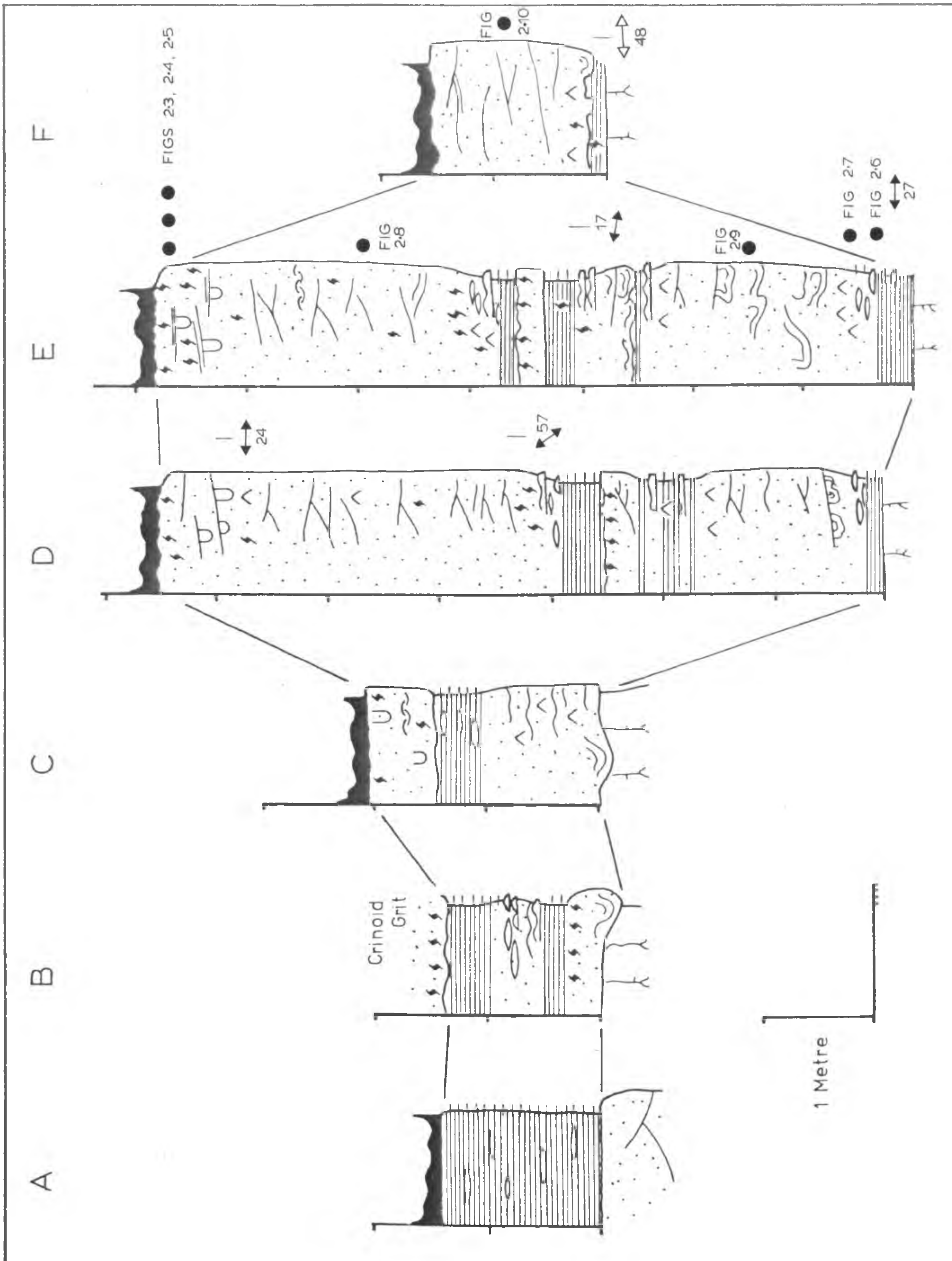


Fig. 2.1 Location of exposures of Facies 1a mentioned in the text.

Fig. 2.2 (facing page). Representative logs of Facies 1a. Locations of logs A - F are shown in Fig. 2.1.

FIG. 2.2


A
B
C
D
E
F
Crinoid Grit
1 Metre
FIGS 2·3, 2·4, 2·5
FIG 2·10
48
FIG 2·8
17
FIG 2·9
FIG 2·7
FIG 2·6
27
24
57

centred feeding trails of (?) burrowing bivalves (Fig. 2.3). Diplocraterion is abundant at the top of the unit and shows both protrusive and retrusive spriete (Fig. 2.4). Repeated periods of deposition, bioturbation and then erosion at this level can be seen (Fig. 2.5).

At Cloughton Wyke and Blea Wyke coarsening upwards is by the exclusion of silt and shale laminae (Fig. 2.6) and by the increase in bedform scale, whilst the fining upwards is by a reverse of this process in the middle of the unit, and by a lowering of scale and modification of bedform type at the top. The coarsest sand occurs within wave ripple sets at the base of the unit and is medium-grained. At the top of the unit the sand is very fine-grained (3 phi) and well sorted. Petrographically it is a slightly micaceous quartz arenite with minor amounts of glauconite.

The entire sequence in the two main exposures appears to show wave generated cross-stratification. Small scale wave ripples give way vertically to larger scale structures (Fig. 2.7) similar to the truncated wave ripple laminae of Campbell (1966) and the bulk of the upper part of the unit consists of this laminae type (Fig. 2.8). The maximum amplitude seen is 25cm. and wavelengths were not measurable due to later erosion. These sedimentary structures are similar to those described by Levell (1980) and De Raaf et al. (1977). They demonstrate evidence of lateral migration over adjacent crestlines and locally foresets all dip in one direction. The erosion surfaces which give the form discordant nature are usually low amplitude ones,

Fig. 2.3 Bioturbated bedding plane surface showing assorted grazing trails of sediment surface feeding organisms. Note the centred trails (arrowed) formed by (?) burrowing bivalves. Facies 1a, Cloughton Wyke.

Fig. 2.4 Top of Facies 1a at Cloughton Wyke. Note the upwards increase in bioturbation and the Diplocraterion burrow showing both protrusive and retrusive spriete. This photograph closely resembles that shown by Evans (1975, p. 16) from recent sediments in the Wash.

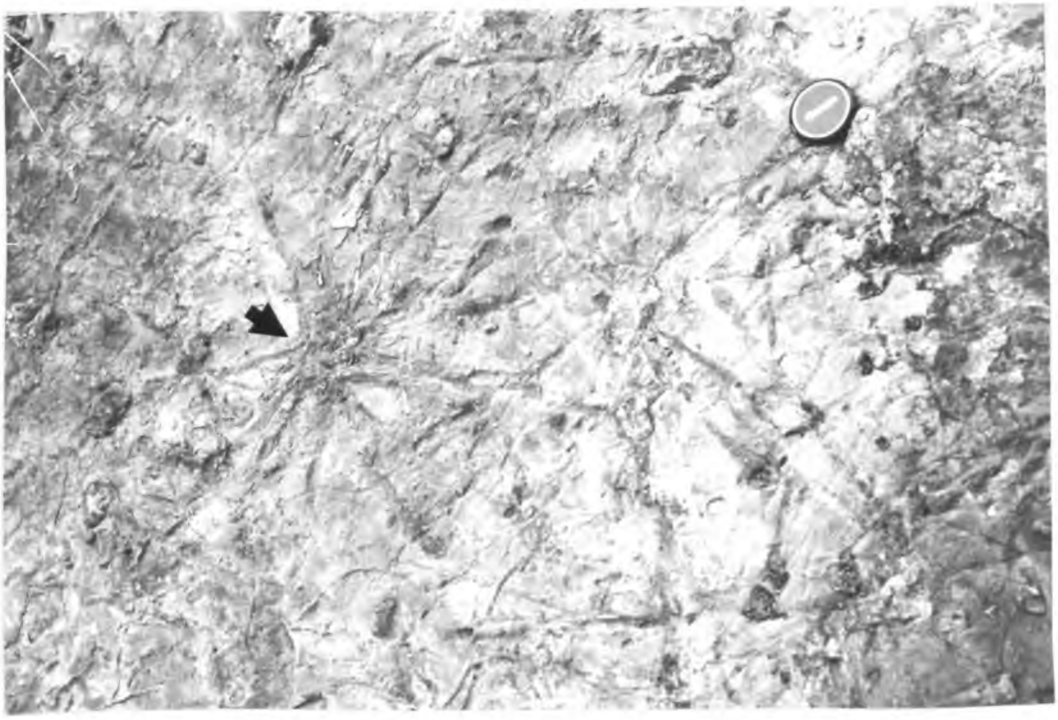
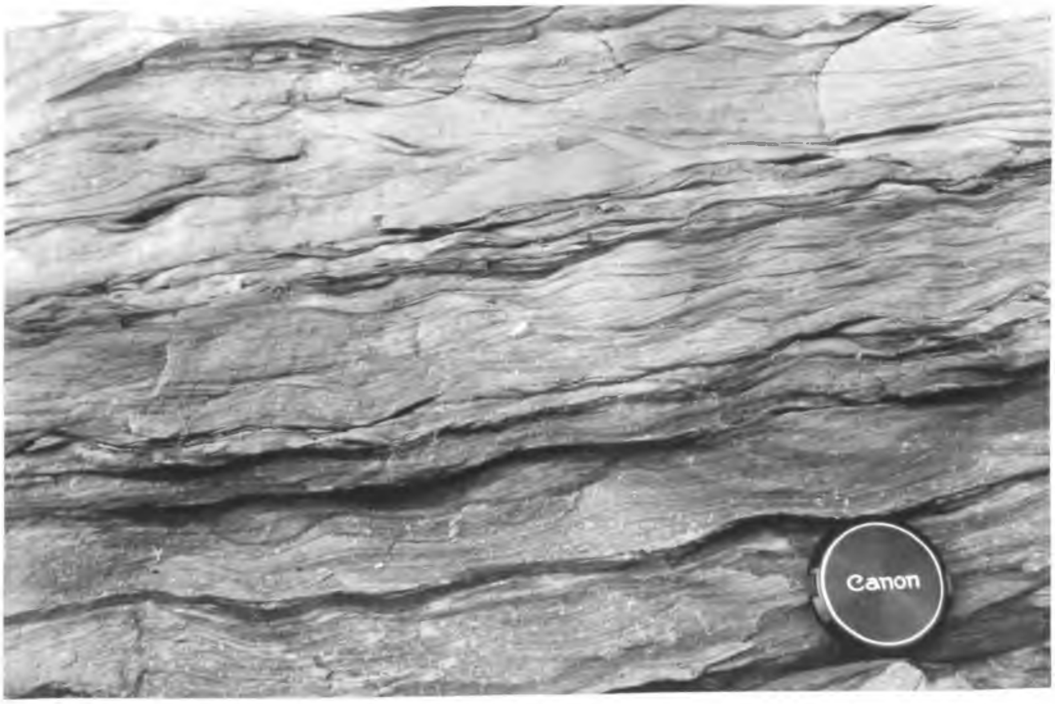


Fig. 2.5 Top of Facies la at Cloughton Wyke, showing the upwards decrease in scale of sedimentary structures and increase in bioturbation. Note the repeated periods of deposition, bioturbation and subsequent erosion at the level of the hammer.

Fig. 2.6 Basal coarsening upwards sequence at Cloughton Wyke showing a gradation from striped silty shales through lenticular bedding to larger scale structures. The upwards coarsening is by a decrease in silt/shale laminae.

Fig. 2.7 Wave generated structures from the lower part of Facies 1a at Cloughton Wyke. The lower part of the fig. shows climbing ripples, in the middle bundlewise accretion of laminae occurs and at the top larger scale cross-sets are present. Deposition rates were probably rapid and the marked vertical increase in the scale of the cross-laminations should be noted.

Fig. 2.8 Large wave/current produced cross-stratification from Facies 1a at Cloughton Wyke, in the form of complex trough, undulatory and low angle sets. Note the low and high angle scour surfaces and minor pervasive bioturbation. These structures are very similar to the truncated wave ripple laminae of Campbell (1966).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but rarely steeper sided scour surfaces occur. Undulating cross-stratification also occurs, which De Raaf et al. compared with hummocky cross-stratification (Harms et al. 1975).

Near the top of these two sequences planarflat laminations and small scale current ripples can be seen where not destroyed by subsequent bioturbation. The lenticular bedding at the base and middle of the unit gives bipolar palaeocurrent roses (measurements were taken from foreset dip directions). Interference ripples and Runzelmarken (Wrinkle marks, Reineck 1969) occur within the lower fining upward part of the unit, above a sequence containing major soft sediment deformation (Fig. 2.2). Large scale unorientated convolute laminae of multiple slump origin occur, in some cases with scoured tops followed by further failure. Water escape structures are present in the middle of the larger convolutions (Fig. 2.9) and the sausage shaped 'pillow' bodies can be traced for over a hundred metres at Cloughton Wyke. Similar structures are seen 7km away at Blea Wyke.

North of Blea Wyke the unit thins to 2m at Hawsker and less than one metre at Whitby where it is represented by 30cm of convoluted, bioturbated very fine-grained sandstone overlain by streaked and lenticular siltstones (Fig. 2.2). This thinning is a primary sedimentary feature. Inland exposures show thin streaked mudstones and siltstones with thin lenticular wave rippled sandstone interbeds, and they occur at the same stratigraphic horizon at Darnholme, Collier Gill and Wheeldale (Fig. 2.1).

The southernmost exposure at Yons Nab (Figs. 2.1, 2.2) is again much thinner than at Cloughton Wyke, and it shows a different combination of sedimentary and biogenic structures (Fig. 2.10). The sequence coarsens upwards from shale to rapidly alternating laminae (0.5 - 2mm thick) of dark organic rich siltstones and very fine-grained sandstone and finally to sandstone. Wave generated symmetrical ripples give way vertically to wedge, minor trough, planar and hummocky cross-stratification and the major cross bedding gives a bipolar palaeocurrent rose. None of the bioturbation seen in the sections to the north is found here, and one shallow scour surface is overlain by a mudflake lag.

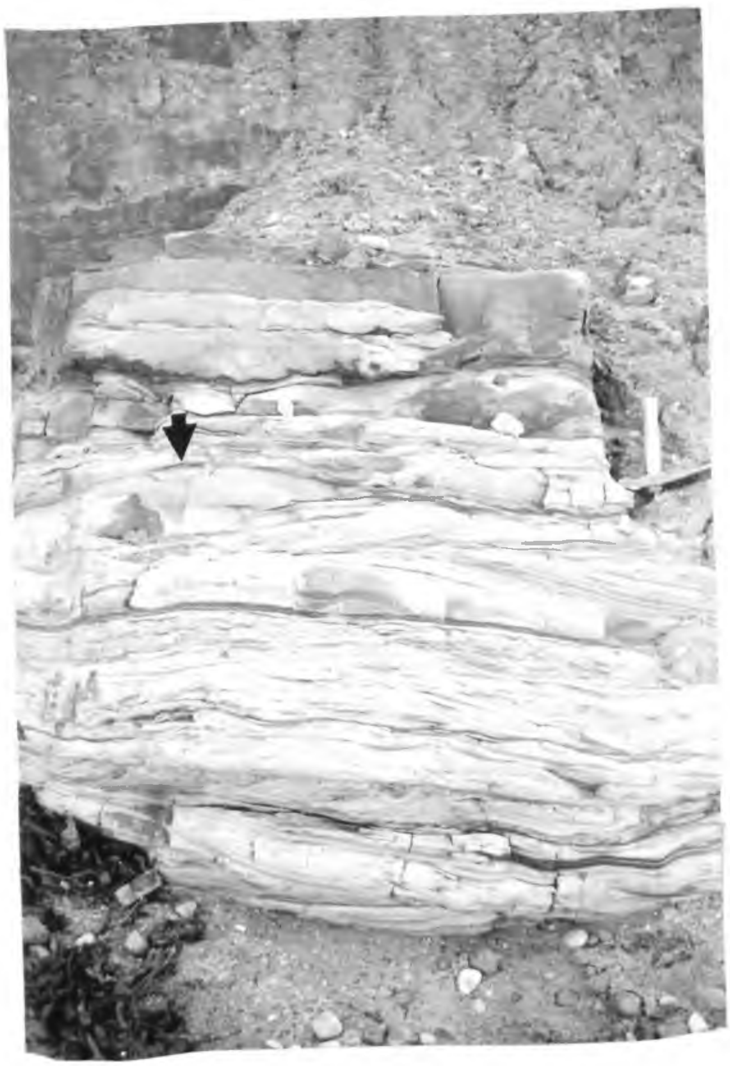
This whole unit is overlain by a mixed series of marine sediments, but immediately by dark shales. In the north of the Yorkshire Basin an erosive based sandstone, the Crinoid Grit, occurs directly above the Gristhorpe Member. The Crinoid Grit is also found at Cloughton Wyke, 3m above the lower Scarborough Formation coarsening-upward fining-upward unit.

2.2b. Interpretation and Discussion

The palaeocurrents taken from this unit show bipolar current directions, at Yons Nab in medium scale planar and minor trough cross stratification and elsewhere from individual wave generated lenticles in the coarsening-upward part of the unit. The northern sections appear to be dominated by wave generated structures and major current produced cross-stratification (avalanche and reactivation surfaces) are absent. De Raaf et al. (op. cit.) and Levell (op. cit.)

Fig. 2.9 Large flat-topped convolution at Cloughton Wyke. Parts of the sediment have been completely liquified and show no internal structures. Note the water escape structures in the centre of the largest 'pillow' under the hammer head.

Fig. 2.10 Facies 1a coarsening upwards unit at Yons Nab. Wave generated structures are well represented, including hummocky cross-stratification (arrowed).



infer a combined current/wave formation for structures of similar morphology and the evidence of lateral migration, locally dominant unidirectional foresets and steeper scour surfaces may indicate a wave dominated combined wave/current formation for these unusual structures (see Harms, 1969). Clifton (1976) showed that medium scale cross bedding is very unlikely to develop in very fine sand as a result of oscillatory currents alone. The bedforms present in this sandstone resemble those demonstrated by Davidson-Arnott and Greenwood (1976) from their bar crest facies, taken from box cores. These were formed by spilling rather than breaking waves where shoreward wave asymmetry and local bedcurrent velocities produce lunate megaripples, the result of unidirectional currents. These wave generated currents (return flow and longshore types) introduce considerable complexity landward of the breaker zone in modern beaches (Clifton 1976), and this explains the unusual sedimentary structures seen in the northern sections (Fig. 2.8).

The hummocky cross-stratification seen at Yons Nab is similar to that of Hamblin and Walker (1979) which they interpreted as having formed by the reworking of storm dominated density currents by the oscillating motion of storm waves, below fair weather wave base and above storm wave base. These structures are similar to those at Cloughton Wyke but the bipolar palaeocurrent readings may result from mixed wave and tidal influence. The lack of bioturbation and the prominent interlaminations of coarser and finer sediment appear to suggest subtidal deposition.

Towards the top of the unit at Cloughton Wyke and Blea Wyke bedforms decrease in scale, indicating waning energy conditions, and include evidence of swash and current ripple marks (small scale troughs). This energy loss could result from the shallowing of the environment. The presence of Runzelmarken and interference ripples in the middle of the unit also suggests shallow water. Wrinkle marks form by the action of strong wind on very thin layers of water over partly cohesive sediment, and indicate intermittent emergence of the sediment surface (Reineck, 1969).

The upper and inland fining-upwards parts of the sequence are similar to some modern tidal flat sediments. Evans (1965, 1975) describes sandy tidal flats from the Wash which show in an ascending (prograding) sequence, offshore, lower sand flat, lower mudflat, inner sand flat and Arenicola sandflat, higher mudflats and salt marsh. McCave and Geiser(1979) showed that the lower mudflats were rare and that the normal sequence was of overall fining upward style. In the Wash the lower sand flats are dominated by current produced megaripples (McCave and Geiser, op. cit.), and this is usually the case in modern sandy tidal flat sequences (Dalrymple et al. 1978). However wave produced structures do occur in these environments (van Straaten, 1959) and the sandy tidal flat area of Cholla Bay, Mexico, appears to be dominated by wave action (McKee, 1957). The upper parts of the Cloughton Wyke and Blea Wyke sections resemble the upper and Arenicola sand flats of Evans (1975), and are on a similar scale. McKenzie (1975) reports Diplocraterion from intertidal sediments in the Cretaceous of Colorado, pointing out the similarity with the crustacean

Corophium from modern upper tidal flats in Germany, and Goldring (1963) suggested a possible intertidal origin for _Diplocraterion yoyo_. _Arenicola_ does not produce spriete but it is possible that _Diplocraterion_ filled _Arenicola's_ niche in ancient sediments. Overall the very varied bioturbation seen in Figure 2.5 can be compared with the highly active infauna found in beach related tidal flats off Sapelo Island, Georgia (Howard & Dorjes 1972).

The lenticular bedded and streaked siltstones at Whitby and Collier Gill may well represent upper mudflat sediments behind the main intertidal zone. No evidence of roots associated with salt marsh colonisation are found. Soft sediment deformation of the type seen at Cloughton Wyke is common in intertidal sediments (Klein, 1977). Several ideas have been put forward for their mode of formation. Neither wave impact shock (Dalrymple 1979) nor current drag (Allen and Banks 1972) could produce failure on such a scale. Klein (1975) and Wunderlich (1967) related their production to differential loading in water sodden sediments in tidal flats, resulting in liquifaction. The large scale nature of the deformation may indicate liquifaction under seismic shock, as suggested by Johnson (1977) for late Precambrian shallow marine deformations. This would explain why the convolutions are found only in the lower part of the unit and not in the upper part.

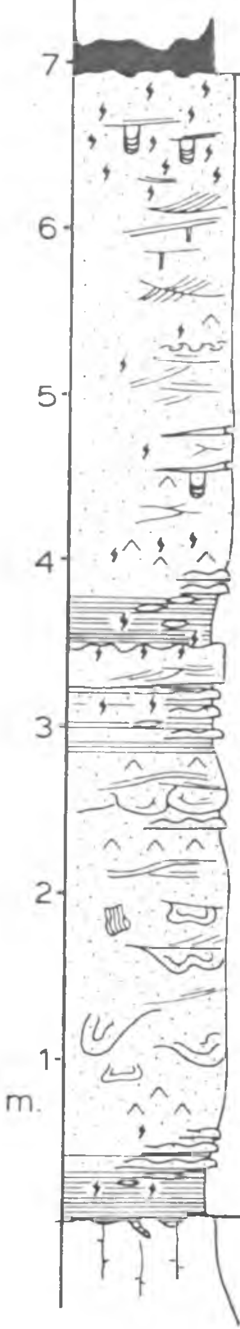
No channels are seen in this unit although they play a major part in tidal flat drainage. They rework large areas of muddy intertidal flats (Reineck, 1958) but appear to be more stable in sandy tidal flats (Evans, 1975). Only less than five percent of the unit is exposed and this may explain the lack of observed channels. An alternative explanation is that they were poorly developed, as on the intertidal sand bars in the Bay of Fundy (Knight and Dalrymple,1975) or off Sapelo Island (Howard and Dorjes,1972). The mudflake conglomerate seen at Yons Nab may have originated from channel erosion.

Overall this unit appears to represent a regressive intertidal and subtidal sequence, with subsidence occurring during deposition giving the double profiles at Cloughton Wyke and Blea Wyke. The coastline was probably orientated NNE-SSW with subtidal conditions to the east of a fairly stationary intertidal zone, seaward of higher mudflat sequences on a low abandoned deltaic area. There is no evidence from any exposures for beach sediments within or adjacent to this unit.

An environmental interpretation for the Cloughton Wyke section is given in Fig. 2.11. If this interpretation is valid one can apply Kleins (1971) model for determining palaeotidal range. Mean low water would correspond to the top of the coarsening-upward unit and mean high water with the top of the fining-upward sequence. Applying this to Fig. 2.11 gives an approximate value of 3m, which compares with the Wash (5m) and North Sea intertidal flats (2.4 - 4m).

This is certainly not a typical intertidal sequence as it is dominated by wave activity. The bedforms suggest a large fetch and the dominance of rough (storm) weather conditions, especially in the upper part of the unit. Deposition must have been rapid and this environment was abandoned as suddenly as it was produced. It is quite unique within the Ravenscar Group.

FIG. 2.11



DESCRIPTION	INTERPRETATION
Dark fossiliferous calcareous shales, marine fauna.	Sudden transgression to deeper (suspended sediment) marine environment.
Wave dominated bedforms giving way upwards to low angle and current ripples Increase in bioturbation with Diplocraterion prominent Thin shell debris lags.	Regressive tidal sand flat, wave generated bedforms give way to swash and runoff forms Increase in bioturbation as wave energy was moderated on gently shelving, prograding sand flat
F.U.-C.U. sequence with thin sharp based sandstones, with bioturbated tops	Subsidence and transgression followed by regression Subtidal environment with storm derived (?) coarser units
Major multiple convolutions in large wave generated bedforms Runzelmarken and interference ripples at the top	Liquifaction of sediment in a wave dominated shallow marine-intertidal area
Dark shales coarsening up to lenticular bedding and larger scale wave generated forms.	Progradational sequence from offshore muds to shallower wave influenced zone, following sudden transgression.
Convolute laminated root colonised iron rich siltstones coarsening down to sandstone.	Non-marine fining upward channel sequence. Root colonisation marks abandonment.

Fig. 2.11 Description and interpretation of Facies 1a at Cloughton Wyke (Fig. 2.1).

2.3. Facies 1b. Coarsening-upwards shale to sheet sandstone body

The Eller Beck Formation

This marine unit has been the subject of fairly recent, mainly petrographic, work by Knox (1969, 1970, 1973). The present account is an attempt to elucidate a depositional history and environment for the Eller Beck Formation, an approach lacking in Knox's research. Five widely separated logs are presented in Fig. 2.13, giving a general coverage of the whole unit, including one of a previously unknown locality (E). This locality has an important bearing on palaeogeographical reconstructions, being the most southerly known outcrop.

2.3a. Description

Knox divided the Eller Beck Formation into three units, a series of basal ironstones, overlain by shales with siltstones, coarsening-upwards into sandstones. The sandstone unit on the coast has silty intercalations in the lower part, affording a division into lower and upper sandstone units. This twofold division does not continue far inland. The overall coarsening-upwards nature occurs throughout the basin; the Eller Beck Formation is a laterally continuous unit of sheet form.

The basal ironstones are pervasive and were thoroughly investigated by Knox. At Cornelian Bay (Fig. 2.13E) a typical ironstone overlies non-marine beds. It contains a variety of bioturbation forms including Thalassinoides, Monocraterion, Diplocraterion and Rhizocorallium, and a fully marine shell fauna.

The shales are organic rich, striped and silty, becoming coarser

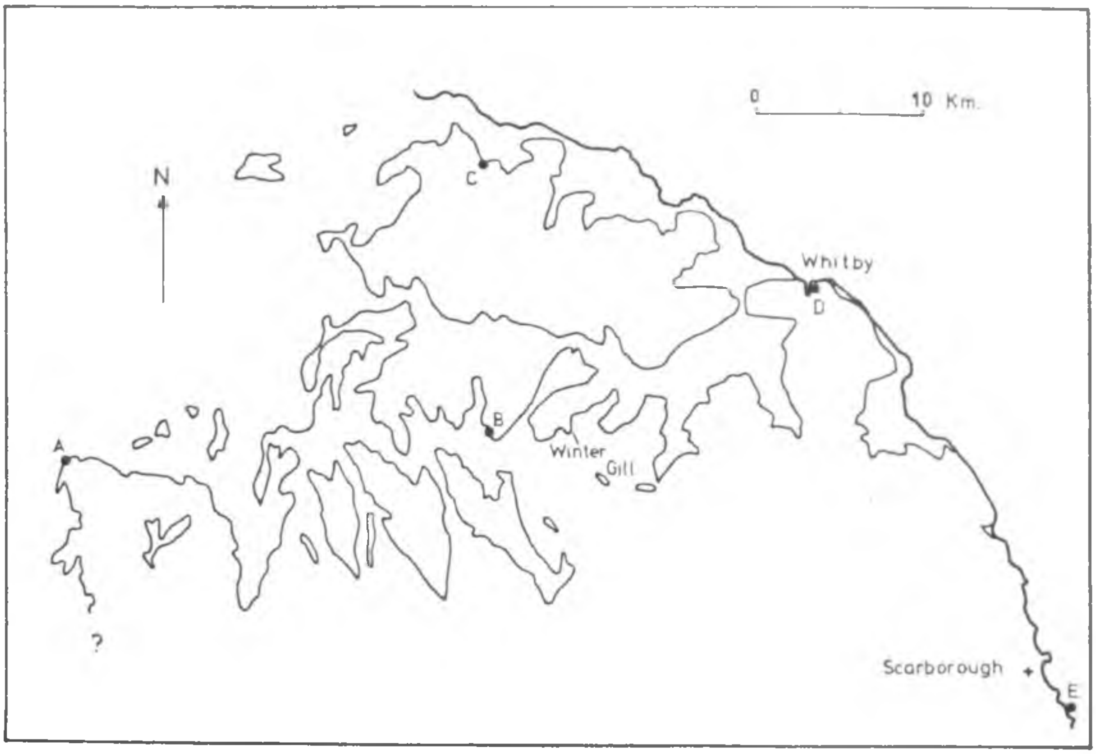
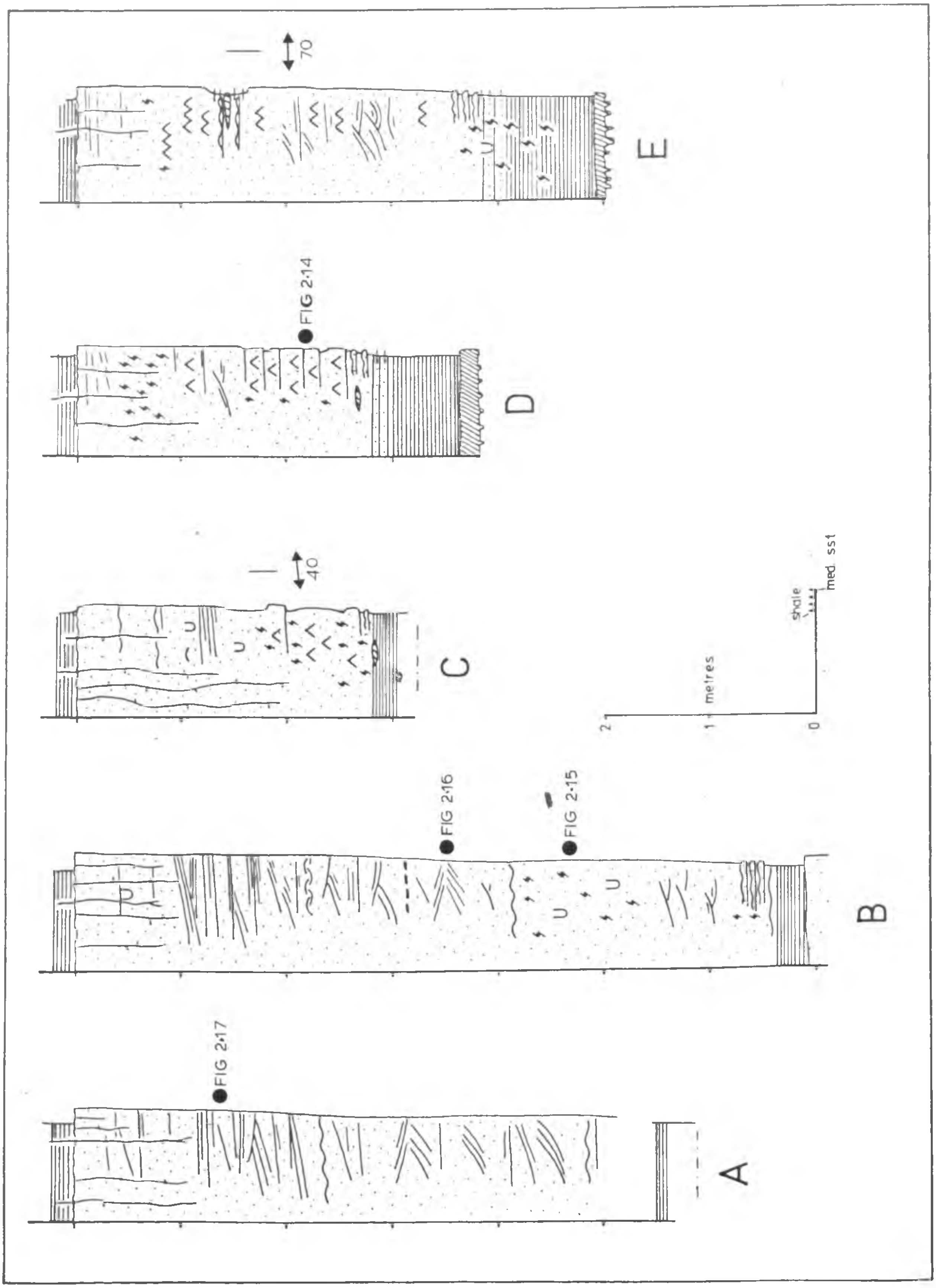


FIG. 2.12

Fig. 2.12 Location and outcrop map of Facies 1b.

Fig. 2.13 (facing page). Representative logs of Facies 1b. Locations of logs are shown in Fig. 2.12. A- Carlton Bank, B- Great Fryupdale, C- Kilton Beck, D- Whitby and E- Cornelian Bay.

FIG. 2.13


A
B
C
D
E
FIG 2·17
FIG 2·16
FIG 2·15
FIG 2·14
70
40
metres
2
1
0
shale
med. ss1

and bioturbated on the coast. They thicken towards the south-west and contain a fully marine fauna. They also coarsen-upwards rapidly, and locally the overlying sandstone unit has a sharp erosive base. Extensive, thin (0-2m) lenticular sandstone bodies occur within the shale unit at two localities. These are iron rich and at Winter Gill (Fig. 2.12) include a thin bioclastic limestone (Knox, 1970).

Knox divided the sandstone unit into two parts, but this only applies to the coastal exposures. Here the lower sandstone is dominated by small scale wave generated oscillation ripples. These occur as sharp based cosets, showing bundlewise accretion of foresets, and individual beds fine-upwards (Fig. 2.14). These beds are thin (Fig. 2.13D) and preserve syneresis cracks in their upper part. Rapid interlaminations of very fine-grained sandstone and siltstone (up to 20 per cm.) are marked. Wave ripples at any one locality show strong preferred orientation and flat crested ripples appear higher up. Fine and very fine-grained sandstone dominates and Knox reports Runzelmarken from this lower unit. At Kilton Beck (Fig. 2.13C) the lower sandstone is quite heavily bioturbated, and at Cornelian Bay includes large scale trough and wave generated cross-stratification.

The upper sandstone is coarser, up to medium-grained, and is found throughout the northern parts of the Yorkshire Basin. The coastal exposures are fine-grained and frequently show bioturbation (Fig. 2.13D). Bedding is largely destroyed by root penetrations at the top, and at Lofthouse, adjacent to Fig. 2.13C several stages of root growth occur within the sandstone itself (Knox, 1969). Where visible, flat lamination and subordinate mixed low angle and trough cross-

Fig. 2.14 Small scale wave-generated cross-stratification from the Eller Beck Formation at Whitby (Fig. 2.12). Note the bundlewise vertical accretion of foresets (arrowed) analagous to the chevron structures described by Reineck and Singh (1973, p. 25). Note also the localised fining upwards of the beds (above the arrow) and the sharp base of the sandstone at the top of the Fig.

Fig. 2.15 Ophiomorpha burrows at Great Fryupdale (Fig. 2.12). Note the 'knobbly' texture of the burrow walls (arrowed), caused by the attachment of faecal pellets to the walls as linings.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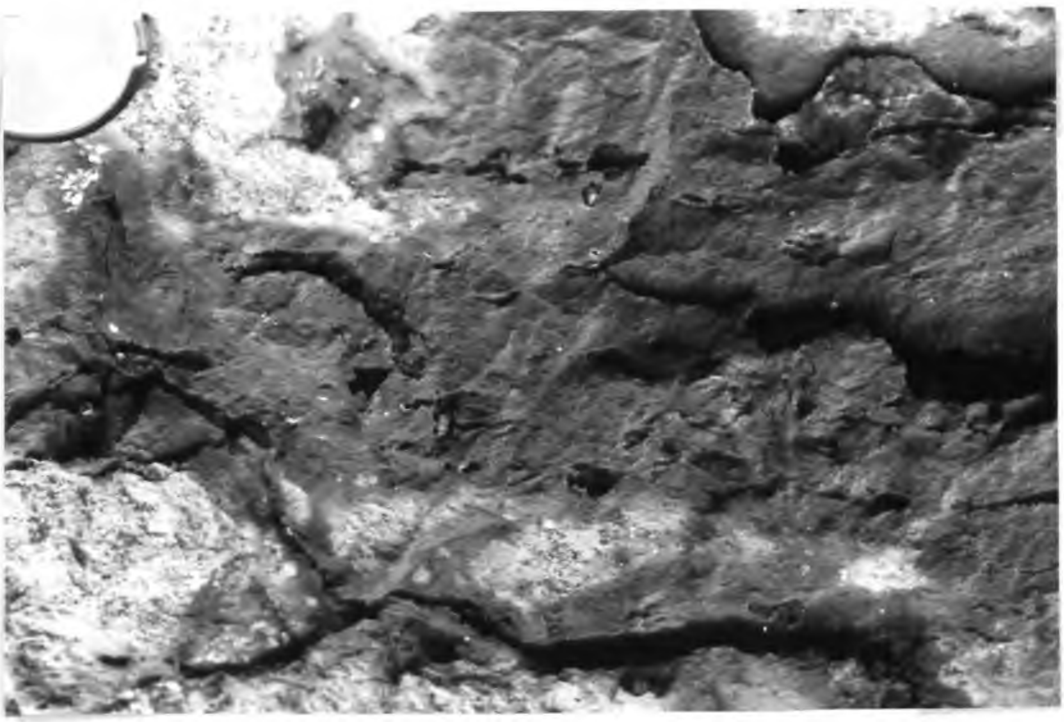


stratification are the main sedimentary structures present.

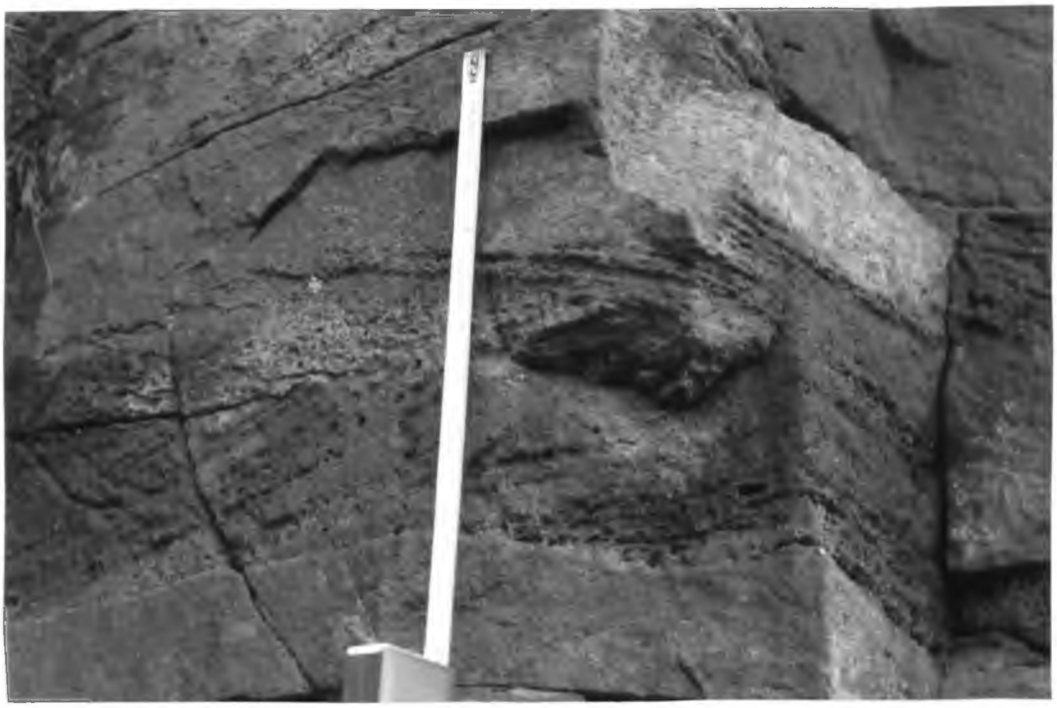
The central and south-western parts of the area show thicker, better sorted sandstones, although shale lenses are found in some western exposures (Knox). At Great Fryupdale (Fig. 2.13B) the lower part is heavily bioturbated, including Rhizocorallium, Diplocraterion Monocraterion, Thalassinoides, Arenicolites and Asterosoma. These forms give way vertically to Ophiomorpha (Fig. 2.15) which is especially concentrated along certain horizons, suggesting varied deposition rates. Above this sandstone, and at Carlton Bank (Fig. 2.13A), large scale cross-stratification in well sorted fine-grained sandstone dominates. 'Herringbone' cross bedding is present in both localities (Fig. 2.16) with trough, planar low angle and flat laminations also occurring. Minor scour surfaces are present, preserving both organic and shell debris lags and bioturbation is rare.

The top two metres of these two exposures show different sedimentary structures, with flat lamination predominant over low angle (5-8°) cross lamination (Fig. 2.17) showing low angle internal discordances. The sandstone here is medium-grained and unbioturbated. This general vertical increase in grain size and variation in sedimentary structures is typical of the central, southern and western exposures. Over the whole outcrop area the Eller Beck Formation was colonised by plants immediately after deposition and in certain central localities Knox reports channels eroding the topmost sandstone. These post date the Eller Beck Formation and there is little evidence of contemporaneous channel activity. No distributary mouth bars occur and there is no clue as to the source of the clastic sediment.

At Winter Gill the top of the sandstone unit includes a ferruginous

Fig. 2.16 'Herringbone' cross-statification from the Eller Beck Formation at Great Fryupdale. Planar accretion surfaces showing a directly opposed sense of dip which is usually thought to be indicative of deposition under reversing (tidal) currents.

Fig. 2.17 The Eller Beck Formation at Carlton Bank (Fig. 2.12). The top of Facies 1b shows flat and low angle laminations with low angle discontinuities between sets (arrowed) in well sorted fine/medium-grained sandstone.



variation, with chamosite ooliths occurring in a sandy matrix (Knox, 1970). This is a local, isolated development and there is no evidence of its lateral relationships with the rest of the formation. On the coast the Eller Beck Formation is overlain by thin root shales and siltstones, preserving vertical *in situ* *Equisitites* suggestive of freshwater sedimentation.

2.3b. Interpretation and Discussion

The coarsening upwards profile, fully marine fauna and colonisation by plants on the abandonment of the environment suggests a marine to non-marine progradational sequence. There is little evidence of erosion at the base of the formation within the outcrop area, although the sand bars found within the shale member may have resulted from the reworking of underlying deposits. There is considerable evidence that the underlying deposits represent an abandoned delta lobe of very low relief. The transgression over these sediments produced a very shallow, gently shelving sea.

The shales and lower bioturbated sandstones appear to be offshore marine from their fauna and low energy bedforms. The lower parts of the sandstone body at Carleton Bank and Great Fryupdale show higher energy structures.Herringbone cross bedding is usually taken as being indicative of tidal currents (De Raaf and Boersma, 1971), whilst the other cross-stratification present, trough and low angle, are common on shoreface deposits. At the top of the Eller Beck Formation flat lamination and low angle bedding showing low angle internal disconformities occur in well sorted fine-medium-grained sandstone. This closely resembles the foreshore features seen on modern beaches

(Thompson, 1937). Knox's statement that this flat lamination and the muddy nature of the lower sandstone suggests low energy conditions is rejected. The presence of flat topped ripples (McKee 1957), Runzelmarken and syneresis cracks all suggest periodic exposure or fluctuations in water level concomitant with tidal variation.

This overall coarsening-upwards and vertical variation in bedform type suggests progradation of a strand line over nearshore and finally offshore sediments, similar to that reported by Elliott (1975). However there is no evidence of interspersed lagoonal deposits within or above the Eller Beck Formation, so it would appear to represent a beach rather than barrier island system.

Water depths pertaining at the time of deposition can be estimated from the thickness of offshore to foreshore deposits preserved, giving maximum figures of 7m in the south west, 3-5m on the coast (not allowing for compaction). This would indicate a very shallow shelving sea, with deeper water to the south-west. Several other factors point to this palaeogeographic reconstruction. In the south-west the Eller Beck Formation is overlain or laterally equivalent to mudstones, fine-grained sandstones and micritic limestones (The Blowgill Member), apparently thick (c. 7m at Brown Moor, Fig. 1.1) offshore deposits. Palaeocurrents, taken from oscillation ripples and more importantly larger scale cross-stratification, give a rough north-east south-west orientation. There is also a marked increase in the shale : sandstone ratio within the Eller Beck Formation to the south-west (Knox, 1969).

The northern and eastern coastal exposures include rather a large amount of bioturbation. This would suggest that the wave energy was moderated by the length of the broad gently shelving platform. This wave energy may have been further moderated by other factors. The lowest and middle parts of the sandstone unit in the central and western parts of the area indicate tidal activity. It may be that these sandstones represent offshore bar deposits similar to those found in deeper water off the eastern coastline of U.S.A. (Duane et al. 1972) where linear shoals subparallel the shoreline and are either isolated or merge with the shoreface. Campbell (1971) demonstrated them adjacent to an Upper Cretaceous beach shoreline in New Mexico, but in a lower energy environment. Greenwood and Davidson-Arnott (1974) showed that storm waves break over outer bars in Kouchibougiac Bay, moderating wave activity on the coast.

These shoals or banks would be suitable for oolite formation if protected. The chamosite oolite found in the Eller Beck Formation at Winter Gill (Knox, 1970) overlies a coarsening-upward sequence, but unfortunately it is no longer exposed in full. It may have formed in a lagoon isolated by local rapid strandline progradation giving the low energy features discussed by Knox. As the shoals are formed by nearshore processes, and indeed merge with the shoreface it would be difficult to distinguish them from normal shoreface deposits. The lower parts of the sandstone at Great Fryupdale may demonstrate bedforms produced by tidal effects on the shoreface (Davis et al. 1972).

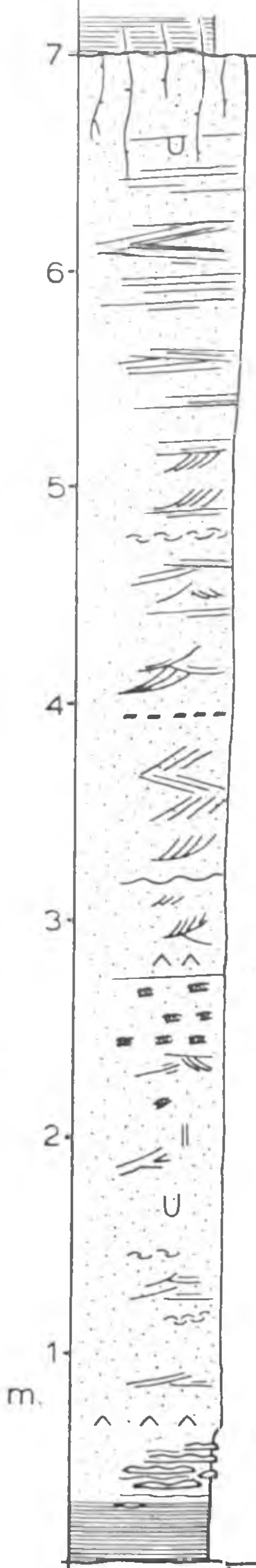
Variable deposition rates are demonstrable in the lower parts of the sandstone unit, at Whitby by the thin fining-upward sandstone beds, and at Great Fryupdale by the concentration of bioturbation along certain bedding planes. This latter observation corresponds to that of Kumar and Sanders (1976) who demonstrate alternating well bedded and bioturbated horizons, related to storm and fair weather periods off Sapelo Island. The vertical dominance of Ophiomorpha over other bioturbation forms in Great Fryupdale is recorded from other marine deposits (Howard, 1972).

The very shallow dips of the bedforms in the inferred swash zone at the top of the Eller Beck Formation suggest a broad shallow beach area. Root bioturbation makes it difficult to detect washover effects, although they would have a very similar internal structure to the laminated beach (see Elliott 1978, p. 160 after Schwartz 1975). However the repeated truncation of roots reported by Knox at Lofthouse may indicate this process. There is no evidence of aeolian dunes above the foreshore deposits as reported by several authors (Bernard, Le Blanc and Major, 1962), and it appears that plant colonisation must have occurred very soon after abandonment of the beach as the strand line prograded. A summary of the overall interpretation is given in Fig. 2.18.

Rapid beach progradation is usually related to abundant sand supply either by input from a local distributary or by the destruction of an adjacent deposit, with the clastic material introduced to the depositional site by longshore drift. As such the Eller Beck Formation strandline may be associated with deltaic input within the Yorkshire Basin (as in the Sao Francisco Delta, Coleman and Wright, 1975) or from the longshore introduction of material exotic to the area. No distributaries are exposed so the latter hypothesis seems most likely. Rapid progradation would be possible over the very shallow shelving sea that was produced by the initial transgression over a low abandoned deltaic area.

Fig. 2.18 Description and interpretation of Facies 1b at Great Fryupdale (Fig. 2.12).

FIG. 2.18



DESCRIPTION	INTERPRETATION
Silty shales, thin coals with thick roots on a sharp base.	Abandonment and colonisation by plants. non-marine marsh deposits.
Flat laminations and parallel low angle cross-strat. in well sorted medium sandstone, with internal discordances. Very rare bioturbation, thick roots disrupt sediments at top.	Coarsest sediment deposited by swash and backwash on a migrating broad high-energy beach.
Trough, low angle and herringbone cross-strat. in fine/medium sandstone. Flat lamination and rare wave rippled surfaces. Plant and shell debris lags	Subtidal deposition under mixed wave and tidal processes. Tidal effects on the shoreface ? Linear sand bar ?
Bioturbated fine sandstone. Vertical increase in Ophiomorpha over other forms. Almost totally reworked along certain bedding planes.	Lower shoreface sediments. Variable (storm and fairweather ?) deposition rates.
Coarsening upwards silty shales to wave rippled very fine silty sandstone.	Offshore deposits with increasing energy from suspension to wave influenced sediments.
Iron rich sandstone on non-marine shales.	Deposits of initial transgression

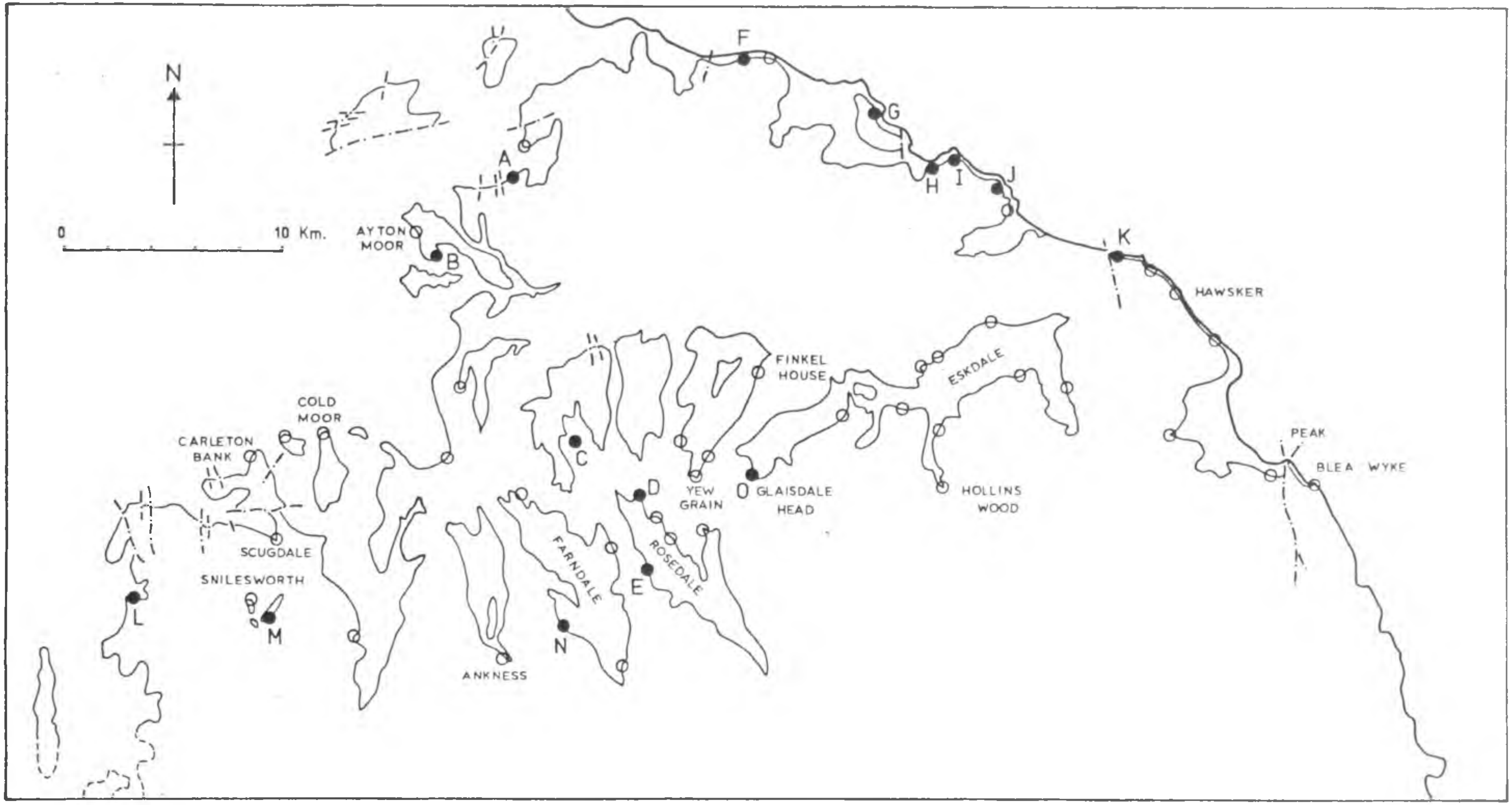
2.4. Facies 1c. Coarsening-upwards shale to linear sandstone body, The Dogger Formation.

2.4a. Introduction

The marine Dogger Formation has an erosive contact with underlying Toarcian and Whitbian deposits and appears to be quite separate from the Lias. It can be divided into two parts, a thin lower iron rich series with an overlying coarsening-upwards unit. The former has been studied extensively (Rastall 1905, Richardson 1911, Tonks 1923, and Rastall and Hemingway 1939, 1940, 1941, 1943, 1949) and consists of heavily bioturbated sideritic sandstones and oolites with local areas of green chamositic oolites and sandstones. These rocks contain the ammonite Leioceras costatum (McMillan, 1932, Rastall and Hemingway 1941) and are therefore of upper opalinum age. They occur in the south-east of the area associated with eroded and phosphatised lag deposits, and thin away to the north-west where they pass into a pebble horizon and are finally not represented. The furthest south-easterly exposure (Blea Wyke, Fig. 2.19) lies adjacent to a major fault and is anomalous, being much thicker (40', 12.5 - 13m) and highly muscovitic. It contains an upper opalinum fauna (Richardson, 1911) and these chamositic rocks must be of the same age as the other iron rich parts of the lower Dogger Formation. This is an interesting exposure in that spherulitic siderite can be seen replacing the original chamosite, also reported elsewhere by Rastall & Hemingway and Hemingway (1974). It would appear that the chamositic and sideritic rocks have a similar genesis, with variable diagenetic alteration producing the two distinct types.

Fig. 2.19 Outcrop map of the Dogger Formation (modified from the Geological Survey and Rastall and Hemingway). Infilled circles with letters refer to the localities shown in Fig. 2.20, and listed below. Other localities are represented by open circles and those mentioned in the text are named.

A Guisborough Wood
B Cribdale Gate
C Cleugh Gill
D Rosedale Head
E High House Farm
F Loftus
G Port Mulgrave
H Runswick Bay
I Kettleness
J Deepgrove
K Whitby, East Cliff
L Osmotherly
M Scotland Farm
N Keysbeck
O Glaisdale Head (east)


N
0
10 Km.
AYTON MOOR
COLD MOOR
CARLETON BANK
SCUGDALE
SNILESWORTH
ANKNESS
FARNDALE
ROSEDALE
YEW GRAIN
GLAISDALE HEAD
FINKEL HOUSE
ESKDALE
HOLLINS WOOD
HAWSKER
PEAK
BLEA WYKE
A
B
C
D
E
F
G
H
I
J
K
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M
N
O

FIG. 2.19

Black (1934) discovered the ammonite Ludwigia murchisonae from four north-westerly localities in black shales, indicating younger marine strata than described above between the Lias and the deltaic beds. He noted that these shales were overlain by sandstone and plant beds but was unsure as to their relationships with the rest of the Dogger within the central part of the Yorkshire Basin. These black shales overlie a clean biosparite in certain western localities, and this limestone also contains Ludwigia murchisonae (Black, op. cit.). Following Black's work Rastall and Hemingway produced a series of papers on the Dogger, but this work suffered from their method of studying a small area and then writing a paper on it. Their final paper criticised their earlier work and presented the idea of a coarsening-upwards sequence in the central part of the basin. They missed an identical sequence on the coast, but in one area suggested shallow inshore conditions with variable, pebbly sediments mixed with ooliths derived from contemporary deposits (1949). Their detailed petrographic work is invaluable as many of the iron rich exposures are now obscured or heavily weathered.

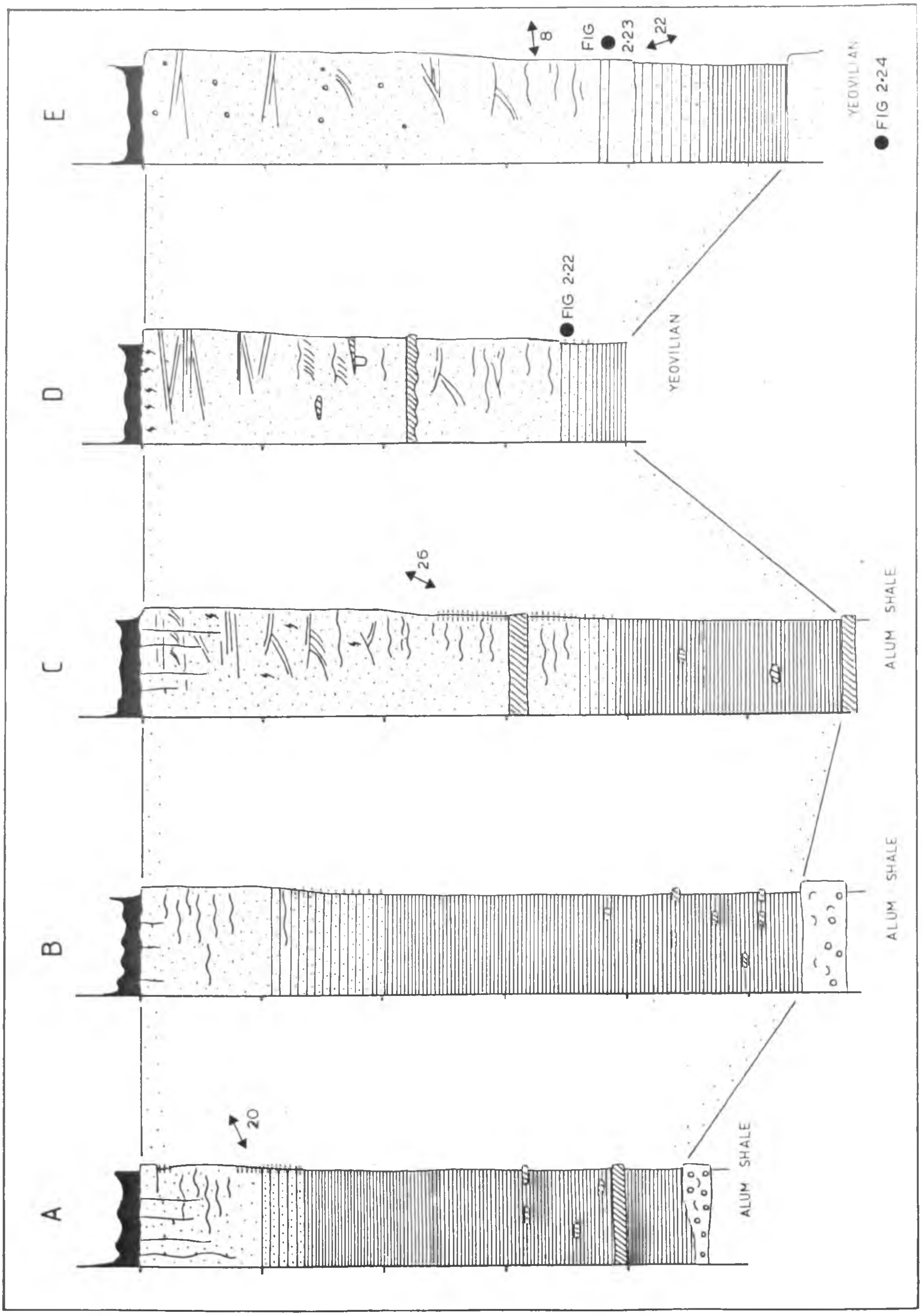
The lowest Dogger therefore consists of an unconformably based iron rich series in the south-east, with a gently erosional contact over Liassic sediments. A younger bioclastic limestone sequence is found in localised exposures in the western area, concentrated into erosional based hollows (Hemingway, 1974). The youngest part of the Dogger is a coarsening-upward sequence and this account is an attempt to provide a palaeogeographic and environmental reconstruction during murchisonae times.

2.4b. Description

Fifteen of the better exposures are presented as logs in Fig. 2.20

Fig. 2.20 Representative logs (A-O) of Facies 1c. Locations of these exposures are shown in Fig. 2.19.

FIG. 2.20A



A
B
C
D
E
20
26
8
22
FIG 2·22
FIG 2·23
FIG 2·24
ALUM SHALE
ALUM SHALE
ALUM SHALE
YEOVILIAN
YEOVILIAN

FIG. 2.20B

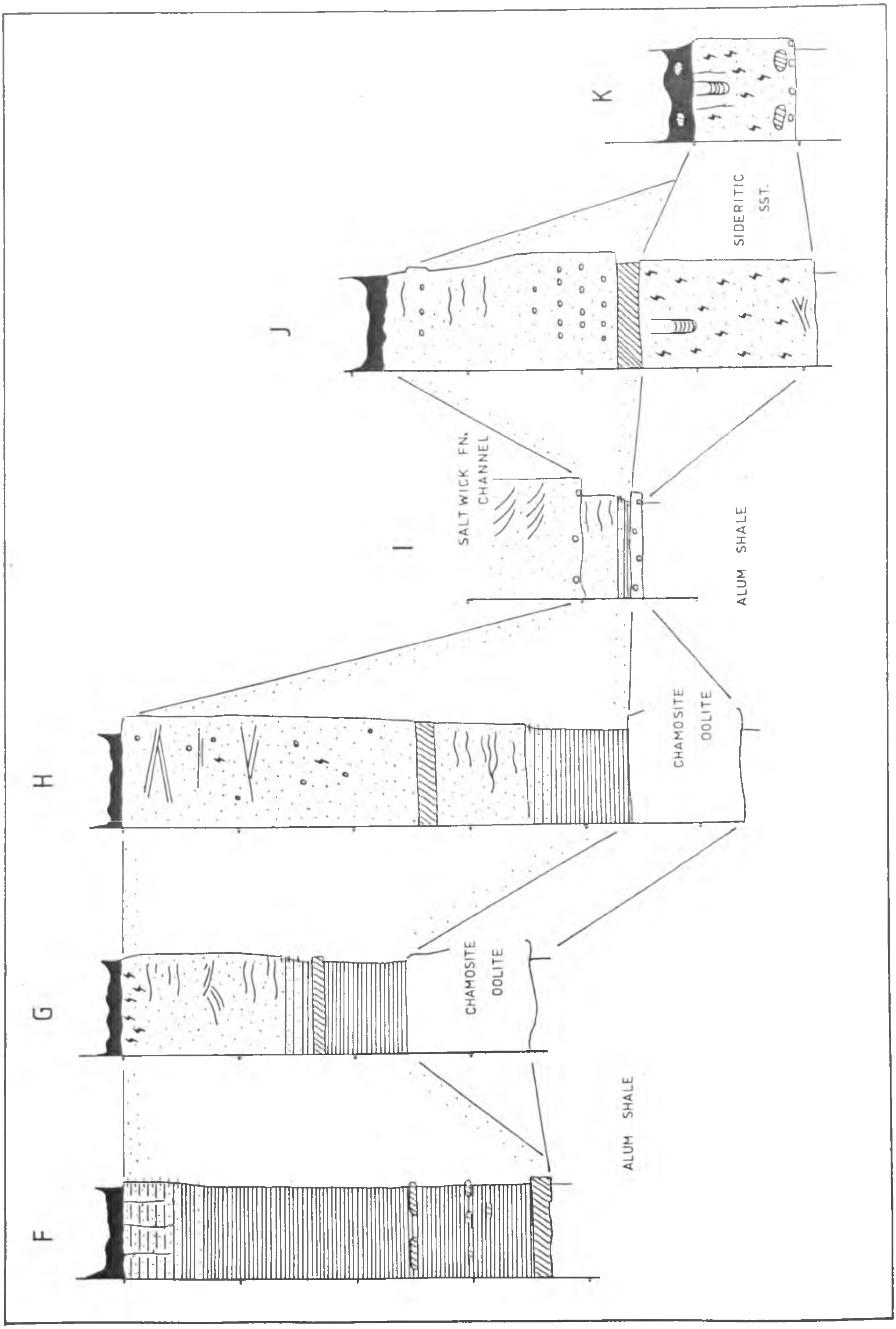
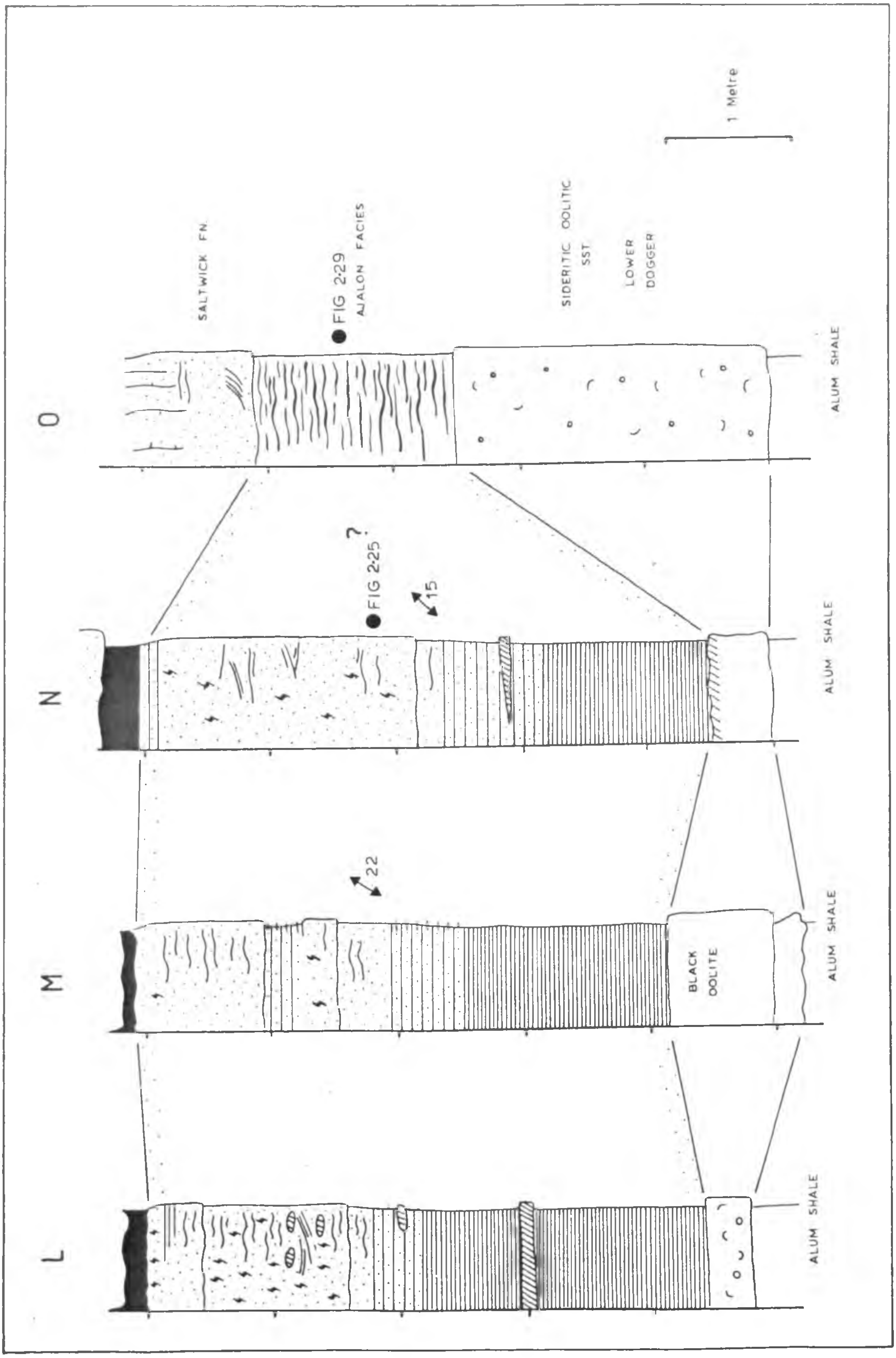

F
G
H
I
J
K
ALUM SHALE
CHAMOSITE OOLITE
CHAMOSITE OOLITE
SALTWICK FN. CHANNEL
ALUM SHALE
SIDERITIC SST.

FIG.2.20C


L
M
N
O
SALTWICK FN
FIG 2·29
AJALON FACIES
SIDERITIC OOLITIC SST
LOWER DOGGER
1 Metre
FIG 2·25 ?
15
22
BLACK OOLITE
ALUM SHALE
ALUM SHALE
ALUM SHALE
ALUM SHALE

and they are representative of the variation within the upper Dogger Formation in the Yorkshire Basin. Their locations are shown in Fig. 2.19. Post-depositional erosion by channels in the overlying Saltwick Formation reduces the available information, especially in the western parts of the outcrop (Fig. 2.21), but a broad overall pattern can still be discerned. Many of the exposures mentioned by Rastall and Hemingway no longer exist, or are severely degraded, and Fig. 2.19 indicates those that remain plus several new ones discovered by the author. The localities mentioned in the text are shown in Fig. 2.19.

At the base of the coarsening-upwards sequence is a laterally persistent clay ironstone containing a rich marine fauna, especially Rhynconellids and Terebratulids, but also Trigonia, Astarte, Isognomon, Pentacrinus ossicles and belemnite fragments. It is thickest at Ayton Moor (66cm) and contains abundant phosphatised pebbles. At Guisborough (Fig. 2.20) they reach 3cm in diameter and make up 40% of the ironstone. In Farndale this unit is represented by a white uncalcareous clay with sandy pyritic burrow infills, weathering to boxes of ironstone. Scattered ooliths are found at most localities and in Snilesworth the base of the sequence is represented by a black, hydrocarbon-impregnated shelly oolite with phosphatic pebbles (the black oolite of Rastall and Hemingway, 1939). The clay ironstone thins out eastwards (Fig. 2.21) and appears to be related to the bioclastic sparite found in Scugdale. Here an ironstone occurs between the limestone and overlying coarsening upward unit.

Overlying the basal ironstone is a well developed series of dark organic rich shales. They are brittle and well laminated, reaching a maximum recorded thickness of about 5m in the north-west around

Fig. 2.21 Outcrop map of Facies 1c showing the easterly depositional limits of the basal clay-ironstone and *murchisonae* black shales. Note the widespread erosion of the Dogger Formation by Saltwick Formation rivers, especially in western areas.

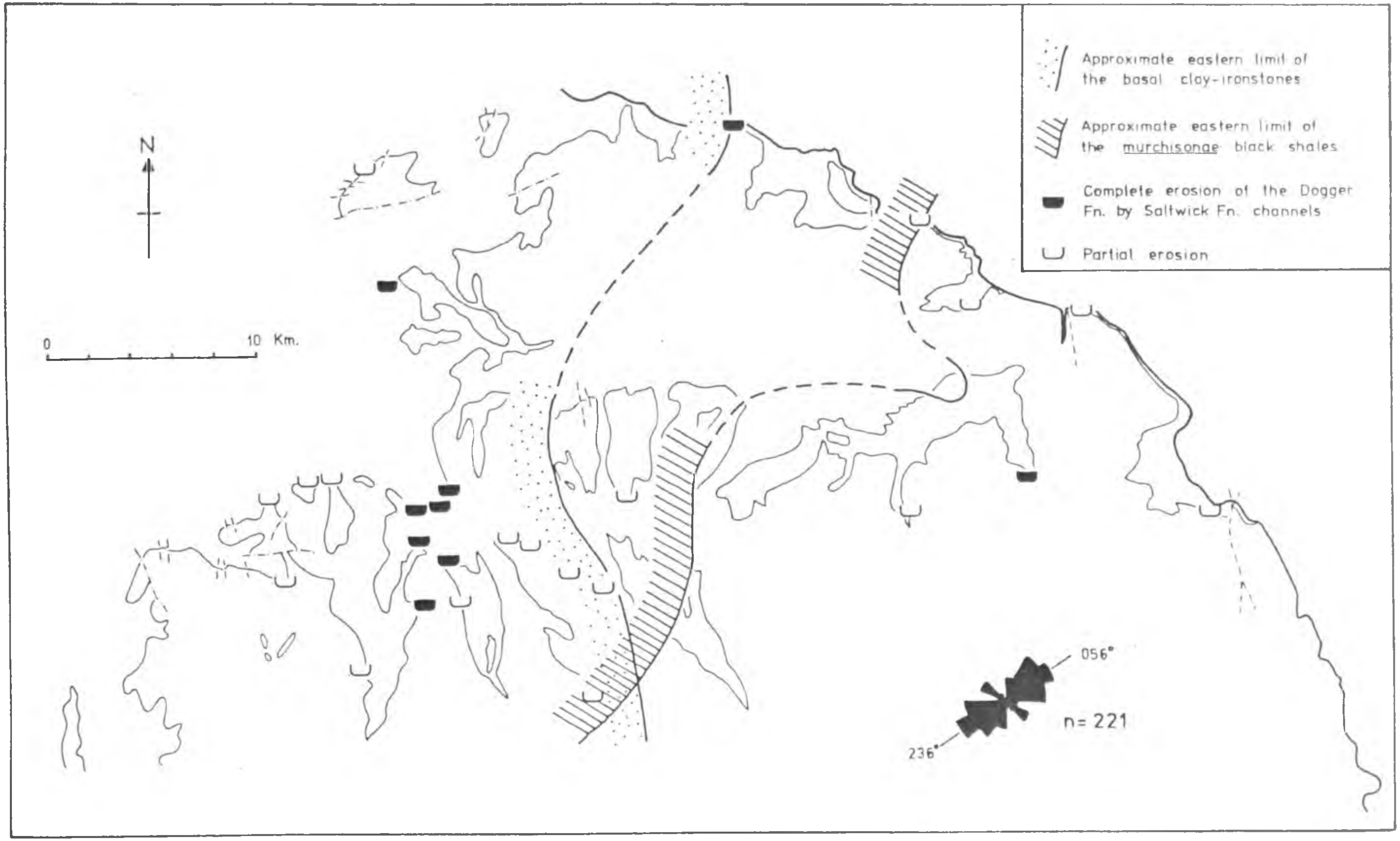

Approximate eastern limit of the basal clay-ironstones
Approximate eastern limit of the murchisonae black shales
Complete erosion of the Dogger Fn. by Saltwick Fn. channels
Partial erosion
N
0
10 Km.
056°
236°
n= 221

FIG. 2.21

Guisborough (Fig. 2.20). Ironstone nodules and thin beds occur, especially near the base. Normally these are barren but rarely contain ooliths, and at Osmotherly one ironstone horizon is fossiliferous. At the base of these shales the fauna is varied and fully marine, whilst above it is normally restricted to the ubiquitous thin shelled Isognomon (Perna) Pseudomonotis substrata (Rastall & Hemingway). These shales also contain Ludwigia murchisonae, a crushed specimen of which was found at Carleton Bank confirming their age. The delicate lamination is completely undisturbed by bioturbation, and the fissility of these shales is due to local concentrations of mica and plant debris parallel to bedding.

The finest-grained sediments are found in the north-west, and they coarsen both vertically and laterally, towards the south-east (Fig. 2.20A). They also thin markedly in this direction and were not deposited east of a line from Kettleness to Rosedale (Fig. 2.21). The coarsening upwards is very gradual, by thin pinstripe inclusions of silt and very fine grained sandstone (Fig. 2.22). Vertically these thicken into lenticles and finally are reworked into symmetrical oscillation ripple marks. In some localities the overlying sandstone has a sharp erosional contact (Fig. 2.22) but usually the shales grade into the coarser sediment (Fig. 2.23). A detailed view of the gradational coarsening-upwards (Fig. 2.24) shows local sharp based well sorted fine-grained sandstones and the gradual decrease in shale and siltstone vertically.

The overlying sandstone is very fine and fine-grained in the western exposures (Fig. 2.20C). Sedimentary structures are variable, mostly shallow trough, low angle and wave generated forms, including

Fig. 2.22 Facies lc at Rosedale Head (Fig.2.19). Note the thin pinstriped sandstone/siltstone inclusions in the basal shale, with rarely developed lenticular bedding. The overlying sandstone has a sharp erosional base, a localised feature.

Fig. 2.23 Gradual coarsening-upwards of Facies lc at High House, Rosedale (Fig. 2.19). The transition from black shales, by the rucksack (arrowed) to massive weathered sandstones at the top of the figure is by a gradual increase in the sandstone/shale ratio. The sandstone by the rucksack (to the left) is a localised Yeovilian (?) deposit, the Rosedale Sandstone.

wavy bedding. Bioturbation is common including Arenicolites, Monocraterion and Thalassinoides. At Farndale an unusual bioturbation form is preserved. It consists of radiating burrows 1-2cm in diameter with well developed striations, infilled with ironstone (Fig. 2.25). The centre is not exposed and the radiating tubes post-date earlier burrows of suspension feeding organisms. This must have been a deeper sediment burrow, and is allied to Arthrophycus, which Frey and Howard (1970) report from the lower Campanian of Utah as occurring in nearshore marine sediments. An anomalous exposure at Ankness preserves over 8m of heavily bioturbated very-fine grained sandstone with Diplocrateron, Rhizocorallium, Monocraterion, Laevicyclus and Thalassinoides.

The north-western central exposures consist of fine-grained moderately well sorted sandstone and the exposure at Finkel House preserves low angle sedimentary structures which give a bipolar palaeocurrent pattern. Towards the centre of the Yorkshire Basin the grain size becomes coarser and bioturbation very rare. The sandstone becomes fine to medium in grain size and at several exposures includes small phosphatic pebbles. Further south Rastall and Hemingway (1949) report an increasing oolite content as well as phosphatic pebbles, and both appear to be reworked from an earlier (opalinam Dogger?) sedimentary source. At Yew Grain and in several exposures in Rosedale now covered, Rastall and Hemingway report a thin (20-30cm) hydrocarbon impregnated black oolite overlying the coarsening upward sequence. This appears to have formed in situ but is very localised.

Inland, in the coarsest sediment, high energy structures predominate with low angle and flat laminations occurring in all exposures (Fig. 2.26).

Minor trough and higher angle planar cross bedding also occurs and in eastern Rosedale one exposure shows a strong unidirectional palaeocurrent direction in planar accretion surfaces with eroded tops, overlain by low angle and flat laminations (Fig. 2.27). In many exposures the coarsest sediment has a sideritic matrix, and it was frequently tried for ironstone during the last century. Heavy sphaeroidal weathering is frequent (Fig. 2.28) often obscuring structures.

This north-west to south-east variation in sediment type is well marked and can also be demonstrated from the coastal exposures (Fig. 2.20B). At Loftus well laminated black shales occur between the Liassic Alum shales and the Saltwick Formation. At Port Mulgrave this shale has thinned and overlies a lower Dogger chamosite oolite. The thin sandy streaks and lenses seen at the top of the shales at Loftus have developed into a thicker sandstone with wave generated oscillation ripples. On the south side of Runswick Bay the coarsest clastics seen inland are again found, with planar low angle and flat laminations the dominant structures present. At Kettleness there is large scale post depositional erosion by Saltwick Formation channels, but it can be seen that the black shales have thinned away. This must have been a result of primary non-deposition. The lower Dogger is represented by a thin ironstone with phosphatic pebbles which represents the Kettleness ridge of Rastall and Hemingway (1939). This ridge separates chamositic lower Dogger sediments to the north from sideritic ones to the south. At Deepgrove these sideritic sandstones are overlain by pebbly flat laminated sandstones, heavily weathered into ironstone boxes.

Fig. 2.26 Flat and low angle sedimentary structures in the Dogger Fn. at Yew Grain (Fig. 2.19). The lower part of the block contains small phosphatic pebbles giving a knobbly weathered texture.

Fig. 2.27 Planar accretion surfaces truncated by flat and low angle laminations at Rosedale East. Note the uniform palaeocurrent direction shown by the high angle cosets.

South of Whitby the Dogger Formation is generally represented by a hard bioturbated ironstone with Diplocraterion. Its thickness varies slightly (~ 1 metre) and it is overlain by dark shales from which roots penetrate into the Dogger. Locally, at Hawsker and Peak Alum quarries, this sideritic sandstone is overlain by bioturbated plant rich siltstones and sandstones which appear to pre-date plant colonisation. South-east of the coarsest sediment inland two localities show an unusual sequence (Glaisdale Head and Hollins Wood). The sequence at Hollins Wood was described by Rastall and Hemingway (1941) as a flaggy chamosite-oolite with ripple marks crossed by mollusc or worm tracks. It is a very sandy oolite, spastolithic (distorted ooliths) with interlaminations of mudstone sideritised to ironstone. A very similar deposit has been found at Glaisdale Head (Fig. 2.29) where it is very sandy, bioturbated and plant rich. The organic fragments are pyritic and delicate interlaminations of ironstone are preserved. This lithology is very similar to that seen at Peak Alum works, although here there is no interlaminated ironstone, and Rastall and Hemingway named it the Ajalon Facies. All these exposures lie to the south-east of the coarse clastic sediment that can be traced from Runswick Bay to Rosedale. They appear to be contemporaneous, in that they always overlie the lower Dogger Formation iron rich series.

2.4c. Interpretation and Discussion

Although the exposures are scattered and lateral correlation difficult in places there is a strong linear zoning of sediment types and bedform morphology. This north-east south-west trend is roughly

Fig. 2.28 Heavy sphaeroidal weathering at Blakey Mines, Farndale (Fig. 2.19). Note the bipolar low angle cross-sets, dipping to the left below the notebook and to the right at the right of the notebook. Flat lamination can be seen above the scale.

Fig. 2.29 Sample of the Ajalon facies, Glaisdale Head. Sandy oolitic laminations interbedded with thin ironstone streaks. Note the general bioturbation, destroying the laminations in the centre of the sample. The organic debris (base) has been heavily pyritised.


1 CM

parallel to the palaeocurrents taken from wave generated ripples just above the shale unit (Fig. 2.21). Although oscillation ripples often show a wide variation these readings were mostly taken from individual beds overlain and underlain by fine-grained sediment. As such, and bearing in mind the strong preferred orientation shown, they may reflect a dominant wave transport pattern.

There is no evidence of internal disconformity or major erosion within these younger murchisonae Dogger sediments and the distribution of sediment types appears to be primary with lateral variation from north-west to south-east. In the north-west a thick marine shale sequence is found with thin streaks and laminations of sandstone near to the top. This represents offshore marine sedimentation with coarser clastic input, including oolites from an adjacent shoreline, possibly under storm produced density currents. Nearer to the central part of the basin the shale is thinner and coarsens upwards to fine-grained bioturbated sandstone with a variety of sedimentary structures. This appears to represent nearshore sand deposition in low to moderate wave conditions allowing a fairly active infauna. Locally bioturbation occurs in horizons, indicating periodic deposition. Tidal activity is indicated by the bipolar palaeocurrents at Finkel House.

Some thin sandstone beds have sharp bases suggesting a sudden influx of sediment, probably from erosion of a nearby shoreface or foreshore under storm activity. Most of this introduced sediment is fine-grained sandstone, and the coarsest sediment in the area is restricted to the exposures that show sedimentary structures normally found in beach and shoreface deposits. These lie on a line from Runswick Bay to northern Rosedale where medium-grained sandstone was deposited along with reworked ooliths and phosphatic nodules. This high energy environment is in marked contrast to the very slow deposition rates associated with the phosphatisation of modern nodules (Balurin, 1971, Manheim et al. 1975), and they probably derive from erosion of either earlier Dogger sediments or the Lias. The presence of ooliths suggests that the former is the more likely source. The deposits at Runswick Bay, Rosedale and adjacent exposures show typical flat laminations and low angle cross stratification found in modern clastic shorelines. There are subtle differences between these structures and those found in the Eller Beck Formation. The planar forms have a higher angle of dip, and this can be explained by the increased grain size, a relationship shown by Russell and McIntire (1965).

South-east of the line of coarsest sediment those deposits found are very variable. In most of this area the Dogger Formation is only represented by opalinum sediments. There is no evidence of erosion above these ironstones and they frequently show plant colonisation. The pebbly deposits of Deepgrove (Fig. 2.20B) show only horizontal laminations. Again the phosphatic nodules cannot have formed in situ and a possible origin would be as washover from the adjacent strand line. The Ajalon facies (Rastall and Hemingway) is interesting. It appears to be contemporaneous, being found between the opalinum Dogger and the Saltwick Formation. The interbedded mudstones and bioturbation indicate quiet water deposition with alternate influx of sandy sediment reworked into oscillation ripples. The spastolithic ooliths also suggest variable energy conditions, high for their formation, low for their deformed growth. The position behind the shoreline suggests a lagoonal environment of formation for these deposits. However their exact lateral relationships with the other sediments is unknown.

They show no evidence of plant colonisation or exposure.

The overall pattern of upper Dogger Formation sediments gives a series of linear zones, with an offshore marine area adjacent to nearshore sandstones and finally shoreface and foreshore sediments. There must have been progradation in the central parts of the area, giving the coarsening upwards profile. This progradation was only over a relatively short area and the lateral variation in sedimentary pattern is also marked. The orientation of the shoreline parallel to the main wave generated palaeocurrent directions in the nearshore region may indicate that deposition was under the influence of longshore drift. This would inhibit progradation and help to explain the linear zone of foreshore deposits.

Water depths are hard to gauge. In the central area the coarsening-upwards sequence is about 5m thick and water depths would be approximately the same (not considering compaction). In the far south-east the opalinum Dogger may well have been exposed in murchisonae times, explaining the strong sideritisation of the sediment. Water depths in the north-west are problematical. They must have exceeded the shale thickness Hemingway (1974) reports its maximum development as 12m, but this exposure was not found and its existence is doubted). Allowing for a high compaction figure and adding 5m for the coarsening upward sequence would give depths exceeding at least 15-20m. This shelving sea would also restrict progradation.

The anomalous exposure at Blea Wyke shows 'herringbone' cross bedding giving way to low angle beach laminations above. It would appear that in part at least similar environmental conditions pertained during opalinum times adjacent to the main outcrop area. Exact environmental analysis of the older Dogger sediments in the main outcrop area is very difficult due to the deep weathering, bioturbation (which completely destroys sedimentary structures) and diagenetic alteration. They and the younger bioclastic limestone of the south-west must represent shallow marine carbonates.

2.5. Discussion on Facies 1

Although the three types of coarsening-upward sequence are different in detail they do show several overall points of similarity. All three were deposited by the progradation of shorelines, presumably in conditions of near static sea level. They all have sharp bases, indicating rapid, sudden transgression over the underlying sediments. Gentle subsidence of these earlier sediments below sea level can be discounted for this would allow wave reworking of the earlier sediments and one would expect evidence of this. A gradual transgressive shoreline would probably give a noticeable deposit (see Johnson, 1975). Only the upper Dogger Formation has a lag deposit, formed of phosphatic pebbles reworked from underlying sediments. This lag is thin and probably formed very rapidly as a sheet during transgression. The other two sequences show no lags and this is probably the result of transgressions over mainly fine grained sediments, thought to be abandoned delta lobes or alluviated profiles.

The cause of the transgressions is unknown, but for the reasons discussed above gradual subsidence is unlikely. The effects of major faulting in the Mesozoic of the North Sea are well documented (Zeigler 1975, 1980 in press) and tectonic activity plays a major part in controlling sedimentation. As such these sharp rises in sea level may be a result of large scale fault block movement, but there is no direct evidence for this. The proposed seismic shock formation of the soft sediment deformation in the Blea Wyke Member is only circumstantial.

The scale of the coarsening-upwards profiles are very similar (3 - 7m) and all show an offshore mudstone to foreshore transition. This similarity in scale is probably a result of comparable physical conditions during deposition, such as water depth and tidal range. The two younger sequences were the result of transgressions over very flat coastal marsh areas and progradation of both formed a sheet of sediment, with rapid deposition over a very gently shelving offshore area. The upper Dogger Formation shows a higher offshore dip with deeper water adjacent to the shoreline. This would greatly inhibit the rate of progradation.

The thicker shales of the murchisonae Dogger, associated with deeper water, are unbioturbated and show a restricted fauna. They were probably deposited in anoxic organic rich environments where bottom and sediment dwelling fauna were absent. Nearer the shoreline and in the other two sequences the shales show a more oxygenated regime, giving mixed fauna and an increase in bioturbation. These shales are generally paler and show a higher clastic to organic sediment ratio. This ratio would in part be controlled by water depths and distance from the shoreline.

Essentially the sequences show stable progradation and a simple coarsening-upwards profile. This ideal profile can be modified in two basic ways. Subsidence or repeated transgression would give a repeated profile, seen in the Blea Wyke Member of the Scarborough Formation at Cloughton Wyke. Sudden progradation would give a sharp step in the profile. This is seen at Rosedale Head within the Dogger Formation

(Fig. 2.22) where a sharp erosion surface marks the boundary between the basal shales and shoreface sandstones. In both cases these modifications are simple local effects and do not substantially alter the overall vertical variation.

The petrography of the Eller Beck Formation and Blea Wyke Member is consistent with a derivation from associated deltaic deposits, either by the destruction of older sediments or by the introduction of clastic material by distributaries. In either case the sandstones would have to be introduced into the depositional area by longshore currents. The upper Dogger Formation appears to derive much of its sediment from earlier marine deposits. This fact, plus palaeogeographic considerations appears to separate it from the 'deltaic' sediments in the Ravenscar Group. None of the three coastal sequences show evidence of aeolian activity behind the foreshore. This appears to be very common in many similar modern environments and it would appear that these Jurassic examples were rapidly fixed by vegetation following deposition.

CHAPTER 3

FACIES ANALYSIS OF MIXED CLASTIC AND CARBONATE MARINE SEDIMENTS - THE LEBBERSTON MEMBER

CHAPTER 3

FACIES ANALYSIS OF MIXED CLASTIC AND CARBONATE MARINE SEDIMENTS - THE LEBBERSTON MEMBER

The Lebberston Member divides readily into two parts, a lower calcareous (Millepore Bed, Whitwell Oolite and Upper Limestone, Fig. 1.5) suite and an upper non-calcareous series, the Yons Nab Beds (Hemingway and Knox, 1973). These two parts are quite distinct and will be dealt with separately.

3.1. Facies Association 2. Mixed clastic and carbonate sediments - The Millepore Bed, Whitwell Oolite and Upper Limestone.

The Millepore Bed outcrops on the coast and represents a partial transgression over non-marine Sycarham Member sediments, and shows major lateral variations as it thins northwards. The exposure of this sequence is good and includes two faulted-in outliers south of Scarborough (Fig. 3.1). Scattered inland exposures delimit the northern extremity of the transgression. The coastal Millepore Bed can be correlated by lithology and stratigraphic position with two oolitic horizons that outcrop in the Howardian Hills (Fig. 3.1). The lower one is thickest and named the Whitwell Oolite and Hudleston (1874) termed the younger one the Upper Limestone. These oolites are now very poorly exposed but one reasonable outcrop remains (at Crambeck) and a recently cored I.G.S. borehole (at Brown Moor) was made available for logging and sampling under the direction of Dr. G.D. Gaunt. All the localities mentioned in the text are shown in Fig. 3.1.

Fig. 3.1 Location map of exposures mentioned in Chapter 3.

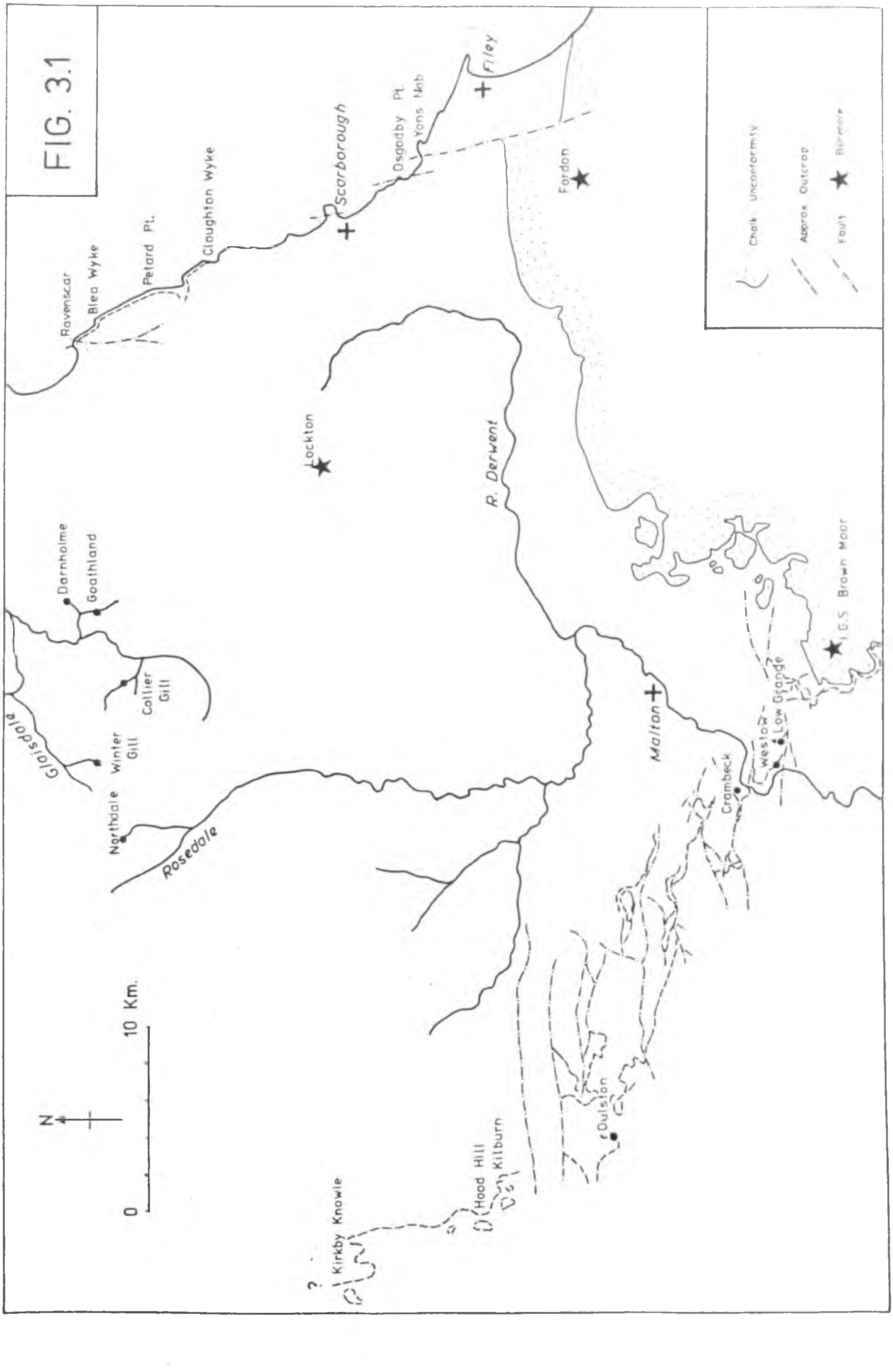

Ravenscar
Blea Wyke
Petard Pt.
Cloughton Wyke
Scarborough
Osgodby Pt.
Yons Nab
Filey
Fordon
Lockton
R. Derwent
Darnholme
Goathland
Collier Gill
Winter Gill
Glaisdale
Northdale
Rosedale
Malton
I.G.S. Brown Moor
Low Grange
Westow
Crambeck
Oulston
Kilburn
Hood Hill
Kirkby Knowle
?
N
0
10 Km.
Chalk Unconformity
Approx. Outcrop
Fault
Borehole

FIG. 3.1

3.2. Facies 2a. Mixed calcareous sandstones and quartz arenites, strongly bioturbated, with low angle laminations predominant

3.2a. Description

This facies is found in the northern extremities of the Millepore Bed outcrop where the unit is at its thinnest. Where intense bioturbation has not completely destroyed all record of sedimentary structures low angle and symmetrical wave generated ripples are the dominant forms present. The five inland exposures, although thin, are quite distinct from the non-marine beds in which they occur. At Winter Gill and Northdale (Fig. 3.1) well sorted fine-grained sandstones overlie a thin heavily bioturbated silty sandstone (Fig. 3.2). These exposures are unfossiliferous and their upper contacts with non-marine beds are not seen. The sandstones thin as they pass through Collier Gill (Fig. 3.2) and Goathland to Darnholme (Fig. 3.2). Here only the lower silty bioturbated sandstones are found and the complete relationship with non-marine beds can be seen. The unit has thinned rapidly and Darnholme represents the northernmost exposure. Hemingway (1974) suggests other exposures to the north but his information is very vague and they were not found. The Darnholme section preserves a fully marine fauna, mostly of whole articulated bivalves including Pleuromya apparently in life position. Pholodomya and Modiolus are also found together with the marine gastropod Littorina.

Decalcification of these sandstones is marked and also occurs at Blea Wyke and Ravenscar (Fig. 3.2), on the coast. Here thin shell debris lags occur within low angle bedforms, and Pentacrinus ossicles are common. Weathering is intense and readily picks out the bioturbation

Fig. 3.2 Logs of Facies 2a, localities shown in Fig. 3.1

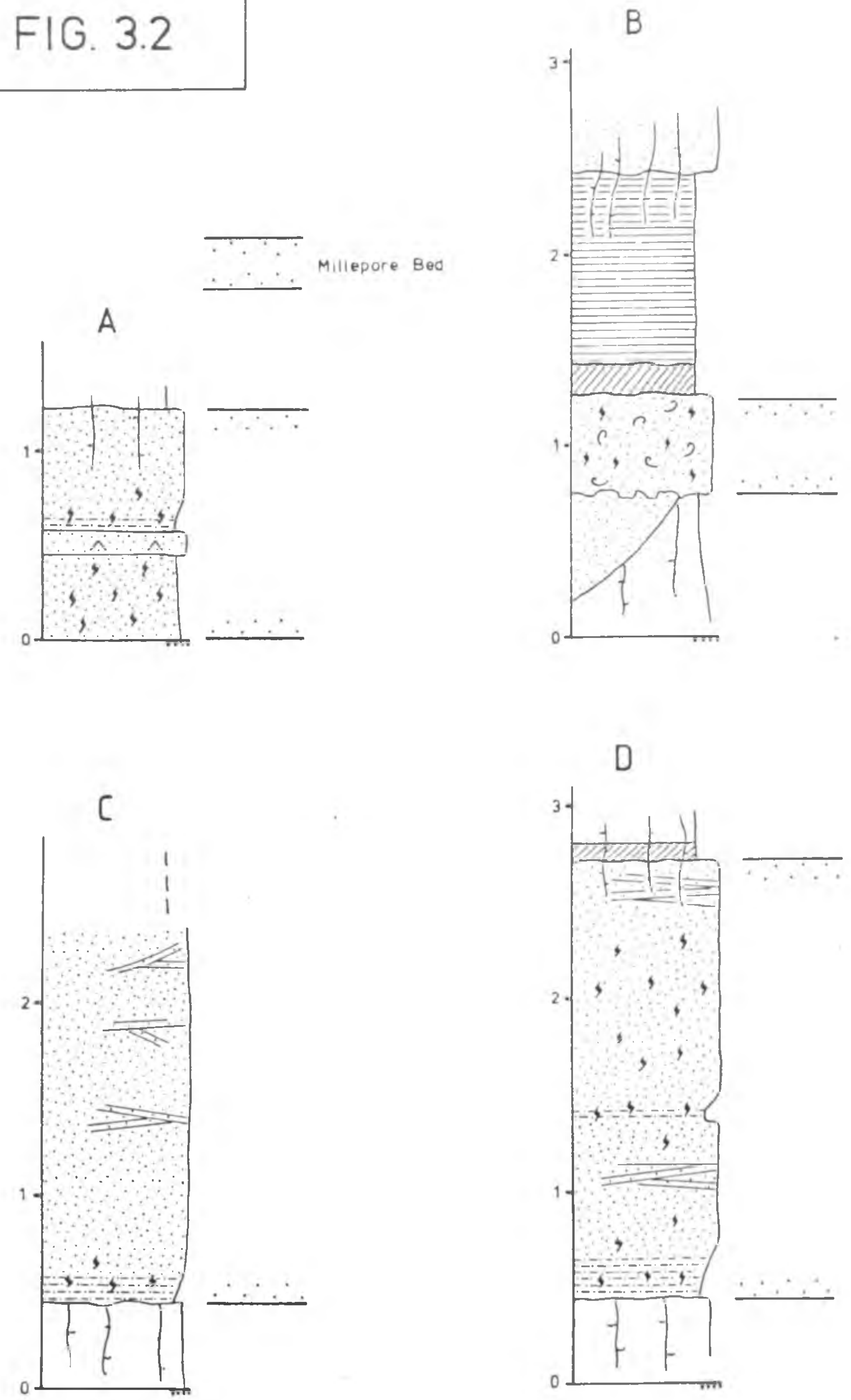
A - Collier Gill

B - Darnholme

C - Winter Gill

D - Ravenscar

FIG. 3.2



seen within this facies (Fig. 3.3). Diplocraterion and Thalassinoides are the commonest forms found at Blea Wyke together with horizontal burrows preserving spriete. Usually the sandstones have been completely reworked and individual forms are unrecognisable. In these northern coastal sections bioturbation is dominant and the low angle laminations occur in localised patches, usually at the top, or base, of the unit.

At Cloughton Wyke this facies is thicker and calcareous. Reworked ooliths and scattered sandstone clasts are found throughout this section (Fig. 3.4). Again this exposure shows a complex inter-bedding of bioturbated horizons and cleaner units showing low angle and small scale cross-stratification. The base of this section is erosive and the lower part fines upwards from a basal conglomeratic sandstone to organic rich flat-laminated siltstones. A hardground is found in the middle of this section and it is overlain by a conglomerate of sandstone clasts, large plant remains and bioclasts. The hardground can be recognised by its very irregular surface, preserving overhangs (Fig. 3.5) and the overlying clasts show evidence of early cementation in thin section. Although 'oysters' are present in the conglomerate there is no evidence of encrustation or of boring. The top of the exposure at Cloughton Wyke shows well developed low angle laminations which give a very variable palaeocurrent direction. Iron concentration is commonly associated with the bioturbated horizons and this can also be seen at Osgodby Point (Figs. 3.6, 3.7) where the top part of the section is heavily reworked with Thalassinoides dominant. Overlying this main iron rich bioturbated horizon is a thin unit of quartz rich bioclastic limestone with low angle laminations. This facies is not represented in the south-western exposures of the Yorkshire Basin.

Fig. 3.3 Intense bioturbation in the Millepore Bed (Facies 2a) 200m south of Petard Point (Fig. 3.1). The main forms present are Rhizocorallium, Diplocraterion and Thalassinoides.

Fig. 3.5 Hardground overlain by conglomerate in the Millepore Bed (Facies 2a) at Cloughton Wyke (Fig. 3.1). The surface of the hardground is very irregular, preserving overhangs. The small scale cross-stratification and general position in Facies 2a suggest a beach rock mode of origin for this feature. Ruler is 15cm long.

3.2b. Interpretation and Discussion

The fining upwards sequence at the base of the Cloughton Wyke section represents deposits of the initial transgression, introducing previously cemented sandstone clasts and eroding underlying non-marine sediments. From the low angle laminations and the proximity of the limits of deposition to the north this facies appears to represent a shoreline sequence. These sedimentary structures are similar to those found at the top of Facies 1. The intense bioturbation and inclusion of smaller scale cross bedding suggests that wave energy was moderate. Most of the bioturbation probably occurred in a back beach environment and the varied interbedding of cleaner well sorted arenites suggests a variably shifting foreshore area. This is also evidenced by the Cloughton Wyke section (Fig. 3.4).

The hardground at Cloughton Wyke appears to represent a beach rock. The small scale cross bedding below is variable and suggestive of a back beach environment rather than foreshore deposition. Early lithification in these environments occurs below the sediment surface, in between an upper mobile sediment area and a lower region of stagnant pore water (Bathurst,1975). Subsequent erosion exhumes the beach rock and exposes it, allowing a variety of forms of erosion. Solution has been recorded as an important factor in the weathering of a beach rock. Revelle and Emery (1957) showed overhangs and depressions suggestive of dissolution rather than abrasion in such an environment. This dissolution is aided by boring organisms and algae which produce CO_2 during the hours of darkness encouraging the solution of $CaCO_3$. A similar solution mechanism was suggested by Taylor and Illing (1969) for the production of cuspate pits in Persian Gulf beach rocks, again

FIG. 3.4

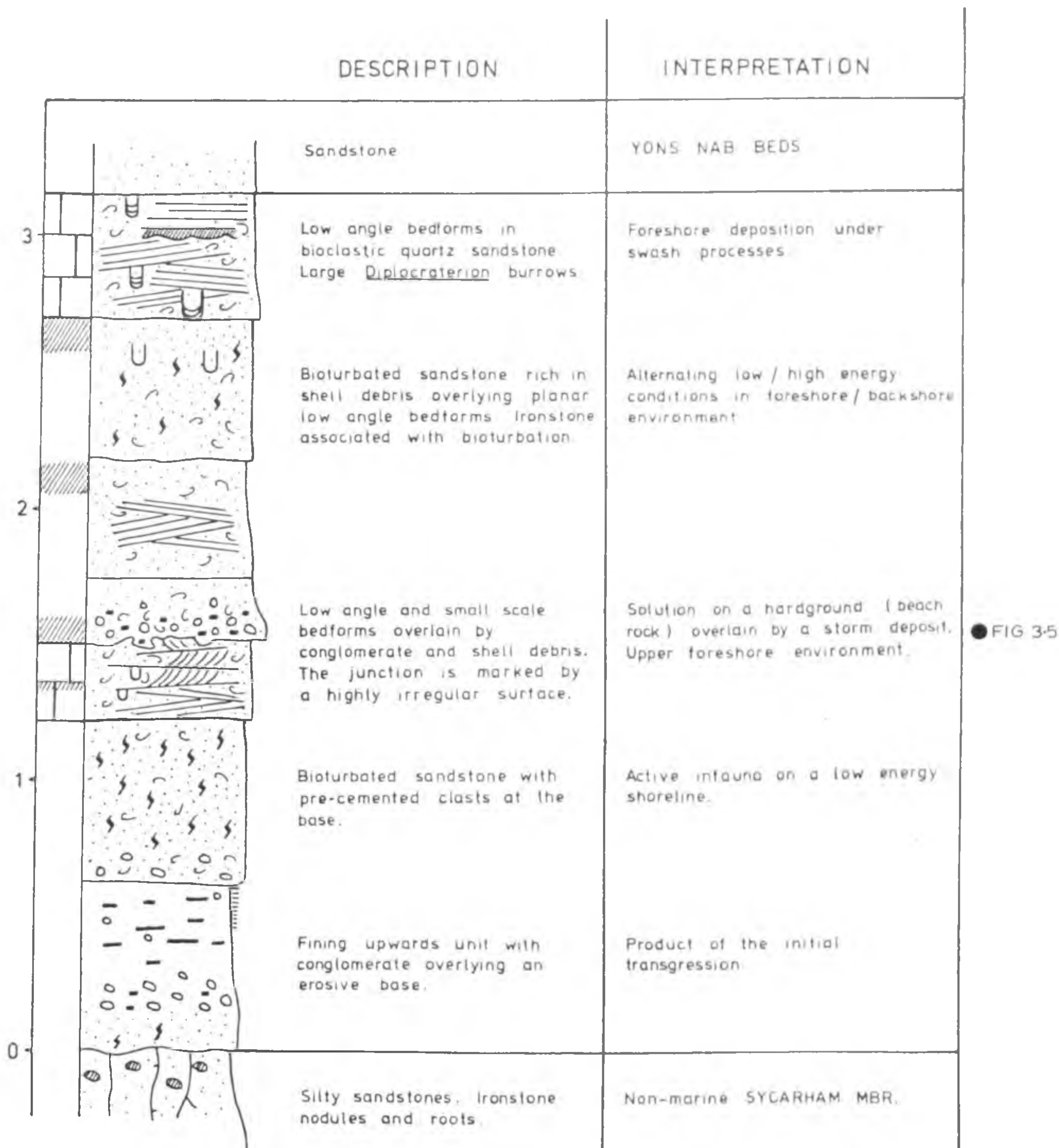
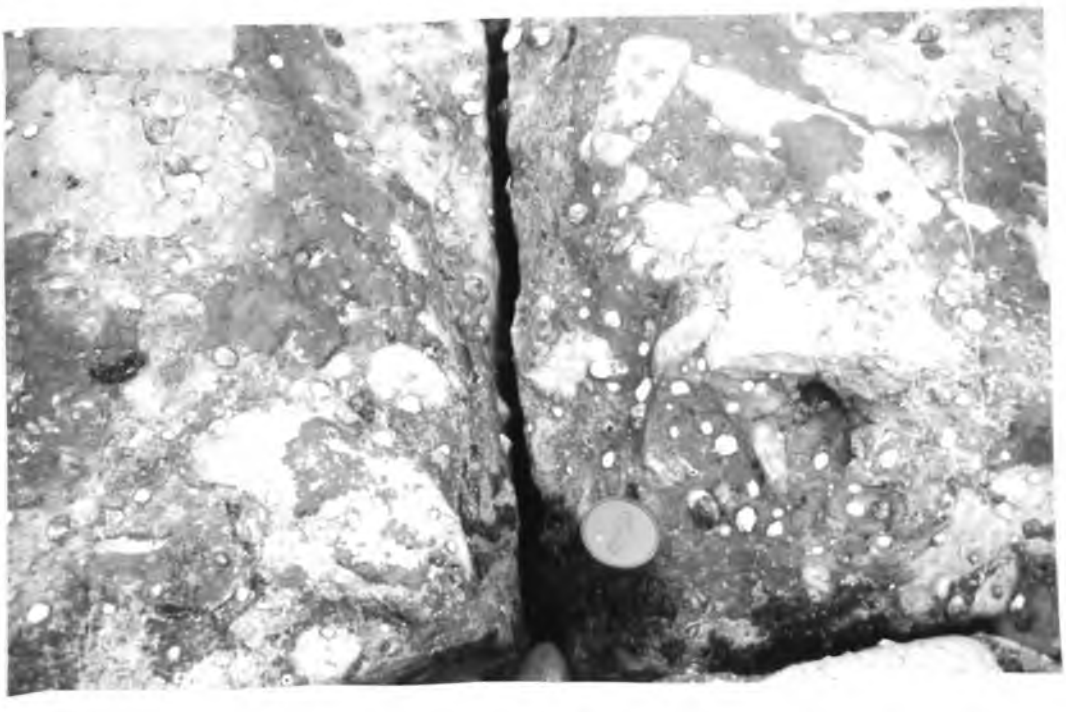


Fig. 3.4 Description and interpretation of Facies 2a at Cloughton Wyke (Fig. 3.1).

Fig. 3.6 Complete reworking of the top of the Millepore Bed at Osgodby Point (Fig. 3.1) by a highly active infauna. Thalassinoides is the horizontal branching form, Diplocraterion the paired vertical tubes. Bedding plane surface view.

Fig. 3.8 Coarse conglomerate in an ironstone matrix in the Millepore Bed (Facies 2b) at Osgodby Point. The clasts are quartz arenite and of similar lithology to the surrounding Millepore Bed sediment. An interpretation is discussed in the text.



aided by a coating of blue-green algae. Talbot (pers. comm.) has studied similar features on modern Ghanaian beaches, and he suggests a combined solution and abrasion mechanism for their erosion. No oyster encrustrations are seen, and no boring that could not be attributed to soft sediment bioturbation. The cross laminations below, the general situation, and the very irregular surface precludes a submarine hardground interpretation for this feature.

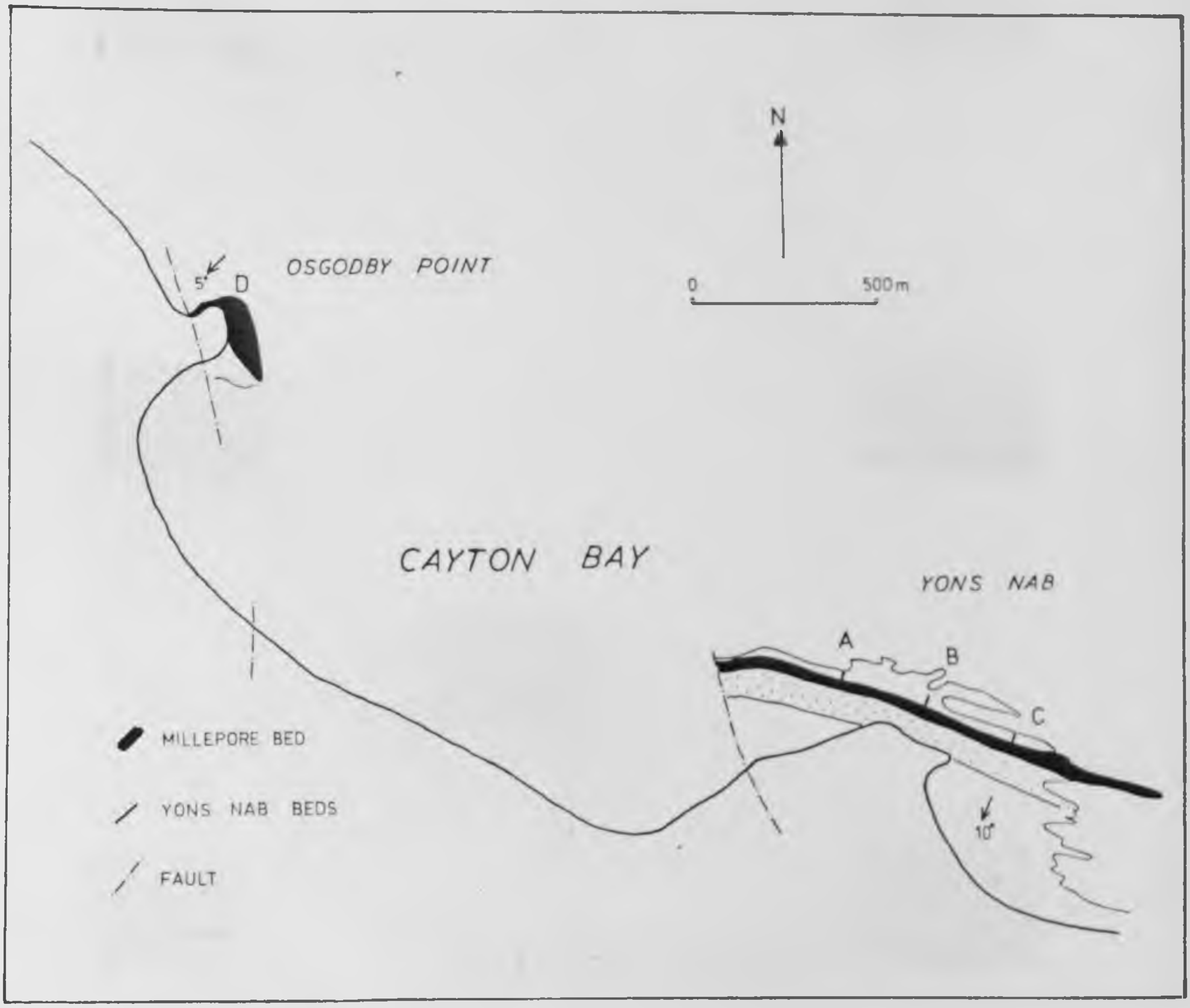
This hardground dies out within the limit of the exposure and appears to be a discontinuous feature. This is also recorded from Bikini (Bathurst, 1975) where beach rock has a very irregular distribution on the foreshore. The clasts in the conglomerate overlying the hardground are not restricted to locally derived sediments, as they include oolitic limestones and offshore Millepora bryozoans. This appears to be a storm deposit introducing exotic material. A summary of the Cloughton Wyke section is given in Fig. 3.4. The shoreline appears to have prograded from north to south and at Osgodby Point overlies earlier offshore marine sediments described below.

3.3. Facies 2b. Unbioturbated well sorted carbonate and clastic sediments showing a variety of medium to large scale cross stratification.

3.3a. Description.

This facies is represented on the southernmost coastal exposures at Osgodby Point and Yons Nab. Four logs are drawn from these localities and represented in Fig. 3.7. At both localities quartz sandstone is the dominant lithotype although a sparry calcite cement makes the unit resistant to erosion, and forms reefs on the seaward side of two Tertiary faults. Here the Millepore Bed has a sharp

Fig. 3.7 Representative logs of the Millepore Bed (Facies 2b) at Yons Nab and Osgodby Point with detailed locations shown below (see also Fig. 3.1). All the cross-bedding is drawn to scale. The black palaeocurrent roses are of readings taken from medium to large scale cross-stratification, the open rose from small scale wave-generated structures.



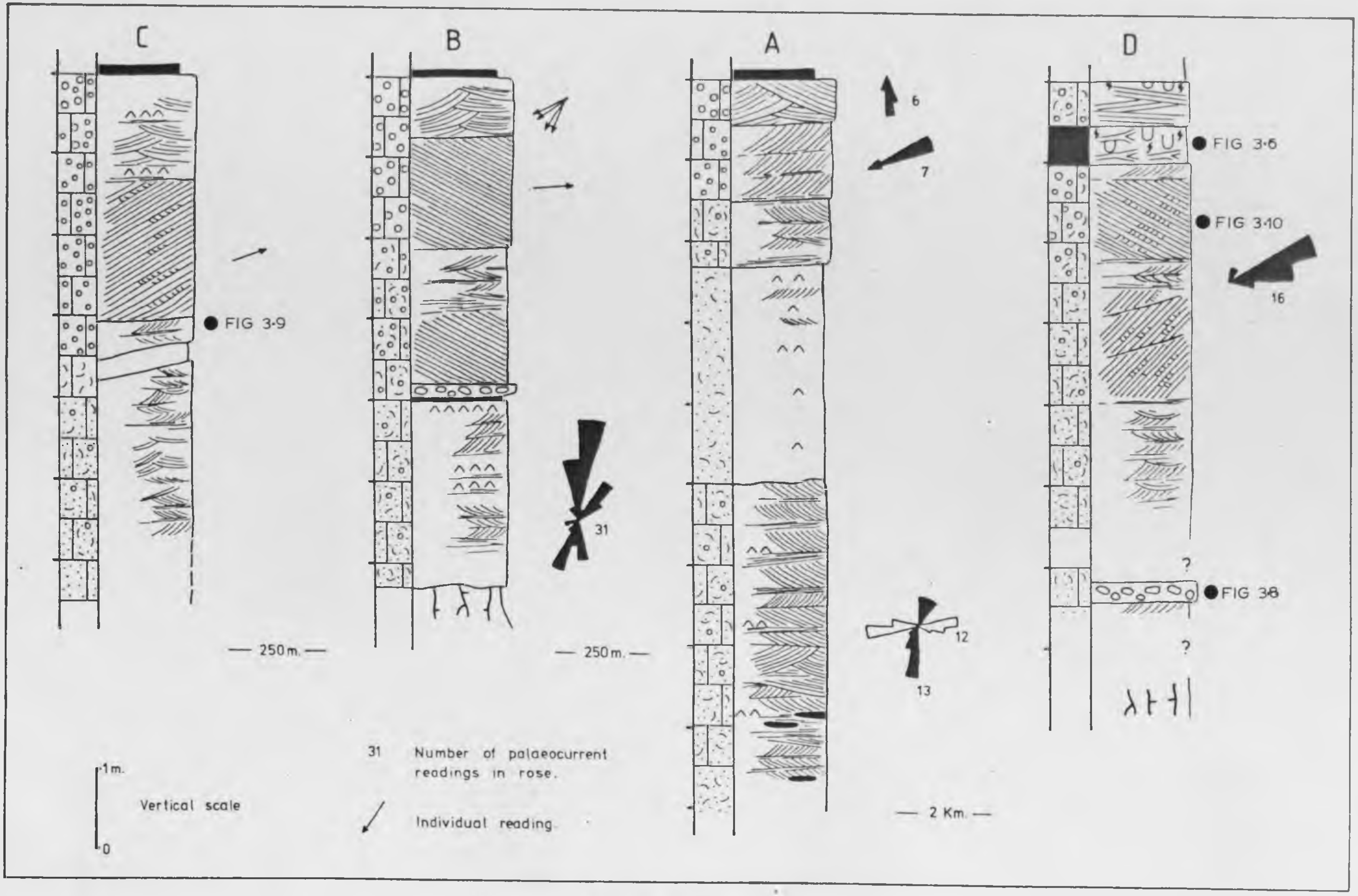

C
B
A
D
FIG 3·9
FIG 3·6
FIG 3·10
FIG 3·8
6
7
16
31
12
13
— 250m. —
— 250m. —
— 2 Km. —
?
?
1m.
0
Vertical scale
31 Number of palaeocurrent readings in rose.
Individual reading.

FIG. 3.7

erosive base over non-marine plant colonised sandstones. It has a variable thickness at Yons Nab where it overrides a non-marine channel sandstone (Log B). Much of the well sorted fine-grained sandstone appears to be reworked from the underlying sediments and the Millepore Bed does not coarsen upwards from shales as seen in Facies 1. The top parts of these two exposures grade into oolitic limestones, which coarsen upward to a grain size of 1mm (maximum long axis 2mm) in Fig. 3.7A. However, scattered ooliths occur throughout the thickness of these sections which again suggests a reworking of exotic material. Bioclasts are common, usually broken and abraded with abundant *Pentacrinus* ossicles and *Millepora*. The fauna is fully marine and Bate (1966) gives a list of ostracods present.

There is marked lateral and vertical variation in sedimentary structures in these localities. At Yons Nab the lower parts show medium scale (25cm) planar tabular and subordinate trough cross stratification. The apparently planar tabular bedforms are, however, usually gently curved when seen in plan view. The foresets dip at 28-33° and appear to be avalanche sets close to the angle of repose. Within any one area of the wave cut platform they give bipolar palaeocurrent patterns (Fig. 3.7) and show a 'herringbone' nature. The tops of individual sets are eroded with the deposition of flat and low angle laminations prior to the next cross set. Oscillation wave rippled surfaces also occur and their palaeocurrent orientations are at a variable angle to those of the larger scale bedforms (Fig. 3.7A), noted in other shallow marine deposits (Allen and Kaye, 1973) of similar type. These rippled surfaces preserve ironstained mud-drapes up to 1cm thick, though usually less, and wavelengths vary from 5-20cm.

Within the lower part of the exposures at Osgodby Point and Yons Nab there occur a series of thin laterally impersistent conglomerates. These consist of early, pre-cemented quartz sandstone and limestone clasts in a matrix of siltstones and shell debris. The clasts are sometimes rounded, suggesting abrasion, and these conglomerates have bioturbated top surfaces. The matrix is lithified by siderite into ironstones. The ironstones shown in Fig. 3.7A grade into a conglomerate between logs A and B, which again dies out before log B. The clasts resemble those found at Cloughton Wyke in Facies 2a, and consist of oolites, quartz sandstones and mixed calcareous/clastic material, indicating a mixed and varied origin although most clasts are similar to the surrounding sediment. Coarse abraded bioclastic debris is common, including abundant bryozoa, and organic wood fragments up to several cms. in length are also found. These conglomerates can be very coarse, as shown at Osgodby Point (Fig. 3.8) where they consist entirely of quartz sandstone. At log A Fig. 3.7 soft completely decalcified sandstones occur within the sequence. They cross cut primary sedimentary structures and have irregular boundaries. It would appear that they are late solution features and are restricted to the non-calcareous sandstones at the base of the facies.

Above the basal sandstones with bipolar palaeocurrent patterns, cross stratification is variable and complex. At log A Fig. 3.7 dominant trough cross bedding gives a unidirectional palaeocurrent sense. These are overlain by very large scale shallow trough cross structures (Fig. 3.7) giving a southerly palaeocurrent rose. Further east large scale avalanche sets occur near the top of the sequence, (log B). At log C one set has a maximum amplitude of 1.9m and infills a very broad shallow erosion surface (Fig. 3.9). The foresets are not simple avalanche sets but have been modified with climbing ripples and small scour surfaces. The infill at C is a fine grained oolite, and contrasts with the quartz sandstones below and sandy oolites found laterally. This erosion surface appears to be a channel, infilled by oolites which represent the youngest sediments found in the Millepore Bed. The wave cut exposure at log C shows that these foresets have a curvilinear convex horizontal plan in the direction of accretion.

These large scale bedforms are also present and dominate the sequence at Osgodby Point (Fig. 3.7D). Again the avalanche sets are not simple, being modified by climbing ripples picked out by the imbrication and alignment of shell debris (Fig. 3.10). Reactivation surfaces are also preserved but the quartz rich oolite here appears to predate the oolite infill at log C, Yons Nab. The palaeocurrent orientations of these large cross beds are all north-easterly and easterly, facing the direction of the presumed shoreline (Facies 2a).

The south-western localities show a simpler pattern of sedimentary structures although exposures are rare and poor (Fig. 3.11). In the lower oolite (Whitwell oolite) bipolar palaeocurrent patterns are found in planar tabular structures up to 30cm in amplitude at Westow and Crambeck. The top of this oolite is quartz rich and shows medium scale unidirectional trough cross stratification. The upper oolite shows a mixture of structures, including planar low angle and trough cross stratification (Fig. 3.12) giving a variable, generally bipolar palaeocurrent pattern. Hemingway (1974) reports a small reef from the lower oolite at Bulmer. Although this is no longer exposed it contained a wide variety of corals and abundant <u>Haploecia Straminea</u>

Fig. 3.9 Broad erosion surface in Facies 2b at Yons Nab (see Fig. 3.7C), thought to represent a channel. The infilling sediment (oolite) is markedly different from the quartz arenite below the persons feet. Discussion in text.

Fig. 3.10 Detail of large scale cross-stratification in Facies 2b, the Millepore Bed, at Osgodby Point (see also Fig. 3.7D). The foresets are complex and include counterflow features such as shell imbrication and small scale cross-laminations (arrowed). Note the repetition of coarser and finer-grained sediment in the avalanche sets, which have an angle of repose of 31 degrees.

Fig. 3.11 The Lebberston Member at Crambeck and I.G.S. Brown Moor borehole (see Fig. 3.1 for locations).

FIG. 3.11

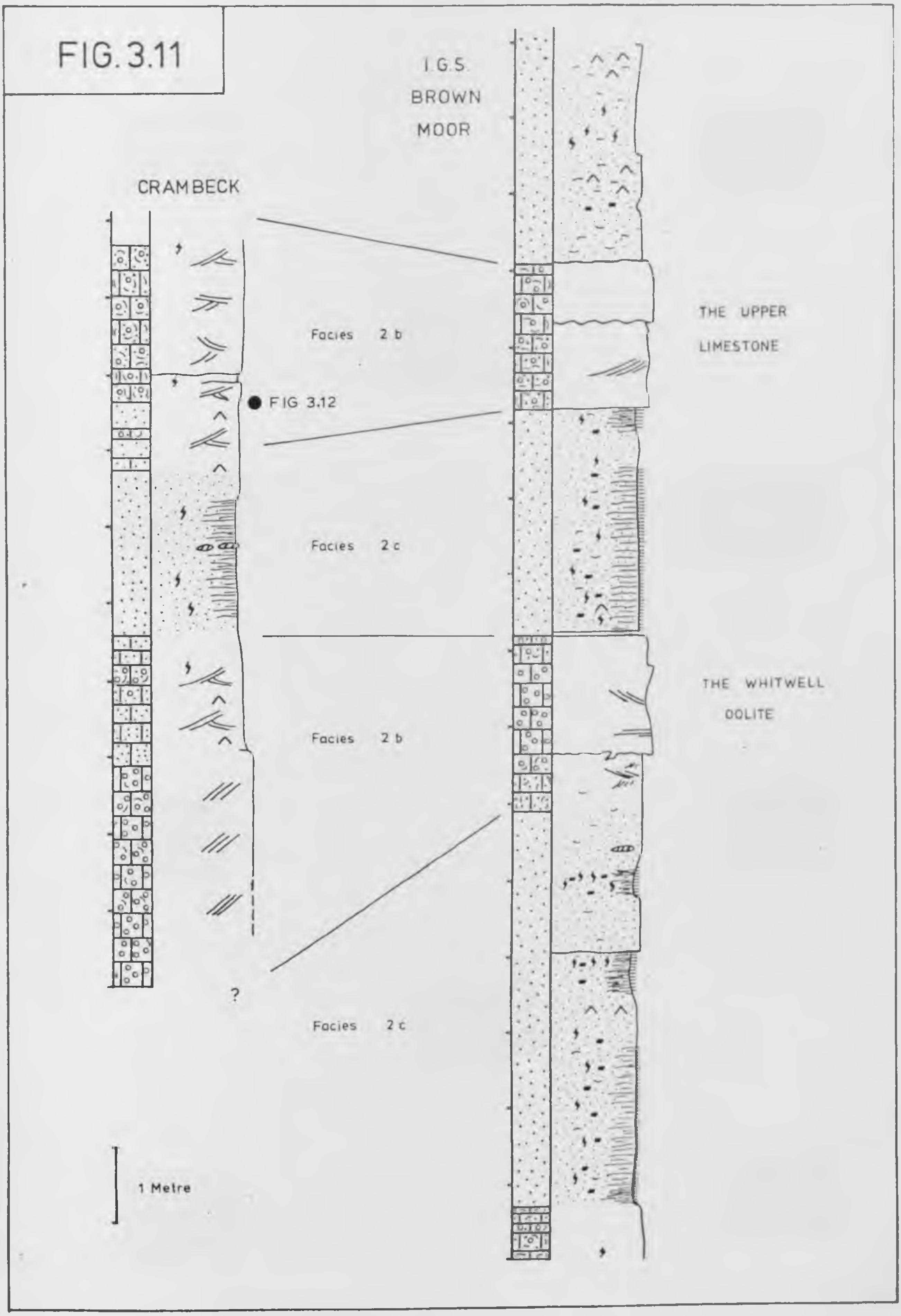

I.G.S.
BROWN
MOOR
CRAMBECK
Facies 2 b
FIG 3.12
Facies 2 c
Facies 2 b
Facies 2 c
?
THE UPPER
LIMESTONE
THE WHITWELL
OOLITE
1 Metre

Fig. 3.12 The Upper Limestone (Facies 2b) at Crambeck (Fig. 3.1). Planar low angle sets with internal discontinuities overlie a trough cross-bedded coset. The apparent bipolarity of the accretion directions is confirmed by the palaeocurrent rose taken from this locality (see Fig. 5.4).

(*Millepora*). The twofold division of these oolites occurs throughout the Howardian Hills and the basal oolite has been traced as far as Hood Hill (Fig. 3.1) (Hemingway, 1974), again no longer exposed. Pre-cemented sandstone clasts are found within the lower oolite at Low Grange farm (Fig. 3.1) and the upper oolite is thinner and contains a much larger porportion of quartz grains than the lower one. In between the two oolites a third facies is developed described below.

The thickness of the lower oolite is very variable. Bate (1966) logged it at nearly 28' (9m) from the Seamer Lime and Stone Co. quarry at Mount Pleasant adjacent to Crambeck. This has since been infilled and levelled for a caravan site. The 28' included 17' (5m) of pure oolite and this is the maximum thickness recorded in the area. Fox-Strangways (1881) stated that it became much more siliciclastic to the north-west and thinned towards the chalk unconformity to the south. This is proven at I.G.S. Brown Moor where the lower oolite is only about 2m thick. South of the Market Weighton area this limestone is represented by the Cave oolite and finally appears to be equivalent to the Middle and Upper Lincolnshire Limestone (Bate, 1966).

3.3b. Interpretation and Discussion

The base of the Millepore Bed on the coast is erosive and much of its lower quartz rich sandstone probably derives from the underlying Sycarham Member. Scattered ooliths and bioclastic debris however indicates a mixed origin for this sediment with the introduction of marine produced detritus. The lower parts of the Yons Nab exposures show bipolar palaeocurrents and a 'herringbone' appearance that has been taken in the past as being indicative of deposition under reversing tidal currents (De Raaf and Boersma, 1971, Banks, 1973). The bedforms appear to have been produced by the migration of both flood and ebb orientated straight to slightly sinuous crested megaripples. From the angle of dip of the foresets these appear to be avalanche forms, but lower dips have been recorded suggesting the presence of accretion ripples. Both forms are described from modern shallow tidal areas by Imbrie and Buchanan (1965). These bedforms build up and form sand waves and shield zones in modern Bahaman sediments with amplitudes of 1-3m (Hine, 1977). During periods of slack tidal activity or storms these megaripples are reworked and flattened out and explain the flat and low angle laminations seen to truncate the cross bedding at Yons Nab. The wave ripple sets found in this part of the exposure have fairly thick ironstone drapes, and following McCave's (1970) suggestions these would appear to have formed under waning, post storm conditions. The orientations of the wave produced forms bear no relation to those of tidal current origin.

Within the lower quartzite part of the Millepore Bed thin impersistent conglomerates mark a different environment to that shown by the megaripples, and the fine-grained matrix indicates lower energy conditions. The large clasts at Osgodby Point have a similar mineralogy to the surrounding sediments and may be equivalent to the subsea cemented clasts shown by Hine (op. cit.) forming in-between sand waves. This environment is of low energy pockets colonised by sea grasses in the Bahamas and would be ideal for the growth of the bryozoans so abundant in the Millepore Bed. Other conglomerates (log B, Fig. 3.7) are smaller, rounded and variable in lithology, including oolites. They appear generally to be lag deposits but again occur in an ironstone matrix.

This latter fact may preclude a sand wave surface lag mechanism of formation, found in similar lithotypes in the Lincolnshire Limestone (Ashton, personal comm.).

Above the dominantly quartzitic sandstones at the base of the Millepore Bed there is a large variation in bedform type. The trough cross bedding found at the top of Log A, Fig. 3.7 have an apparent landward orientation and appear to be similar to the flood orientated cuspate megaripples of Hine (op. cit.),formed on the back of sand waves. The large scale avalanche foresets also have a dominantly east north easterly foreset orientation. The one at Log C is associated with a broad channel and has a curvilinear plan similar to Gilbert-type deltas. It overlies a fine grained channel floor sediment analogous to the pelletoidal sands Ball (1967) records flooring modern channels. The large scale bedforms appear to be comparable with spillover lobes associated with channels cutting through Bahaman tidal sand bodies (Illing, 1954, Newell et al. 1960). Their flood orientation is similar with those at Lily Bank (Hine, op. cit.) where there is a dominant landward energy and sediment flux. The reactivation surfaces at Osgodby Point indicate variable periods of progradation and equilibrium, whilst the small scale climbing cross stratification is a further indication of reversing currents. It is unlikely that this feature would result from flow separation and backflow up the foresets (Jopling, 1965) as suggested by Jindrich (1969) in the tidal channels of the Lower Florida Keys because the small scale cross bedding occurs uniformly over the whole of the foreset area, and is not concentrated in the toesets. The large scale cross bedding at Osgodby Point may have formed within a channel as in similar Florida Key examples, but there is no lateral exposure and evidence of channel margins.

The Yons Nab and Osgodby Point sections appear to give a sequence of events very similar to that reported by Hine (op. cit.) for the formation of the Lily Bank. The initial Lebberston transgression reworked sediment from the underlying deposits and produced a quartzitic sand wave area. The scattered ooliths within this sediment shows an indication of previous oolite formation, presumably from earlier sediments to the south. This sand shoal zone was formed by tidal currents producing megaripples which coalesced to form larger amplitude sand waves. In-between these sand waves were low energy pockets with conglomerates of subsea cemented lumps. Early cementation also appears to have occurred within the sand waves, which on reworking, provided other conglomerate clasts. Patchy early cementation is demonstrated from comparable modern environments, again in the Bahamas (Dravis, 1979).

This shallow marine environment then provided an ideal site for carbonate sedimentation, mostly as coatings to quartz grains, and ooids were formed. At the same time there were modifications to the hydrodynamics of the environment. Following the stabilisation of the Lily Bank shield area channels with terminal flood spillover lobes formed, as tidal flow was concentrated on to particular areas of the shield. This is also demonstrated in the Millepore Bed where shallow channels cut into previously formed sediments and large scale flood orientated lobes were deposited. Ebb orientated lobes are minor in the Lily Bank area and the Millepore Bed also appears to show a dominant landward energy flux. Using Ball's (1967) classification of Bahaman environments the Millepore Bed at Yons Nab and Osgodby Point appears to represent a marine sand belt.

Hoffmeister et al. (1967) demonstrated that the channels formed in the Pleistocene Miami Limestone, a similar analogue, were unfilled and are preserved as fossil valleys. The top of the Millepore Bed however is planar within the outcrop area and it may be that later regression of the Millepore Bed sea, associated with the progradation of Facies 2a, infilled any irregularities formed by the channels. At Yons Nab the topmost large broad trough cross stratification appears from its orientation to represent a final regressional period of deposition, with the seaward migration of highly sinuous low amplitude megaripples of unknown origin. Beach cusps would produce a similar festoon cross stratification (Reineck and Singh, 1973, p. 352). Any attempt to apply a similar model to the south-western outcrops is hampered by the very poor exposure. The bipolar palaeocurrents indicate tidal conditions and from the evidence of Westow the main (Whitwell) oolite had a similar genesis to the coastal oolites. There is no evidence of channelling at any of the outcrops. The very variable thickness suggests that there was a stable sand belt in one area (Mount Pleasant - Crambeck) with gentle subsidence allowing a thick deposition of oolites. Patch reefs occurred within this main belt and the low angle cross stratification above the oolite suggest emergence and wave reworking (Ball, 1967).

3.4. Facies 2c. Bioturbated sandstones with interlaminated siltstones and mudstones.

3.4a. Description.

This facies is restricted to the south-western exposures, and it occurs both between the two oolite divisions and below the main Whitwell oolite. It is soft and easily weathered and subsequently poorly exposed. Above the Whitwell oolite in the Brown Moor borehole it consists of nearly 3m of thinly bedded very fine-grained sandstone with silt interlaminae. Large carbonaceous fragments are abundant together with a varied marine bivalve and gastropod fauna. Bioturbation is common, usually on a small scale, and Thalassinoides occurs at the top of this unit. Faecal pellets are recorded in siltstones both above and below the main oolite, usually as aggregates. Below the main oolite this facies consists of 4m of muscovitic silty sandstones and mudstones, again bioturbated, in a low energy environment showing only small scale oscillation ripples. Thin ironstones occur here and are also found at Crambeck between the two oolites. Thin fining upwards units with reworked ooliths and scattered ironstone nodules are recorded in the Brown Moor borehole. Fordon No. 1 borehole demonstrated pyrite and glauconite from silty sandstones within the Millepore Bed, presumably in a similar facies.

At Crambeck this facies consists of 70% mudstone in places, with interlaminated thin sandy streaks. Wavy bedding and small scale bioturbation is also present but the whole section has been decalcified and no marine fauna were collected. Much of the previous interest in the Lebberston Member in the south-west has centred on the oolites, which were worked for building stone. The sediments in between and below are poorly exposed and were largely ignored. However, from the evidence of the I.G.S. Brown Moor log (Fig. 3.11) it would appear that volumetrically they may be more important than the more spectacular limestones.

3.4b. Interpretation and Discussion

This facies appears to represent a rather different environment to the high energy oolites interbedded with it. No large scale bedforms are found and what sediment movement that occurred was under wave action, producing oscillation ripples. Bioturbation was common in this low energy environment and a high organic turnover is indicated by the faecal aggregates. Similar environments occur within modern oolite provinces, and Ball (1967) named them platform interior sand blankets. They are very extensive and heavily bioturbated with a significant mud fraction. Oolites are driven on to these platform environments during storms and this mechanism can be invoked for the similar occurrence in Facies 2c. The fining upwards units in the Brown Moor borehole may also be storm derived. Apart from these irregular high energy periods the dominant influence on the sediments in modern interior platform areas are wind driven waves. The combination of high energy sandy environments and protected low energy platform interiors is well marked in the Bahamas. Despite the poor exposure this appears to be a suitable model for the association of Facies 2b and 2c in the south western localities (Fig. 3.11).

3.5. Discussion on Facies Association 2 (The Lower Lebberston Member)

The initial transgression appears to have been gradual, with the formation of ooliths to the south of the present outcrop. This exotic material was mixed with reworked underlying sediment as sea level rose. This gradual transgression is in marked contrast with Facies 1 and did not produce a coarsening upwards profile. Initial deposition rates were rapid forming a broad sand wave area south of Scarborough with a strandline to the north. Lily Bank formed adjacent to a steep bank margin, but Ball (1967) using Sand Key, Florida as an example, demonstrated that such a situation is not necessary for the formation of a marine sand belt. The Millepore Bed appears similar to this example, for boreholes to the south (Fordon, Fig. 3.1) show no evidence of sudden increases in water depth in this direction. As sea level stabilised in the resulting shallow gently shelving,sea flood and ebb tides were concentrated into channels, with a dominant shoreward migration of sediment, some of which was carried on to the variable shoreline, as at Cloughton Wyke. This adjacent strandline was of moderate energy, evidently protected by the offshore sand belt and the long shallow area of fetch. It fluctuated in position slightly and was an area of highly active infauna.

The stability of the sea level and decrease in derived terrigenous clastic material allowed the growth of calcareous coatings around bioclasts, pelloids and especially quartz grains. The upper parts of the Millepore Bed are pure oolites suggesting in situ formation. This ooid production gives us more indication of the prevailing environment. The maximum northerly present day formation is $27\frac{1}{2}^{\circ}$N (Lily Bank), and ooid production is governed by water depths, temperature, salinity, biological activity and agitation (see Bathurst, 1975 for discussion, p. 295). Newell et al. (1960) showed that optimal ooid formation is in less than 6' (2m) of water, just below and in the intertidal zone. The exact depth of the Millepore Bed sea is difficult to assess because deposition of the sand wave area occurred whilst sea level was rising, but it must have been less than 8m in the outcrops on the coast. Deposition and infill shallowed the sea and allowed ooid formation.

Early cementation was fairly common in this carbonate rich environment, both on the strand line and within the offshore sediments. Dravis (1979) estimated that hardgrounds form in a few months or less in the high energy Eleuthera Bank, and rapid modern beach cementation is illustrated by the inclusion of recent artifacts (Bathhurst 1975). These early cemented layers were subject to erosion and redistribution as clasts, under inferred storm conditions.

The time involved in the formation of the Millepore Bed is difficult to assess. Hine's work showed that the Lily Bank has evolved since the initial sea level rise 5,700 years ago, and the sand wave area formed 3,500 yrs B.P. on the deceleration of the sea level rise. Newell et al. (1960) estimated a figure of 5,000 yrs for the present Bahaman cycle, and a similar time scale is invoked for the formation of the coastal Millepore Bed. The Millepore Bed differs from the Bahaman model in that it overrides soft bedrock rather than cemented limestones. As such there was a lot more terrigenous material available to be reworked.

In the south western area there were two periods of <u>in situ</u> oolite formation, with derived ooliths introduced as a lag deposit at the base of the Member at Brown Moor. This region appears to show a combination of marine sand belt and platform interior sand blankets, with transgression of the former landwards over the latter. This occurs today (Hine, op. cit.) and is also reported from the Pleistocene (Hoffmeister et al.). The repeated environment suggests that subsidence and transgression occurred after the deposition of the Whitwell oolite. Previous workers (Hemingway, 1974) suggest that this transgression is laterally equivalent to the Yons Nab Beds, and this will be discussed later. The volumetric importance of the platform interior sediments has been ignored and most previous study has concentrated on the oolites.

3.6. Facies Association 3. Laterally variable largely marine mixed fine and medium-grained clastic sediments - The Yons Nab Beds.

The Yons Nab Beds (Hemingway 1949) were named after one locality, first recorded in 1829 (Phillips). A number of authors collected from the extensive marine fauna at this exposure, and Bate (1959) gives a full list of the fossils present. Bate undertook the last major work on this sequence and he described a laterally equivalent marine section at Cloughton Wyke. He regarded all the rocks north of here as 'deltaic'.

This analysis deals with a more extensive series of rocks found between the Millepore Bed and the overlying Gristhorpe Member along the coast from Ravenscar to Yons Nab (Fig. 3.1). This series is marked by lateral variation and repetition and has been divided into four facies described below.

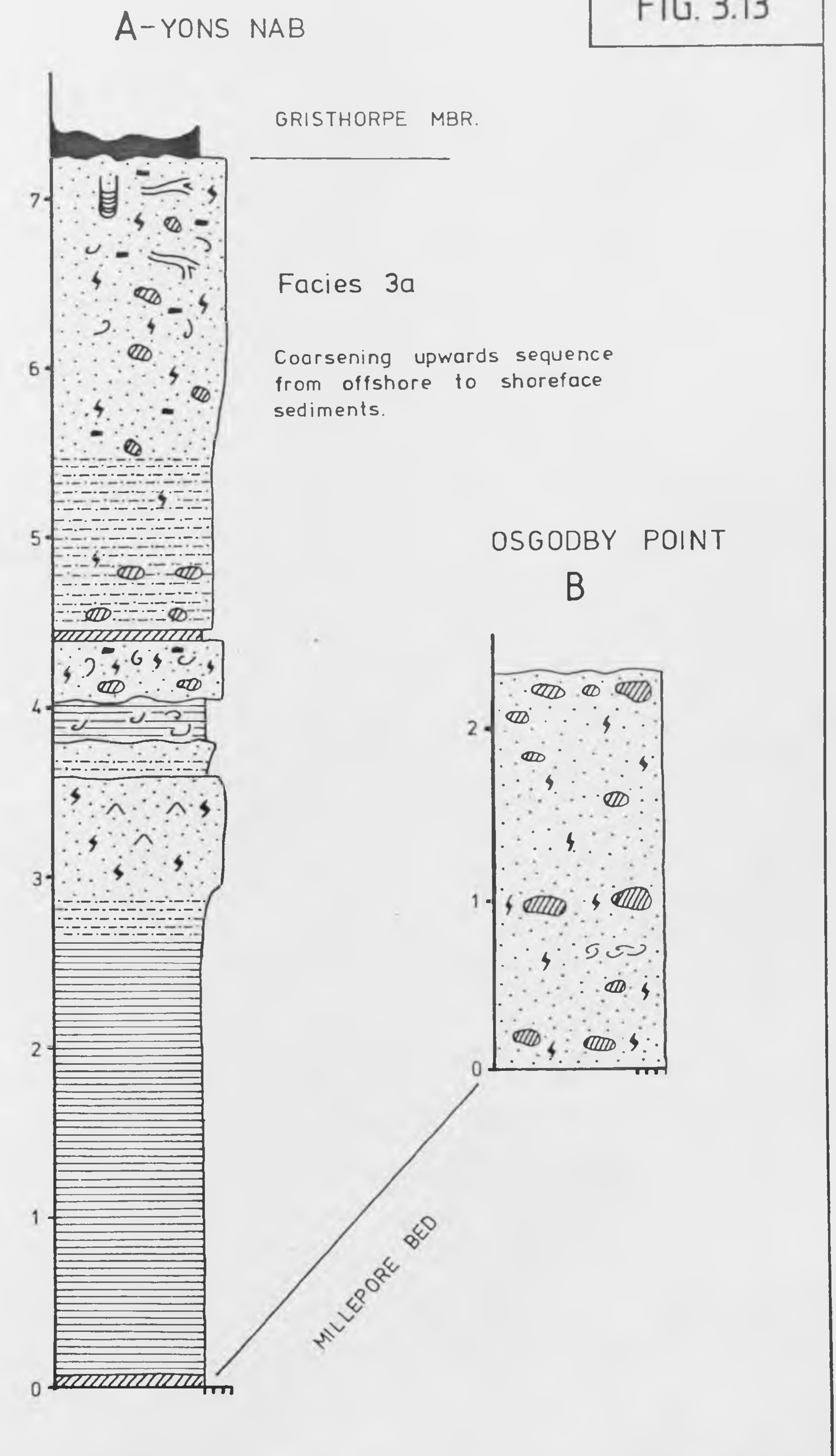
3.7. Facies 3a. Coarsening upwards shale to extensively bioturbated sandstones.

3.7a Description

This facies occurs at one locality, the foreshore exposure at Yons Nab where it is about 7m thick (Fig. 3.13). It outcrops between the Millepore Bed and overlying Gristhorpe Member and has been partly eroded by a younger fluvio-deltaic channel sandstone. In its lowest part it consists of pale laminated silty shales which are generally unfossiliferous and weather out, making their exact thickness difficult to ascertain. They coarsen upwards gradually to a heavily bioturbated silty sandstone with ironstone nodules. Towards the south-east this sandstone has a hard calcareous cement and a particularly rich fauna. Rhizocorallium burrows and symmetrical wave generated ripples are also present. Above this sandstone the sequence is silty with a high

Fig. 3.13 Facies 3a at Yons Nab (A) and Osgodby Point (?) (B)
See Fig. 3.1 for locations.

FIG. 3.13


A-YONS NAB
GRISTHORPE MBR.
Facies 3a
Coarsening upwards sequence from offshore to shoreface sediments.
OSGODBY POINT
B
MILLEPORE BED
0
1
2
3
4
5
6
7

concentration of plant fragments. The top of the section is represented by a fairly well sorted fine to very fine-grained sandstone with shell debris. This sandstone is completely bioturbated with Diplocraterion and Thalassinoides particularly well developed on bedding plane surfaces. Individual burrows are picked out as heavy ironstone accumulations, being resistant to weathering. No sedimentary structures survived the intensive burrowing activity of the varied infauna. Bate (1959) gives a full list of the marine macrofossils present, and in a later work (1966) demonstrates a varied ostracod fauna.

A similar heavily bioturbated sandstone with marine fauna occurs at Osgodby Point (Fig. 3.13) overlying bioturbated Millepore Bed sediments with low angle cross bedding. If these two sandstones shared the same genesis then the thick basal shales and siltstones seen at Yons Nab were not deposited here. The bioturbated ironstones at Osgodby Point may mark a local 'hiatus', but the correlation of the two sandstones across Cayton Bay is based solely on lithology and position and is therefore tentative.

3.7b. Interpretation and Discussion

This coarsening upwards marine sequence is on a similar scale to those in Facies 1. However it can be readily distinguished by its broken coarsening upwards profile and intense bioturbation. The lower shales appear to represent offshore marine sediments with clastic material deposited from suspension. These shales coarsen upwards to shallower marine (upper offshore or lower shoreface) sandstones which are heavily bioturbated suggesting low energy conditions. No evidence for bedform migration or other beach processes is seen. The sandstones are overlain by non-marine sediments and eroded into by a later channel. This coarsening upwards progradational sequence may only represent an incomplete profile, with regression occurring before the marine area could be completely infilled. If the two sandstones are equivalent across Cayton Bay then there must have been a rapid variation in water depth in a short distance. There is no evidence from any of the boreholes to the south that gives information on this environmental interpretation.

3.8. Facies 3b. Uniform well sorted fine-grained sandstone bodies

3.8a. Description

This facies has been recorded at two localities, Cloughton Wyke and Petard Point (Fig. 3.1), and the logs are presented in Fig. 3.14. Both exposures show a similar thickness of clean well sorted fine-grained sandstone directly overlying the Millepore Bed. Both localities terminate in shales with a thin shaley coal seam. The Cloughton Wyke exposure contains broken and abraded shell debris, including Pentacrinus ossicles. Bioturbation is rare but simple subhorizontal and vertical burrows preserved as ironstone nodules have been observed. They appear to be similar to Ophiomorpha, but the ironstone has replaced and destroyed the burrow linings and no pellets were found to verify this identification.

The sand body at Cloughton Wyke can be traced for 350 metres from its southern end, where it is cut into by Facies 3d sediments, to its northern limit where it is laterally replaced by Facies 3c. At Petard Point the exposure is poor but this sand body can be traced for over 100m northwards using cliff photographs. Large scale trough cross stratification occurs at the southern end of each sandbody exposure,

Fig. 3.14 Facies 3b at Cloughton Wyke and Petard Point.
Locations shown in Fig. 3.1.

FIG. 3.14

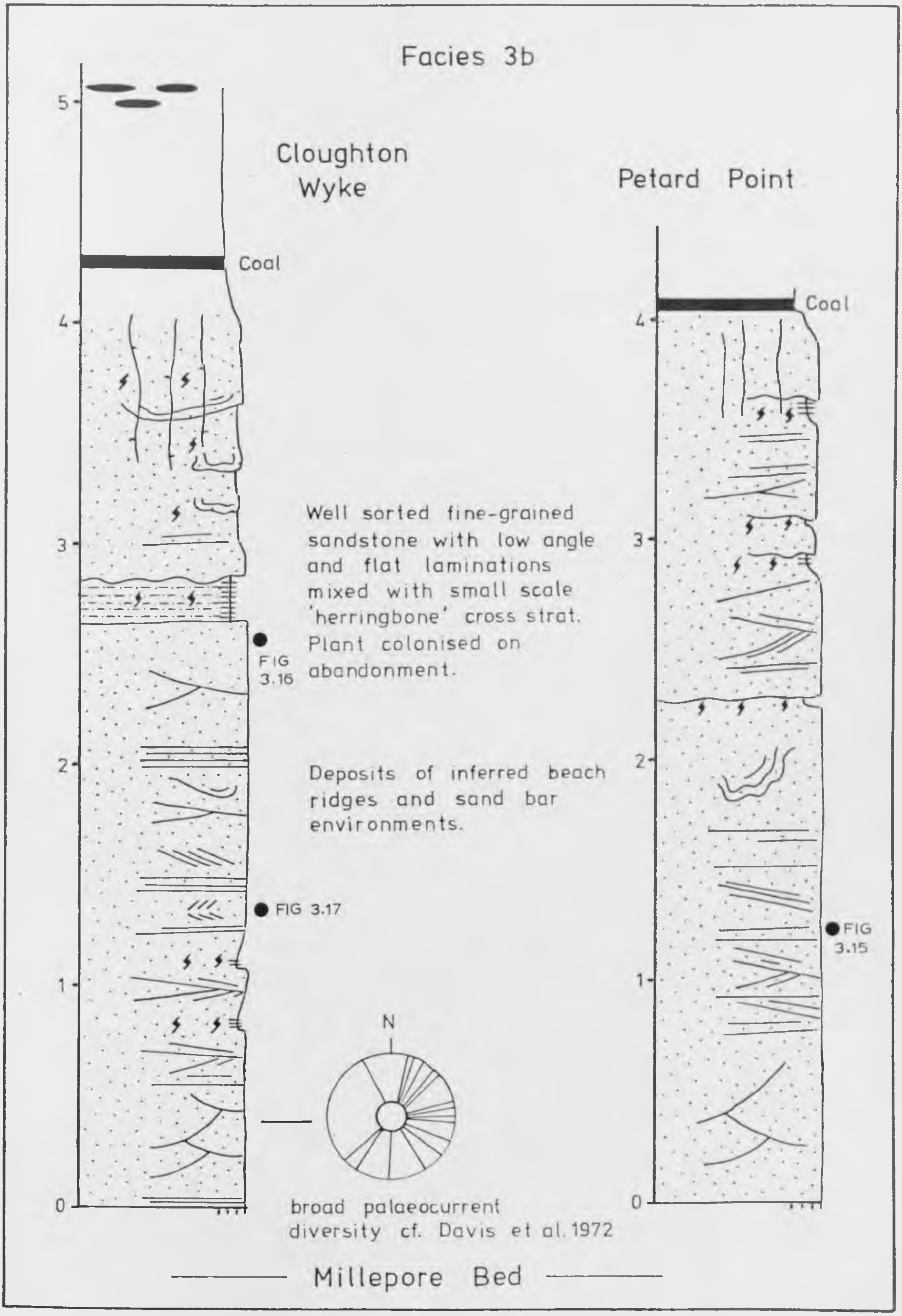

Facies 3b
Cloughton Wyke
Petard Point
Coal
Coal
5
4
3
2
1
0
4
3
2
1
0
FIG 3.16
FIG 3.17
FIG 3.15
Well sorted fine-grained sandstone with low angle and flat laminations mixed with small scale 'herringbone' cross strat. Plant colonised on abandonment.
Deposits of inferred beach ridges and sand bar environments.
N
broad palaeocurrent diversity cf. Davis et al. 1972
Millepore Bed

Fig. 3.15 Detail of cross-stratification in Facies 3b at Petard Point. Note the low angle forms to the right of the notebook. The high angle coset at the top of the photograph shows soft sediment deformation.

Fig. 3.16 Ladder ripples in Facies 3b at Cloughton Wyke. Two sets of wave ripples interfere at approximately 90 degrees.

associated with minor amounts of mudflake conglomerate and ironstone nodules. At Cloughton Wyke these troughs are 20-25cm in amplitude and give variable palaeocurrent directions (Fig. 3.14). Those at Petard Point are larger features, several metres broad (measurement unorientated to palaeocurrent direction). Northwards these troughs give way to varied sedimentary structures, although flat laminations predominate and occur in sets up to 40cm thick. Low angle cross stratification is also prominent (Fig. 3.15) as well as symmetrical wave generated ripples and ladder ripples (Fig. 3.16). These latter bedforms occur near the top of the sections where soft sediment deformation is particularly common. Higher angle cross bedding is also present interbedded with the low angle and flat laminations (Fig. 3.15) and in some cases small scale high angle cross bedding appears to show 'herringbone' structures (Fig. 3.17). Very little of the sand bodies are accessible however and the homogeneous nature of the sediment gives smooth fracture surfaces making it very difficult to pick out structures and allow a thorough in situ analysis. The upper parts of both sandbodies show well bedded sandstones with silty layers and increased bioturbation. Roots penetrate into these upper sediments and plant debris is common.

3.8b. Interpretation and Discussion

Faunal evidence suggests these are marine sediments, with rapid deposition indicated by the general paucity of bioturbation. The low angle and flat laminations that dominate the internal structures appear to have been produced by swash and backwash processes in a foreshore environment, marking emergence of the sand bodies. The high angle and small scale 'herringbone' cross stratification suggests

Fig. 3.17 Facies 3b at Cloughton Wyke showing small scale 'herringbone' cross-laminations (arrowed) in well sorted fine-grained sandstone, indicating tidal activity.

Fig. 3.18 Facies 3c at Roger Trod 350m north of Cloughton Wyke (Fig. 3.1). Bioturbated siltstones and shales with thin sandstone interbeds. Note the wave rippled sandstone below the lens cap, and the flat laminated one 8cm above.

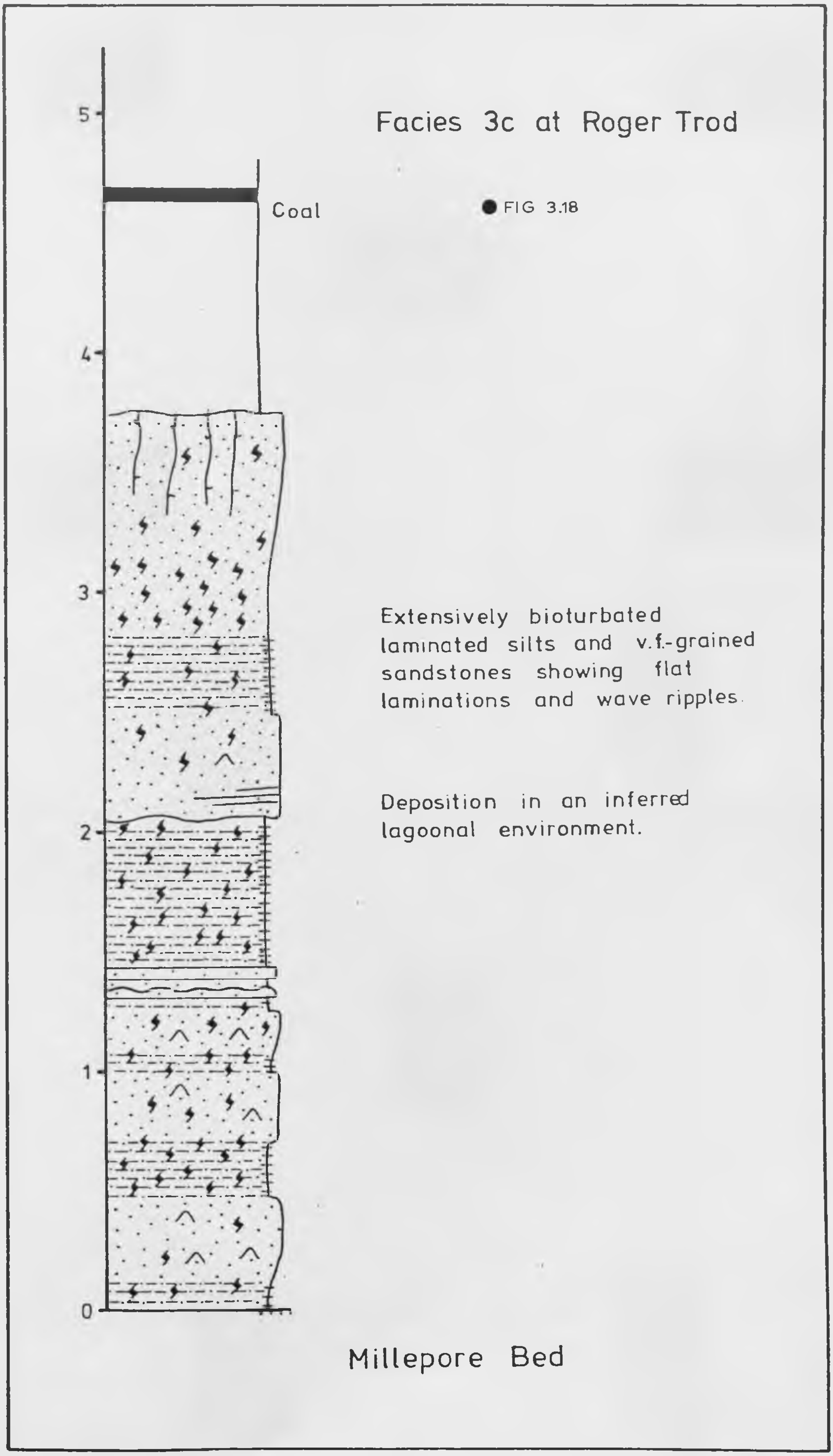
a mixed depositional regime with the influence of tidal currents suggesting submergence. Nearer the top ladder ripples mark an interference of wave action. At the southern (seaward from palaeogeographical considerations) ends of both sand bodies trough cross stratification is present. Those at Cloughton Wyke may indicate tidal effects on the shoreface (Davis et al. 1972). The ones at Petard Point are laterally equivalent to the cross stratification shown in Fig. 3.14, and from their scale they may represent seaward progradation of beach cusps, which produce large scale festoon cross stratification (Reineck and Singh, 1973, p. 352). After deposition these sand bodies were abandoned and colonised by plants. There is no evidence of associated aeolian activity.

3.9. Facies 3c. Bioturbated laminated siltstones and very fine-grained sandstones

3.9a. Description

This facies is found north of Facies 3b at Cloughton Wyke and south of it at Petard Point. At Roger Trod, 350m north of Cloughton Wyke there is a complete exposure of Facies 3c and this is presented in Figs. 3.18, 3.19. It consists mainly of bioturbated silty laminated shales with thin sharp based interbedded sandstones which were normally bioturbated after deposition. Thin flat laminated and wave rippled sandstones also occur as well as lenticular bedding. Bioturbation is heavy, with Chondrites well developed, and no fauna was recorded. The siltstones coarsen upwards to very fine and fine-grained sandstones, with small scale cross stratification and convolute laminae marking soft sediment deformation. Roots occur on the top of these sandstones which are overlain by shales and a thin coal which is also seen at Cloughton Wyke.

FIG. 3.19


Facies 3c at Roger Trod
5
4
3
2
1
0
Coal
FIG 3.18
Extensively bioturbated laminated silts and v.f.-grained sandstones showing flat laminations and wave ripples.
Deposition in an inferred lagoonal environment.
Millepore Bed

South of Petard Point silty bioturbated shales are overlain by thin bedded symmetrical wave rippled sandstones. One large cross set was recorded (Fig. 3.20) of well sorted fine-grained sandstone. Similar sediments to Facies 3c occur at the base of the Gristhorpe Member overlying the coal recorded above the Yons Nab Beds sequence and are well exposed at Cloughton Wyke.

3.9b. Interpretation and Discussion

The fine-grained sediment in this facies suggests the dominance of suspended clastic input into the environment. Small scale wind generated wave ripples reworked thin sandier laminae. Sharp based sandstones mark periodic coarser clastic input, much of which was rapidly bioturbated. One thin (9cm) sandstone shows flat lamination (upper phase?) and others were reworked by waves acting on their upper surfaces.

The heavily bioturbated sediment is similar to that found in modern coastal lagoons (Reineck & Singh, 1973, p. 350). Wave ripple cross bedding is common with input of sand into the environment usually occurring during storms. The flat laminated and sharp based sandstones seen at Roger Tod could represent washover deposition from an adjacent coastline. In modern environments these are rapidly burrowed, especially near water level (Frey and Mayou, 1971). Warme (1967) demonstrated sediments produced by marsh progradation over a modern lagoonal environment where burrowing is intense. This is demonstrated in the Yons Nab sequence where the exposures are terminated by plant colonisation.

The large scale cross lamination south of Petard Point (Fig. 3.20) is overlain and underlain by finer grained sediment. This cross lamination is contrastingly well sorted with foresets dominating its

Fig. 3.20 Facies 3c south of Petard Point showing one large scale cross-set in well sorted fine-grained sandstone, thought to represent a micro delta prograding into a lagoonal environment.

Fig. 3.23 The Yons Nab Beds at Cloughton Wyke. Facies 3d siltstones downcutting into massive fine-grained sandstones of Facies 3b (scour surface arrowed). Note the channel shape in Facies 3d on the left hand side of the photograph. The sediments above the Yons Nab Beds form the Gristhorpe Member (see Section 4.15).

form at the expense of poorly developed toe and bottom sets. This bedform resembles the micro deltas generated experimentally by McKee (1957) and Jopling (1965). They always occur as single solitary bodies (Reineck and Singh, 1973, p. 92) and are hydrodynamically isolated from the adjacent sediment. The scale of this microdelta and the distance of progradation suggests a standing water body, for variations in water depth modify the top sets of such features (Jopling op. cit.). This exposure south of Petard Point may well represent a lagoonal pond isolated from the main, presumably tidally affected lagoon. Neither exposure shows much evidence of tidal variation and both may have been deposited away from a main intertidal zone.

3.10. Facies 3d. Bioturbated erosive based interbedded sandstones and siltstones.

3.10a. Description

A thick (6m) sequence of interbedded sandstones and siltstones overlie Facies 3a sediments at Osgodby Point (Fig. 3.21). This sequence is soft and friable and it proved impossible to log. It is bioturbated at the base with 'U' burrows but usually only Chondrites are preserved. The sandstones are fine-grained and in places show medium scale cross bedding. At the northern end of Osgodby Point these siltstones and sandstones show a primary sedimentary dip to the south (Fig. 3.21). The beds steepen locally to the south here with a slight but marked internal discontinuity. Channel sandstone bodies cut into this facies at the northern and southern ends of this exposure.

At Cloughton Wyke an erosive based siltstone sequence cuts down

Fig. 3.21 The Millepore Bed - Gristhorpe Member transition at Osgodby Point (Figs. 3.1, 3.7). The blocks in the foreground are bioclastic sandy oolitic limestone of the Millepore Bed. The Yons Nab Beds are represented by a thin bioturbated sandstone (Fig. 3.13B) overlain by interbedded siltstones and sandstones of an inferred tidal channel deposit. Note the large width to depth ratio of this channel compared with the two erosive based Gristhorpe Member channels (C and F) above the Yons Nab Beds sequence.

A - Bioturbated sandstone overlying the Millepore Bed (Fig. 3.13B).

B - Low angle surfaces with internal discontinuity, interpreted as lateral accretion surfaces.

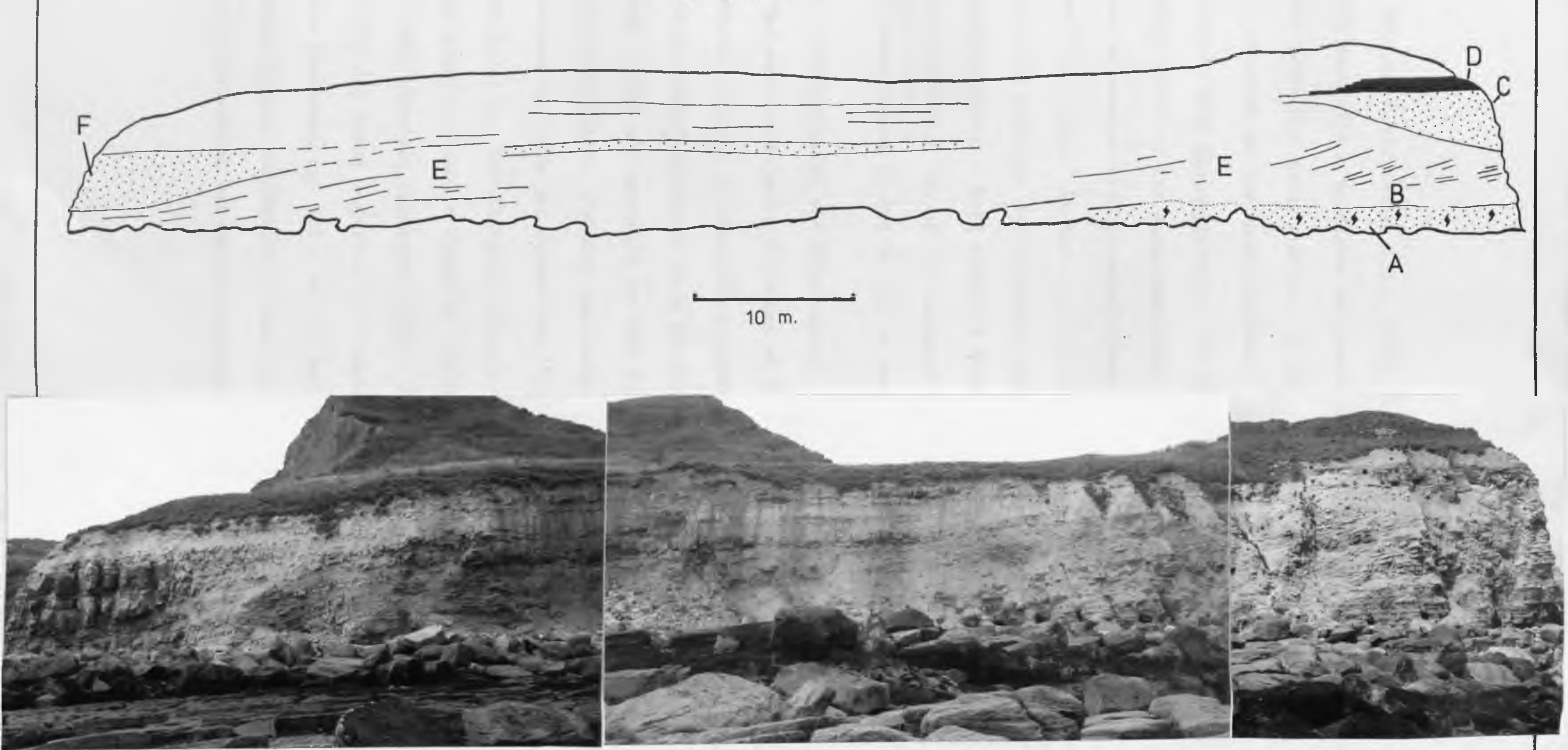
C - Fluvial channel sandstone of the Gristhorpe Member (Facies 4ii Type I) cutting into previous deposits of the Yons Nab Beds.

D - Sudden abandonment of the channel at C is marked by the deposition of dark rooted shales. The contact is very sharp without gradual fining-upwards.

E - (2). Bioturbated interbedded siltstones and sandstones, similar to the cored tidal channel deposits demonstrated by Oomkens (1974).

F - Later sand dominant channel fill with a similar, but less pronounced sharp top as the one at C.

FIG. 3.21

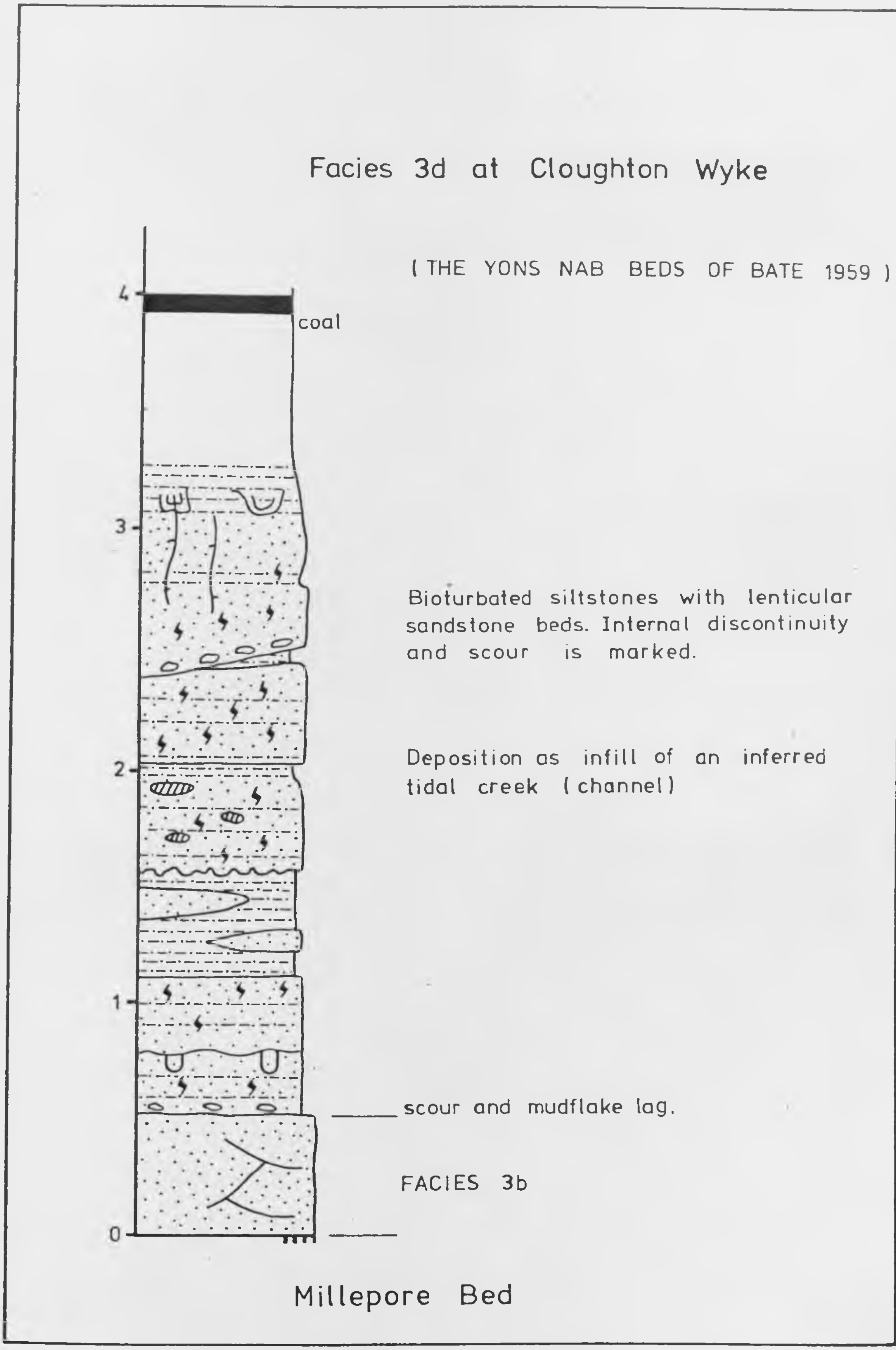


into Facies 3b sandstones (Fig. 3.22). These sediments have an erosive base with a mudflake conglomerate and organic debris lag deposit above the scour surface. It was these sediments that Bate (1959) recorded as the Yons Nab Beds. They are quite heavily bioturbated with *Diplocraterion* and *Chondrites* almost completely reworking parts of the basal deposits. The infill to the erosion surface is complex with internal discontinuity and local channel shapes (Fig. 3.23). It has a marine fauna, including *Lima* and other thin shelled bivalves and ostracods are fairly abundant in the darker siltstones. Soft sediment deformed silty sandstones with roots occur at the top of the sequence and the same coal that is found above Facies 3b and 3c can be seen (Fig. 3.22).

3.10b. Interpretation and Discussion

The sandstones and siltstones at Osgodby Point are bioturbated, suggesting a marine or brackish influence. The primary sedimentary dip and fining upward nature of this sequence suggests lateral accretion, although it was not possible to take palaeocurrent readings to verify this interpretation. Primary sedimentary dips on such a scale can also be produced by mouth bar deposition, but this usually forms a coarsening upwards profile. The interlaminations of sandstone and siltstone seen at this outcrop resemble those in cores from the Quaternary Niger Delta tidal channels (Oomkens, 1974). The large width to depth ratio of the Osgodby Point sequence is compatible with those from modern tidal channels (Oomkens, op. cit.) and is much larger than those seen in the overlying fluvial sandbodies. This exposure is therefore interpreted as a tidally influenced laterally migrating distributary channel.

FIG. 3.22


Facies 3d at Cloughton Wyke
(THE YONS NAB BEDS OF BATE 1959)
4
3
2
1
0
coal
Bioturbated siltstones with lenticular sandstone beds. Internal discontinuity and scour is marked.
Deposition as infill of an inferred tidal creek (channel)
scour and mudflake lag.
FACIES 3b
Millepore Bed

The section at Cloughton Wyke is rather different. It has a demonstrably concave erosional base and channel-like form. The restricted fauna (ostracods and thin shelled lamellibranchs) suggest a partial marine influence. The bioturbation forms, especially the Diplocraterion at the base, also point to a marine environment. The infill is mostly fine-grained and shows a complex series of bedding.

Reineck and Singh (1973, p. 353) describe the general attributes of gullies (tidal creeks) pointing out the bioturbation as well as the variable bedding and sediment associated with these environments. Ostracods are apparently common in muddy creeks and a connection with the sea would allow thin shelled bivalves to be brought in. A fully open marine fauna would not be found, and this helps to explain the restricted fossils found.

Both these exposures seem to represent tidally influenced channels, but of demonstrably varied scale. They are both unique exposures in the Ravenscar Group and it would appear that they represent a stratigraphically restricted heirarchy of marine influenced tidal channels.

3.11. Summary and Discussion of Facies Association 3.

Although there are only five exposures along the coast from Ravenscar to Yons Nab, the lateral variation in this horizon is marked. These sediments are contemporary, for they overlie the contrasting Millepore Bed and terminate in non-marine Gristhorpe Member deposits. North of Cloughton Wyke a thin coal marks the abandonment of the environment and provides a good marker horizon.

The Yons Nab Beds sequence represents a prograding environment with short term periods of stable coastline allowing the deposition of sand bodies under wave and tidal energy. Much of this sand must have been introduced into the depositional area by longshore currents. Rapid advance of the shoreline abandoned earlier sand bodies and a new coastline was formed. In between the upstanding abandoned and new coastlines lagoonal environments developed with most of the sediment deposited from suspension. Thin washover sandstones were introduced during storms which overtopped the coastal sandstones. Marsh progradation cut off areas of standing water into which small streams also deposited coarser material. Plant colonisation helped to fix the upstanding sand bodies, and as the lagoons were infilled these too provided sites for vegetation.

A heirarchy of tidal channels controlled the main water flow behind the coastline, in places cutting through the abandoned sand ridges. Deposition occurred on the point bars of these channels and formed lateral accretion surfaces. As the environment prograded coarser clastic material was introduced into the offshore area, forming the coarsening upwards sequence seen at Yons Nab. The overlying Gristhorpe Member shows a basal sequence of sediments very similar to Facies 3c, suggesting a continued lagoonal environment at Cloughton Wyke and northwards. At Osgodby Point and Yons Nab later Gristhorpe Member channels cut deeply into Yons Nab Beds sediment and mark a complete change from the marine deposition seen in the Lebberston Member to non-marine sediments following progradation.

This broad facies associated is analogous to the modern and ancient sediments of the Niger Delta (Allen, 1965a, 1965b, 1970, Short and Stauble,1967, Oomkens, 1974). In the Niger Delta coastal sequences are overlain and cut into by tidally influenced deposits of the lower deltaic plain. With progradation these deposits are overlain and cut into by the fluvial dominated upper deltaic plain, seen in the Gristhorpe

Member sediments.

In the Niger Delta the beaches are dominated by backwash and swash processes, and small scale cross stratification is rare. Plant colonisation is rapid and destroys the laminations in the upper parts of abandoned beach ridges. In the Yons Nab Beds tidal influence on the sand bodies is more marked suggesting that they were not built up to the same height as in the Niger Delta and were frequently overtopped by tides. There is no evidence of aeolian activity in the Yons Nab Beds which redistributes a certain amount of dry sand on upstanding beach ridges in the Niger (Allen, 1965a).

The lower deltaic plain is dominated by mangrove swamps cut into by meandering tidal channels. In the swamps suspended sediment is dominant with high rates of bioturbation and rapid dissolution of calcareous material (Oomkens, 1974). Drifted plant debris abounds, and the coal that terminates the Yons Nab sequence has a poor root foundation suggesting that it accumulated by such a mechanism. Meandering tidal channels deposit lateral accretion surfaces and cut into and erode earlier coastal sediments. Slow progradation of the Niger Delta allows large scale reworking of coastal sediments, giving them a low preservation potential (Oomkens, 1974). There is evidence from the Yons Nab sequence that deposition was rapid with sudden progradation of the upper deltaic plain Gristhorpe Member. This progradation involved erosion by fluvial channels cutting into the lower deltaic plain sediments.

The rapid progradation helps to explain the paucity of mouth bar and tidal deltas seen on the coastal sections. Lateral migration of channels and inlets reworks coastal deposits (Kumar and Sanders, 1974) and in ancient examples of similar environments ebb and flood tidal deltas form a bulk of the sediments (Hobday & Horne, 1976). Masters (1967) also demonstrated this from a similar example in the Cretaceous of Colorado. In this case marsh progradation is thought to have cut off areas of standing water forming lagoonal ponds, the environment envisaged for the deposits south of Petard Point. This non-tidal environment in front of the sandbody and the lagoonal nature of the Roger Trod section discounts a chenier plain interpretation for the Yons Nab sequence. In such an environment tidal mudflats alternate with sandstone bodies (Hoyt, 1969).

3.12. Evidence from inland.

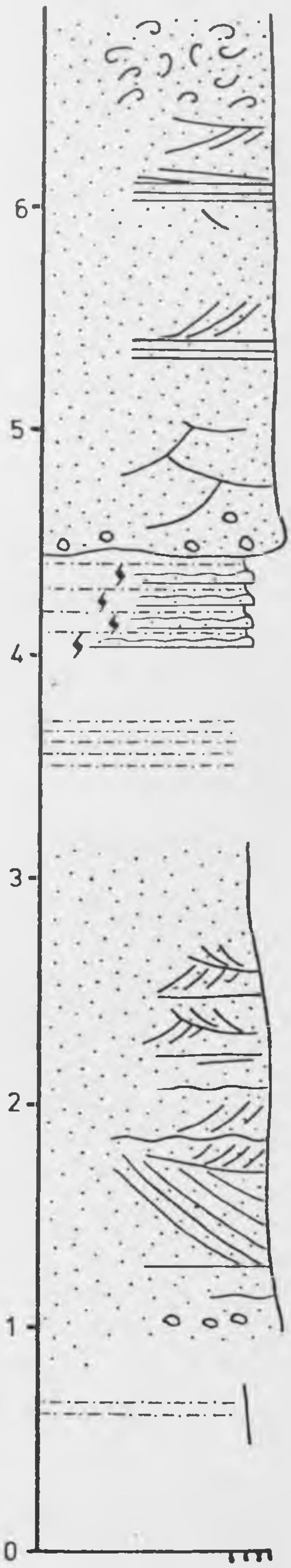
All the exposures so far described have been taken from the coastal sections because inland exposure is very poor. The Yons Nab Beds do not extend as far north as the Millepore Bed sediments, which are overlain by plant colonised shales and sandstones. Further south this horizon occurs high up on the Yorkshire Moors and is not exposed. In the Hambleton Hills exposure is now very poor, and there is no evidence of further marine sediments above the Whitwell and Upper oolites. In the Howardian Hills the only Lebberston Member exposures were in building stone quarries now mostly infilled.

One interesting exposure remains and was logged from the old limestone quarry at Oulston (Fig. 3.1). At the back of the quarry a siltstone and sandstone exposure remains which is presented in Fig. 3.24. The oolites are no longer exposed but the position of the log in the sequence can be fixed from the memoir section (Fox-Strangways, 1886). Above the Upper oolite 1'3" of shale was logged followed by 16' of siliceous sandstone and shaley beds. This 16' is represented by the log in Fig. 3.24. The lower sandstone shows large scale cross stratification which gives a bipolar palaeocurrent rose. This must overlie the Upper oolite and represents a tidal sandstone body with tabular and trough cross bedding deposited under high energy flood and ebb currents. This sandstone is overlain by mixed siltstones with thin interbeds of wave rippled sandstones. These sediments are bioturbated and appear to represent a lower energy environment. Above these poorly exposed fine-grained sediments is a very marked scour surface, overlain by medium-grained sandstone with mudflake clasts. Trough cross bedding within this sandstone gives a unidirectional sense and contains large organic fragments. Flat laminations and low angle cross bedding overlie these troughs and the sequence is terminated by a decalcified sandstone rich in shell debris moulds. The cross stratification and coquina sediment indicate a foreshore environment.

The upper parts of this section resemble sequences described by Elliott (1975) from the Carboniferous of the Northern Pennines which he interpreted as crevasse splay lobes into an interdistributary bay environment. In these Yoredale Sediments, the crevasse splay sandstones were colonised by plants. In the case of the Oulston section rapid sandstone deposition was followed by wave reworking of the sediment in a foreshore environment. Although this section is solitary and isolated it has considerable importance. Following the deposition of carbonate sediments in the lower part of the Lebberston Member there was a regression with later progradation of the shoreline in a mixed interdistributary bay, fluvial and wave dominated environment. Hemingway (1974) followed previous authors in correlating the Yons Nab Beds on the coast with the Upper Limestone of the south-west. It may

Fig. 3.24 A section overlying the Lebberston Member Upper Limestone at Oulston Quarry (Fig. 3.1). A correlation with the coastal Yons Nab Beds is tentative, but both show mixed wave/tide and fluvial influences overlying carbonate sediments. See text for full discussion.

FIG. 3.24



Coquina with low angle and flat laminations of a beach foreshore environment.

Crevasse channel/splay with a sharp erosive base Trough cross strat gives a unidirectional palaeocurrent sense. Note the mudflake lag.

Bioturbated siltstones and wave-rippled ssts of an Interdistributary Bay (?).

Subtidal sand body (bank) with 'herringbone' cross-strat. indicating deposition under reversing, tidal currents.

? The Upper Limestone of the Lebberston Member.

well be that the Oulston section is equivalent to the Yons Nab Beds, both representing delta progradation following a period of carbonate sedimentation.

3.13. Summary of the Lebberston Member.

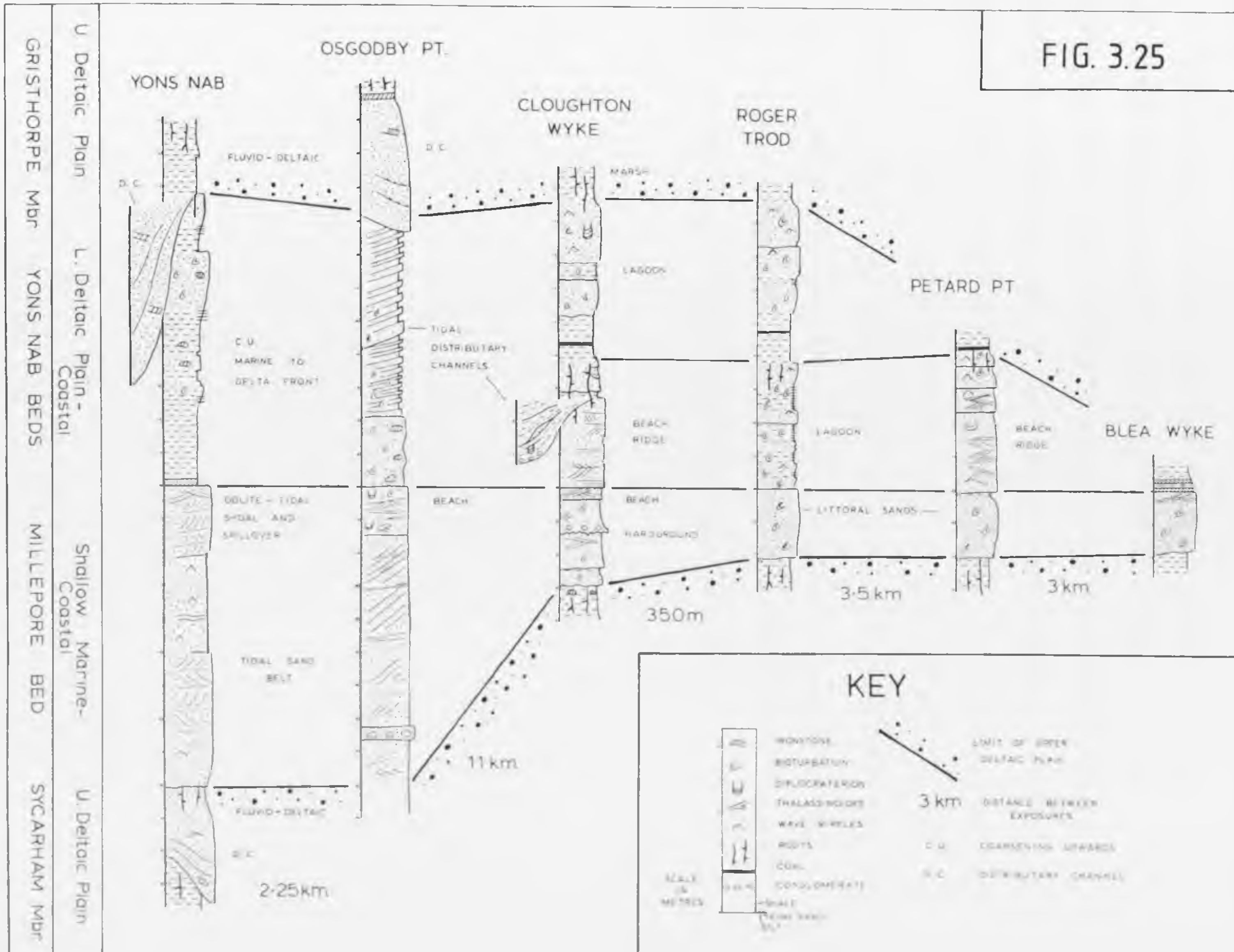
The Lebberston Member deposits seen in the coastal sections are summarised in Fig. 3.25. Following gradual transgression and sea level rise large amounts of sediment from the underlying non-marine beds were reworked and together with introduced marine sediment formed a sand blanket. Sea level stabilised and channels were cut through this blanket, whilst on adjacent areas calcium carbonate was deposited forming ooids. During this period deltaic input into the area must have been reduced to allow a carbonate shelf environment to develop. Adjacent to this was a shifting low to moderate wave energy strandline.

The Yons Nab Beds mark increased clastic input and the progradation of delta front sediments into the region as the delta was reactivated. The shoreline must have advanced from Osgodby Point to beyond Petard Point during this time, marking a further minor transgression. Sand ridges were deposited in very shallow water and the system prograded rapidly. The substrate may well have been already lithified from the evidence of early cementation seen in the Millepore Bed. This is the case in the Bahamas where modern carbonates overlie already cemented Pleistocene sediments.

The lower deltaic plain prograded rapidly on the coast in a wave/tidal environment with fluvial input of sediment. Inland there was a similar story with fluvial, tidal and beach sediments seen at Oulston. We can envisage therefore a mixed wave/tide/fluvial delta system prograding

Fig. 3.25 Summary and interpretation of the Lebberston Member coastal outcrops. Locations of sections shown in Fig. 3.1. The Millepore Bed represents shoreline and offshore sand belt environments overlain by delta front deposits of the Yons Nab Beds.

FIG. 3.25



YONS NAB
OSGODBY PT.
CLOUGHTON WYKE
ROGER TROD
PETARD PT
BLEA WYKE
D.C.
FLUVIO - DELTAIC
C.U. MARINE TO DELTA FRONT
OOLITE - TIDAL SHOAL AND SPILLOVER
TIDAL SAND BELT
TIDAL DISTRIBUTARY CHANNELS
BEACH
MARSH
LAGOON
BEACH RIDGE
HARDGROUND
LITTORAL SANDS
11 km
350m
3·5 km
3 km
2·25km
KEY
3 km
U. Deltaic Plain
L. Deltaic Plain - Coastal
Shallow Marine-Coastal
U. Deltaic Plain
GRISTHORPE Mbr
YONS NAB BEDS
MILLEPORE BED
SYCARHAM Mbr

over carbonate sediments, in a lower deltaic plain environment. Regression finally occurred with a partly erosive base to the overlying prograded upper deltaic plain sediments of the Gristhorpe Member.

Using modern examples it is possible to suggest that the environment was near to the micro-mesotidal boundary allowing oolite formation but restricting large scale washover fan deposits. Moderate to low energy waves reworked the delta front. It is rather more difficult to judge the time span involved in the deposition of the Yons Nab Beds. The Lily Bank formed in 5,700 years, and the modern Niger Delta post dates the Flandrian transgression (Allen, 1970). If one can assume that there is no great time gap between the Millepore and Yons Nab Beds we can suggest that the Lebberston Member represents a period of the order of 10^4 years.

CHAPTER 4

FACIES ANALYSIS OF THE NON-MARINE SEDIMENTS

CHAPTER 4

FACIES ANALYSIS OF THE NON-MARINE SEDIMENTS

These sediments constitute over 80 percent of the deposits studied and occur at three horizons, the Saltwick Formation (25 - 33m thick), the Sycarham Member (25 - 30m) and the Gristhorpe Member (22m) (following Hemingway and Knox, 1973). The coastal exposures give most of the information discussed below whilst inland sections show only sandstone outcrops. These non-marine sediments can readily be divided into erosively based sandstone dominant deposits (Facies 4) and mostly fine-grained laterally extensive rocks (Facies 5). Although these are dealt with separately in the following sections a combined analysis and review of the three stratigraphic horizons is also presented to shed light on the evolutionary history of these parts of the Ravenscar Group. All the localities mentioned in Chapter 4 are shown in Fig. 4.1.

4.1. Facies 4. Sharp, erosively based sandstone dominant bodies.

These generally large scale erosive based bodies are important in that they usually consist of the coarsest sediments seen in the non-marine beds. Black (1928) used the term 'washouts' to describe them and suggested that they were deposited by rivers. From a consideration of morphology, internal structure and overall pattern of sediments involved, Facies 4 has been subdivided into four types in the present study (Table 4.2). Two of these types were further subdivided on a descriptive basis. Although essentially a descriptive classification these divisions relate to the sedimentary processes involved in their formation, which in turn are important in palaeoenvironmental

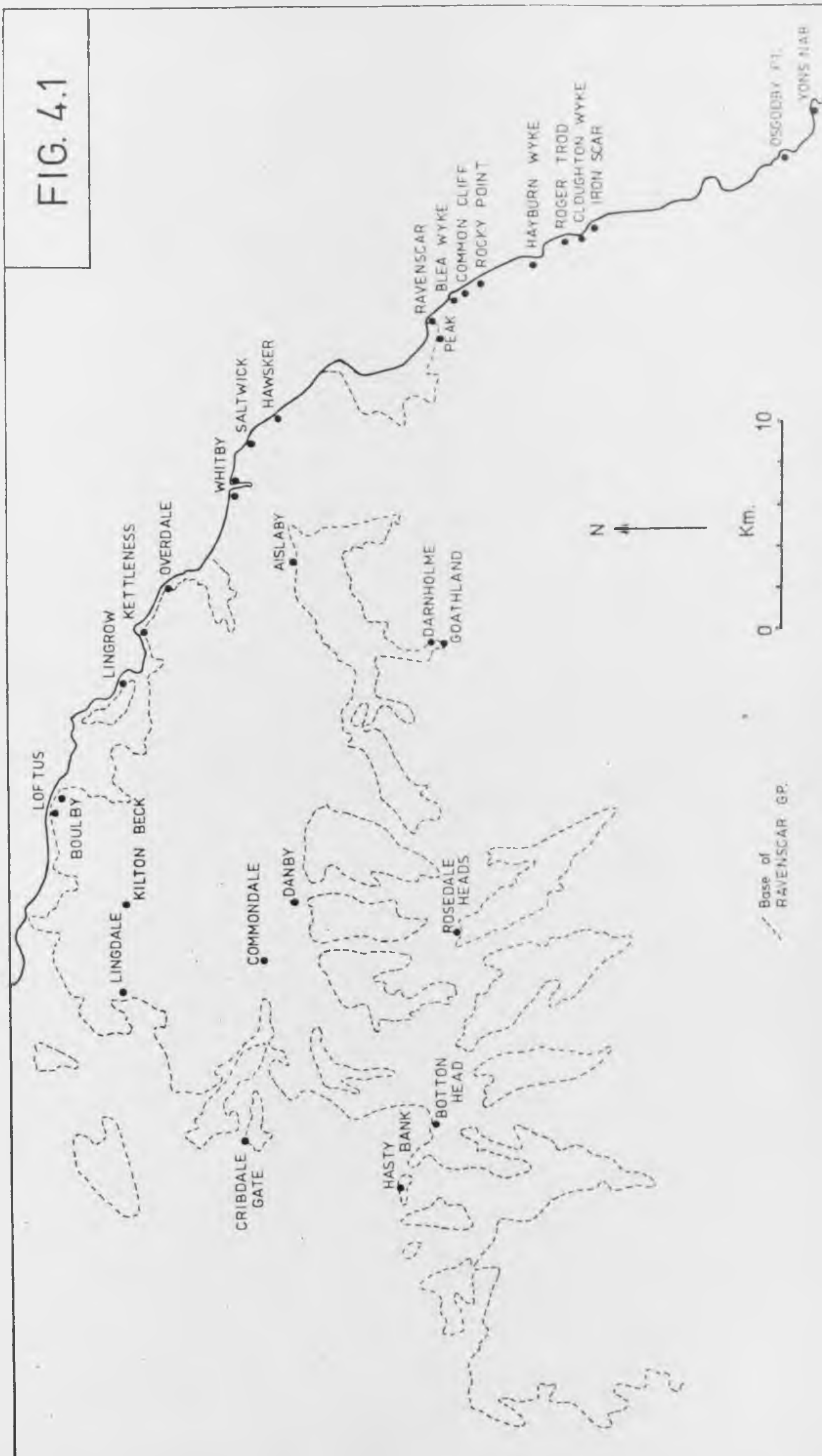


Fig. 4.1 Map of localities mentioned in Chapter 4.

TABLE 4.2

SUBDIVISIONS OF FACIES 4

Facies 4i Solitary sigmoidally-bedded ribbon deposits

Facies 4ii Solitary concave based ribbon deposits

- Type I Homogeneous sandstone deposits
- Type II Sandstone bodies associated with overbank sheet sandstones
- Type III Mixed sandstone and siltstone bodies

Facies 4iii Multiple sandstone deposits

- Type I Multilateral sigmoidally-bedded sandstone deposits
- Type II Complex sheet sandstone deposits with vertically stacked scour surfaces
- Type III Multistorey stacked sandstone deposits

Facies 4iv Clay plugs

considerations. These coarser sediments are the main sources of porosity and permeability within the non-marine sequences, important factors in diagenesis and hydrocarbon reservoir potentials of like deposits, such as in the North Sea Brent oilfields.

4.2. Facies 4.i. Solitary sigmoidally-bedded ribbon deposits.

These sandstone bodies are difficult to identify positively in inaccessible cliff exposures but where they occur around and below high tide mark they can readily be studied. Three well exposed examples occur, at Yons Nab in the Sycarham and Gristhorpe Members, and in the Saltwick Formation at East Cliff, Whitby. They are erosive based and cut through previously deposited sediment. Above this erosion surface basal lag deposits include logs, mudflake conglomerate (intraformational, Allen, 1962) and ironstone nodules in structureless decimetre thick sandstone. This lag sandstone is the coarsest sediment found in this facies, and is usually medium-grained in contrast with the overlying fine-grained channel fill sediment (see Chapter 6, Section 6.1). The main part of these sandstone bodies consist of sets of large scale low angle sedimentary structures in predominantly fine-grained sandstone. Each structure consists of a sandstone bed (20 - 70cm thick) grading upwards into silty sandstone and normally shows a slightly erosional base, lowering the preservation potential of the topmost sediment in the horizon below. These low angle structures dip (10 - 25°) away from one side of the sand body towards the other and usually have an amplitude approaching the channel depth. Their basal erosional contacts are in some cases marked, with local steepening of the low angle dip giving internal discontinuities.

Within each large scale structure small scale trough cross and climbing ripples are preserved, the former giving 'rib and furrow' outcrops on the top of each low angle set. Nearer the base medium scale trough cross stratification occurs with amplitudes up to 25cm. All this cross bedding gives palaeocurrent directions approximately perpendicular to the direction of dip of these low angle surfaces. This criteria suggests that they are epsilon cross stratification (Allen, 1963), which represent lateral accretion on point bar surfaces in meandering river channels (Allen, 1965d). In wave cut exposures this conclusion is further strengthened by the curvilinear plan of these large scale surfaces, as at Yons Nab (Fig. 4.3). Lateral accretion surfaces of point bar origin are also well exposed at West Cliff, Whitby, but the channel margins are obscured by modern beach sand. This latter example highlights the transition from coarser-grained medium scale cross stratification at the base of each accretion unit to rib and furrow structures with siltstone interbeds at the top.

The upper parts of these channels show soft sediment deformation and plant colonisation in siltstones with rare ironstone nodules. This overall fining-upwards is typical of fluvial sediments (Visher, 1965) and is well marked in Facies 4.i. The Yons Nab example is overlain by the Gristhorpe Plant Bed, a fine-grained laminated channel abandonment shale. The outer (cut) banks of these channels are poorly exposed, and in the example at East Cliff, Whitby, has been affected by later compaction. In all examples the final channel fill sediment is dominantly fine-grained and related to Facies 4 iv (see Section 4.6). Small scale faulting and slumping of both channel margins is marked in the Whitby example.

Lateral accretion marks point bar migration perpendicular to the mean river flow direction and tends to produce the rather flat based channel sandstones seen in these examples (Moody-Stuart, 1966). A consideration of individual point bar surfaces can elucidate a number of physical parameters of the rivers that deposited them (Leeder, 1973). Only the Gristhorpe Member example at Yons Nab was sufficiently well exposed to allow accurate measurement of depth and width. The estimated depth was 4.5m. The width of lateral accretion units perpendicular to palaeocurrent readings was 16m. Using the two-thirds approximation (Allen, 1965d), this gives a bankfull width of 24m and a width to depth ratio of $5\frac{1}{3}$. Schumms (1963) equation for the estimation of sinuosity gives a value of 2.2. Discharge can be estimated following Leeder (1973, method A). This channel gives meander wavelength figures of 68 - 1075m. (mean = 270m) which in turn give discharge values of 0.13 - $65m^3$/sec (mean = $2.6m^3$/sec). The results allow this channel to be plotted in a suspended load type of river following Schumms (1972) classification.

The results outlined above compare closely with Nami's (1976) type B channels from the Scalby Formation and represent fairly high sinuosity meandering channels on a relatively gentle gradient. Problems associated with the type of analysis described above have recently been discussed by Ethridge and Schumm (1978). Baker (1978) has shown that the equations used above give anomalous results when applied to tropical rivers with dense vegetation. The figures presented for this Gristhorpe palaeochannel are useful simply as estimates and no correction has been applied for the effects of compaction. Elliott (1976) discusses a similar analysis of a Carboniferous channel sandstone that shows similar internal discontinuities within the lateral accretion

Fig. 4.3 Facies 4i sandstone body in the Gristhorpe Member at Yons Nab (Fig. 4.1). This erosive based sandstone cuts through previously deposited horizontally bedded sediments seen in the reefs at the top of the figure. The bedding seen in the sandstone body is of point bar lateral accretion origin and the channel migrated towards the top of the photograph. The slight curvilinear plan of the surfaces can be seen by considering their strike at the arrows. Palaeoflow towards the right. The lateral accretion surfaces outcrop for 30m across the foreshore perpendicular to their strike.

Fig. 4.4 Low angle reactivation surfaces in planar tabular cross-stratification, from the Sycarham Member at Rodger Trod. The sandstone comes from a Facies 4ii deposit. Upside down fallen block.

sets described above. He ascribed them to the result of point bar scour following "exceptional" flood events. Puigdefabregas and van Vliet (1978) demonstrate similar channels from the Tertiary of the Southern Pyrenees where individual cosets of likewise dipping point bar deposits form as a solitary meander. They suggest that these types of channels were short lived and created by avulsive events. Their preservation in a single channel form was enhanced by rapid burial by overbank fines limiting the chance processes of either re-occupation of the site by later channels or the formation of a meander belt.

Facies 4i channels were deposited by single meandering high sinuosity streams of low gradient, following an avulsive event that shifted a river on to a former area of floodbasin deposition. After a period of well developed lateral accretion they were suddenly abandoned by further avulsion occurring at a point closer to their source. They were rapidly buried by overbank fines (see Facies 5) after initial colonisation by plants. Although only three were easily accessible a number of similar channels were seen in cliff exposures, including two associated with Facies 5ii overbank sediments (see Section 4.9) at East Cliff, Whitby.

4.3. Facies 4ii. Solitary concave based ribbon deposits.

These bodies vary in thickness from 1-6m and were recorded from all three non-marine facies associations. Most examples were inaccessible and it was not possible to take palaeocurrent readings from them to compute true channel widths, although they showed a minimum of 5m. They show no evidence of lateral accretion and are generally symmetrical in cross section. Their concave bases are sharp and erosive, in cases preserving flute and other scour marks. Three types were discerned depending on the sediment infill and their lateral associations.

Type I are found interbedded with fine-grained (Facies 5) deposits and occur throughout the middle parts of the Saltwick Formation, in the Sycarham Member and in the basal parts of the Gristhorpe Member. They consist of homogeneous fine-grained sandstone with coarser (medium-grained) sandstone containing logs and mudflake conglomerate above the basal scour surfaces. As well as having erosive bases they commonly show sharp tops (Fig. 3.21) with mudstone overlying sandstone without the gradual fining-upwards noted in Facies 4i. They contain very little fine-grained sediment apart from the basal mudflake conglomerates. Three main types of sedimentary structures are found, the dominant one being medium scale trough cross stratification with subordinate smaller troughs. Planar tabular forms are also present and these often show marked reactivation surfaces (Fig. 4.4), without the finer-grained drapes normally associated with falling stage modifications (Collinson, 1970). Although on a smaller scale these surfaces may well have formed in a similar way to those described by Jones and McCabe (1980) under steady discharge regimes.

The upper parts of these sandstones preserve smaller scale structures, including climbing ripples. The sharp contacts and sandy infill (Fig. 4.5) are in marked contrast to Facies 4i sand bodies and they bear a morphological similarity to the low sinuosity channel forms described by Moody-Stuart (1966) from the Old Red Sandstones of Spitzbergen. They are also like some British channel sandstones of similar age (see Allen, 1965c). It would be wrong to infer a low

Fig. 4.5 Facies 4ii Type I sand body at Hayburn Wyke (Fig. 4.1). Note the sharp erosive contact with overbank sediment next to the map case and hammer. Note also the sharp upper contact and homogeneous sandy infill thought to indicate rapid formation and abandonment.

Fig. 4.6 Facies 4ii Type II sandstone deposit at Goathland (Fig. 4.1). Note the sharp erosive base (arrowed) cut into previously deposited Facies 5ii sediments. The infill is massive and well sorted sandstone. Shrinkage cracks are well developed in the log in the middle of the channel.

sinuosity origin for these Jurassic examples simply on the lack of apparent epsilon cross-stratification. (see Jackson, 1978 for discussion) but they are clearly separate from Facies 4i deposits. They may represent deposits of straight reaches in-between meander loops or they may have formed by rapid erosion and deposition associated with ephemeral rivers. The dominance of sand deposited as in-channel dunes without marked large scale internal scour surfaces suggests rapid formation by vertical accretion. Their equally sudden abandonment mitigates against a fining-upwards meandering model. They are single and solitary implying rapid burial after their formation.

Type II sedimentary bodies are on a smaller scale than Type I and are found in association with crevasse splay sandstones (see section 4.9 for a full discussion), Facies 5ii. They can be seen in most parts of the succession where Facies 5ii sediments occur, and one typical example taken from the Gristhorpe Member at Goathland is shown in Fig. 4.6. This example has a sharp erosive base and consists of fine-grained well sorted sandstone which only fines upward at the very top of the deposit. The infill is massive, suggesting that it was deposited very rapidly from suspension, although the homogeneous nature of the sediment would tend to mask any structures present. A nearby example in the Sycarham Member at Darnholme shows upper phase plane beds with primary current lineation in well sorted fine-grained sandstone. Small scale climbing ripples with an angle of climb of 45 - 50^{o} were recorded from Roger Trod in a channel of very similar dimensions to the one in Fig. 4.6. All these structures testify to the high flow regimes associated with the formation and infill of these channels, and suggest very rapid deposition. They also occur in the Saltwick Formation at East Cliff, Whitby and in the Gristhorpe Member at Cloughton Wyke. Some examples preserve mudflake clasts and logs throughout their height rather than just in basal lag zones. They infilled to the height of the adjacent crevasse sandstones and were usually colonised by plants on abandonment. They show no evidence of lateral accretion.

These channels appear to have formed and been abandoned very quickly from ephemeral breaks in the channel margins of nearby larger scale feeder channels. They are well documented from modern environments such as the Mississippi delta (Fisk, 1947) where they radiate across fan shaped sandstone lobes. A fuller discussion on their formation is included in Facies 5ii, below (see section 4.9).

Type III deposits have been recorded at three localities; all in coastal exposures in the upper parts of the Gristhorpe Member at Common Cliff, Blea Wyke and Roger Trod. They differ from Type I in that they have a mixed siltstone and sandstone infill. The example at Roger Trod is inaccessible and the other two examples are only partly exposed. All three show major soft sediment deformation and slumping probably as a result of instability due to the dominantly fine-grained fill. The thicker sandstone beds show small scale cross stratification and it would appear that these channel shaped deposits represent low energy forms of dominantly fine-grained suspended sediment flows. None were recorded from inland - their exposure potential is very low. They would appear to represent a fall-off of coarse sediment input at this particular horizon of the Gristhorpe Member.

4.4. Facies 4iii. Multiple sandstone deposits

These are the commonest and volumetrically the most important sand bodies in the Ravenscar Group apart from the braided Moor Grit (see Nami, 1976). At Fox Cliff (between Ravenscar and Blea Wyke) a multiple sandstone body can be traced laterally for 1km. It reaches a maximum thickness of 15m and completely dominates this Sycarham Member section. Similar sandstone bodies also dominate sections in the Saltwick Formation at Loftus, Whitby, Kettleness and on the western escarpment at Botton Heads. Only the coastal exposures show the relationships these sandstones have with Facies 5 sediments and these margins are important in understanding the processes involved in their formation. Three different types of multiple sandstone bodies were recognised from the coastal exposures, but inland a distinction between them is rather more difficult to apply.

Type I is illustrated in Fig. 4.7 and is a typical multilateral sandstone body. It outcrops in the Saltwick Formation at Hawsker where it dominates the section at the expense of finer-grained Facies 5 material. Although it can be traced for 500m. laterally (unorientated with respect to palaeocurrents) and has a maximum thickness of 15m. it is only accessible at two points at its base. This body has a sharp erosive base cutting into fine-grained material, sheet sandstones (Facies 5ii) and a previously deposited Facies 4ii sandstone. The body consists of at least six individual concave based channel shaped forms with marked erosive contacts. Each individual channel shaped body shows low angle surfaces and discontinuities, which although inaccessible appear to represent lateral accretion surfaces. This type of surface is accessible at Kettleness, where it occurs in a similar sandstone body

Fig. 4.7 Facies 4iii Type I sandstone (stippled) in the Saltwick Formation at Hawsker (Fig. 4.1). The low angle bedding in the sand body is thought to represent lateral accretion surfaces. Note the compaction at A where the Eller Beck Formation and the Dogger Formation are closer together than at B. The fine-grained overbank material (black) has compacted more than the section containing the sand body. Drawn from cliff photographs. Full discussion in text.

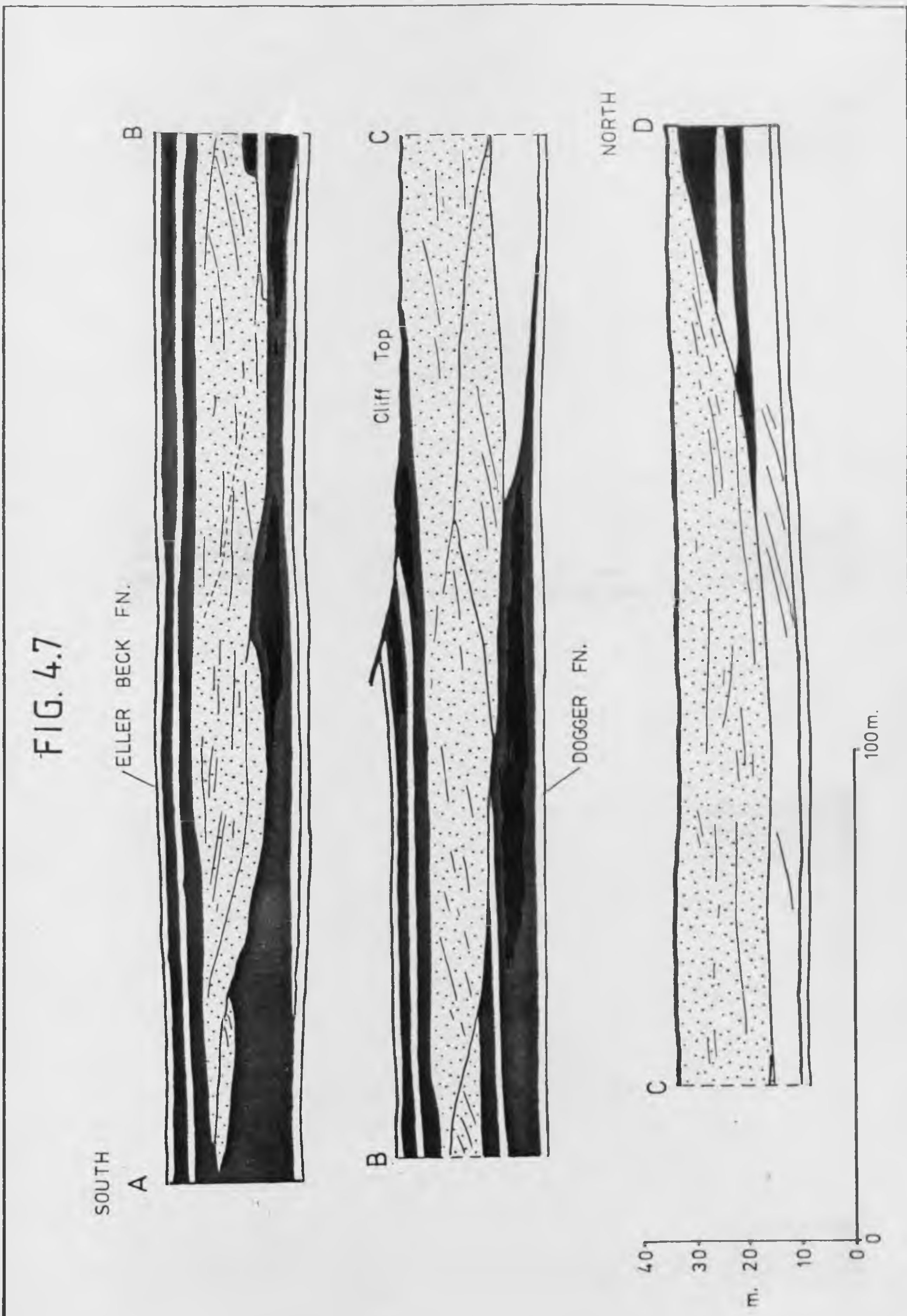
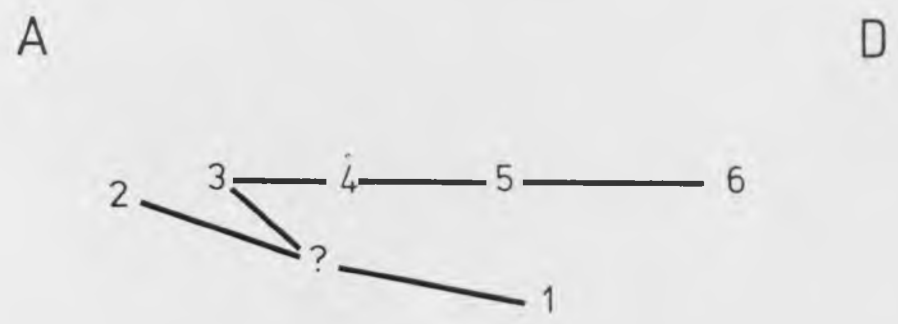

SOUTH
A
B
ELLER BECK FN.
B
C
Cliff Top
DOGGER FN.
C
D
NORTH
100m.
m.
40
30
20
10
0
0

FIG. 4.7

(Fig. 4.8). At Kettleness medium scale cross-stratification gives palaeocurrent readings at approximately 90° to the low angle surfaces, indicating lateral accretion. The vertical scale of these forms (8m.) and the complete dominance of sandstone differentiate them from those described in Facies 4i.

In the example in Fig. 4.7 these low angle surfaces dip to the north and to the south, but as a whole the composite body appears to have formed by channel migration from south to north as below:



The whole body consists of sandstone, which is medium-grained at the base. The large scale scour surfaces are most marked where they cut across earlier, dipping surfaces and where they preserve a mudflake conglomerate lag. These basal erosion surfaces are stepped where they cut through sheet sandstones at B in Fig. 4.7.

The top of the sandbody in Fig. 4.7 is horizontal with respect to the overlying Eller Beck Formation, suggesting that each channel was cut and infilled to the same base level. This is also illustrated at Loftus (Fig. 4.9) where a younger channel cuts through previously deposited sediment of lateral accretion origin. The overlying shales are common to both channels suggesting that they were infilled to the

Fig. 4.8 Lateral accretion surfaces in a large homogeneous sandstone body in the Saltwick Formation at Kettleness, picked out by weathering. The surfaces dip towards the bottom right and accreted in this direction. From the base of the sandstone to the cliff top is 9m.

Fig. 4.9 Facies 4iii Type I complex multilateral sandstone body in the Saltwick Formation at Loftus (Fig. 4.1). A younger channel (right) cuts into lateral accretion sets of an older channel (left). The overlying shales are common to both channels, suggesting that they both cut to the same base level. The sandstone at the top of the figure is of Facies 4iii Type II form. Vertical scale of cliff face is 12m.

same base level. Two further channel shaped bodies occur laterally equivalent to this exposure.

Nami (1976) describes a similar type of sandbody from the Scalby Formation where wave cut exposures of three dimensions prove the existence of a meander belt. Nami's example shows complex meander loop patterns of migration and cut-off with marked internal scour. Each lateral accretion set marks temporary deposition on an accreting meander. Cut-off follows overextension as the river seeks a gradient advantage by straightening its course locally and meander abandonment is followed by further meander accretion at another site. The result is a multilateral sandbody with a flat base in comparison with Facies 4ii bodies, and on a larger scale than either 4i or 4ii forms. They mark the prolonged siting of a river at one point and the two examples at Loftus and Hawsker demonstrate that they can vary in scale. Their flat tops indicate abandonment of the whole system as the river avulsed to a new site.

Type II A number of major sandbodies dominate sections at such places as Fox Cliff (Ravenscar), Whitby West Cliff and Loftus Alum Quarries. None of these sandstones show conclusive evidence of lateral accretion, but this may be due to a function of exposure. The example at Loftus has a lateral extent approaching 1km perpendicular to palaeocurrent readings. Fig. 4.10 shows a typical inland exposure from the Saltwick Formation at Cribdale Gate. Four scour surfaces break up an otherwise homogeneous sandbody which only fines upwards at the top of the figure.

The grain size of these channels is remarkably uniform, lying around the fine-medium boundary, with no marked vertical grain size changes. The sedimentary structures are dominantly medium to large

Fig. 4.10 Facies 4iii Type II sand body in the Saltwick Formation at Cribdale Gate (Fig. 4.1). Note the vertical stacking of scour surfaces (arrowed) in the homogeneous sand body. Rucksack and hammer at exposure base for scale.

Fig. 4.11 Large scale trough cross-stratification in the Gristhorpe Member at Cloughton Wyke. Note the low diversity of palaeocurrent directions from the troughs in this wave cut exposure. Hammer (centre left) for scale.

trough cross stratification (Fig. 4.11) but in a few cases apparently planar forms up to 1.3m in amplitude were recorded. Large scour surfaces occur throughout the sandbodies indicating their composite nature, but these preserve only small amounts of lag material (mostly organic) in comparison to the basal erosion surfaces. This pattern of trough cross-stratification and scours is similar to the stacked channel fills reported by Campbell (1976, Fig. 6) from the Jurassic Morrison Formation of New Mexico. None of the Ravenscar Group examples include cohesive overbank sediment within the bodies, but they fine upwards rapidly at their tops to include small scale cross stratification. The internal scours seem to indicate in-channel erosion and rapid infill followed by further erosion, in a system which shows overall vertical accretion. Palaeocurrent readings taken from these sandbodies show a unimodal pattern with a high percentage length indicating a fairly strong preferred orientation.

Campbell (op. cit.) suggested that the Morrison Formation examples were produced by braided rivers, where composite channels anastomose to form sheet sandstones. The palaeocurrent patterns, high sandstone content and sheet-like outcrop could indicate a similar mode of deposition for these Ravenscar Group examples. However they are not as laterally extensive as the Moor Grit braided stream deposits of the Scalby Formation (Nami, 1976) and their sedimentary structures are much smaller. The channels described above show little evidence of large in-channel bars that Cant and Walker (1976) describe in their model of braided deposits taken from the Devonian Battery Point Sandstone of Quebec. For the size of the sandstone bodies the sedimentary structures present are relatively small. The multiple scours seem to indicate migrating channels and thalwegs within the sandstone unit, which is also suggested by the low amounts of mudflake conglomerate lag seen above these scours. These erosion surfaces may indicate the alteration of bed profiles during flood, as in the Brahmaputra (Coleman, 1969). Fisher and Brown (1972) suggest that distributary channels are typically straight, stabilised and without channel meandering but with a variably shifting thalweg. They are normally sited in one area for a prolonged period and result in multistorey sandstones. Anastomosing rivers, such as the Solimoes in the Amazon Basin (Baker 1978) would produce similar deposits, but this example also shows scroll bar development.

These sandstones are rather problematical. They do not appear to be true braided stream deposits of the Cant and Walker (op. cit.) model. The prolonged siting of a river in one place, as suggested by Fisher and Brown (op. cit.), would produce continued deposition and reworking. Reworking of sandy banks would cut down the chance of meandering and lateral accretion (Schumm, 1968). Vertical accretion would keep pace with subsidence or overbank accretion, giving vertical stacking of scour surfaces from in-channel sediment. This type of sand body may well indicate large-scale delta distributary sedimentation, where a river occupied a site for a prolonged period of time.

Type III. Multistorey sandstones occur when an original depositional site is revisited after a period of time. Fig. 4.12 shows such a situation where two channels merge and become one sand body. The lower channel is of Facies 4ii Type I form with a sharp top overlain by fine-grained sediment, in this case rooted mudstones. After a metre of abandonment mudstones were deposited a second channel cut down into the older one and where the two coalesce there is a sharp scour surface overlain by mudflake conglomerate. Just out of picture shot in Fig. 4.12 is a prominent accumulation of mudflake conglomerate overlying this scour zone (Fig. 4.13). The base levels to which these two channels have aggraded are clearly different and the time gap represented by the metre of mudstone accumulation will have been significant. Wolman and Leopold (1957) give a mean overbank deposition rate of 1.5mm yr^{-1} and this figure would give a time gap of at least 600 yrs, ignoring compaction.

Another example of this type of composite channel can be seen at Roger Trod in the Sycarham Member. Here lateral accretion sediments of apparent point bar origin are overlain by levee deposits. These are cut into by a crevasse channel (Facies 4ii, Type II) which accreted to a higher base level and this in turn is overlain by a Facies 4ii Type 1 channel with a sharp top. All three episodes suggest noticable time gaps between channel depositional periods.

The type of composite sandbody under discussion can include any of the channel facies described above and can result in a body of practically any dimensions. They result from the random re-positioning of channels after avulsion and demonstrate the'interconnectedness' discussed by Leeder (1978) and Bridge and Leeder (1979). Fisher and Brown (1972) make the point that in sedimentary systems such as deltas where there is a large fine to coarse-grained sediment ratio heavier channel sands will tend to 'sink' into overbank deposits. This would give areas of relatively low relief which would be favourite sites for avulsing rivers and these would then cut into the underlying channel sand.

Fig. 4.12 Vertical stacking of two channel sandstone bodies in the Saltwick Formation at Rocky Point (Fig 4.1). Note the sharp top of the lower channel overlain by overbank mudstones. Both are cut into by the younger channel, with the scour surface arrowed. Discussion in text. Vertical scale of cliff - 7m.

Fig. 4.13 Major accumulation of mudflake conglomerate above the scour surface shown in Fig. 4.12. The irregular clast orientation and poor sorting suggest rapid deposition with the material probably having been derived locally, possibly from the overbank mudstones overlying the lower channel in Fig. 4.12. Note the very large clast at the bottom of the figure (centre).

4.5. Discussion on Facies 4i, 4ii and 4iii

The channel types found in the three non-marine horizons are rather variable, both in scale and morphology. From a study of Tertiary fluvial sandstone bodies Friend et al. (1979) pointed out the difficulty of classifying such channels into simple braided, low sinuosity and strongly meandering divisions. They discuss a number of controls on channel morphology and lay emphasis on the distinction between ribbon sandstone bodies and those of sheet form. Ribbons reflect low or high flow strength, strong banks (e.g. vegetated fine-grained overbank sediment), flash flooding regimes (as inferred for Facies 4ii Types I and II) and differential vertical movement of the alluvial area (e.g. downcutting). Sheets reflect intermediate flow strength, weaker banks, a more steady flow regime and relative stability of the alluvial area. Facies 4iii Type II sand bodies fall directly into this category and Facies 4iii Type I forms reflect a stability of alluvial sediment and base level. In the Ravenscar Group examples the morphology of the sand bodies appears to be related to the duration of site occupation, which is probably linked to the size of the river involved.

Friend et al. demonstrate a type of channel sand body not found in the parts of the Ravenscar Group under discussion. These are complex ribbon sandstones with up to 5 storeys, marked by the type of scour surfaces seen in Facies 4iii Type II examples. Nami's (1976) composite sandstone bodies from the Scalby Formation fall into this group, and they may well occur (although unexposed) in the lower parts of the Ravenscar Group.

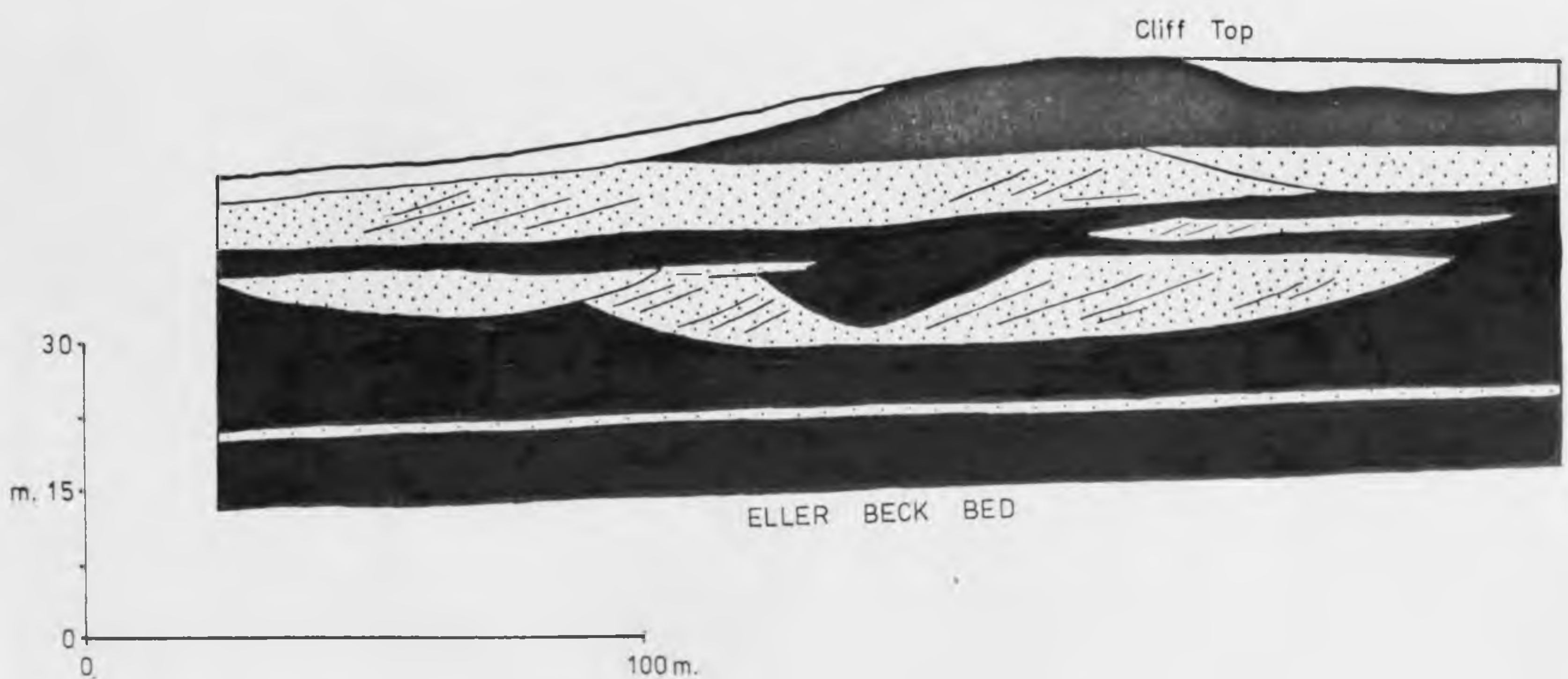
Multistorey (Type III) sandstone bodies can be differentiated from multilateral ones on a number of criteria if exposure is good. Firstly the base levels will be varied in the former and this will result in an increased chance of including overbank material within the sand body, as at Roger Trod. In comparison multilateral sand bodies cut to the same base level and will tend not to include fine-grained material. Multilateral bodies would be composed of channels of the same scale because they are formed by one river. As such they would tend to show similar sediment types, distributions and structures. Multistorey Type III channels on the other hand can consist of any combination of channel type and will show varied sediment and structures. Puigdefabregas and van Vliet (1978) also demonstrate composite sandstone bodies from the Tertiary of the Pyrenees, formed from the vertical stacking of meander belts. Their examples fall in between Facies 4iii Type I and Type II in being multistorey sand bodies formed from meanderbelts, and represent persistent meandering streams that accreted in a stable position. A meander belt of Type I form could eventually form a Type II sand body as its accretion keeps pace with overbank deposition. They are potentially members of an isomorphological system.

4.6. Facies 4iv Clay Plugs

The examples of this final type of channel shaped sediment were recognised from the coastal outcrops. One of them was recorded by Wilson (1948) from the Saltwick Formation at West Cliff, Whitby and consists of siltstone and mudstone infilling an erosion hollow cut into Facies 4iii Type II sandstones. Fig. 4.14 shows a similar but inaccessible fine-grained deposit from the Sycarham Member (Hawsker Member) at Hawsker. It forms part of a composite sand body and has an erosive base cut into low angle structures of presumed lateral

Fig. 4.14 Example of Facies 4iv from the Hawsker Member at Hawsker (Fig. 4.1), showing an erosive channel shaped body (centre) cutting through lateral accretion units and infilled by fine-grained sediment. Discussion in text. Black shading is fine-grained material, stippled shading is sandstone. Taken from cliff photographs.

FIG. 4.14



2x Vertical Exaggeration

accretion origin. The dip and sense of accretion of these structures are identical on both sides of the clay plug which suggests that they were formed by the same meander loop. The fine-grained sediment of the plug must have been deposited from suspension in a hydrodynamically different environment to that which formed the point bar deposits. Allen (1965d) describes three modes of abandonment for river channels. Fig. 4.14 resembles a chute cut-off where a river shortens its course by cutting through its own point bar sediments. This cut off must then have been abandoned by avulsion leaving a hollow on the floodplain which was infilled by overbank material. Ox-bow lakes would also form this type of sediment. The fine-grained nature of this facies severely restricts its outcrop potential inland.

4.7. Facies 5. Non-marine overbank sediments.

These are volumetrically the most important non-marine sediments in the Ravenscar Group varying from 30 - 100% of any given section (usually over 60%). A detailed study of this facies is worthwhile because vertical and lateral variations within it provide a great deal of information which can be related with Facies 4 to give overall models for deposition and environmental evolution. Unfortunately these sediments are dominantly fine-grained and inland exposure is poor. As a result most of the following analysis was taken from coastal exposures. This facies can be broken down into a number of distinct subdivisions which are described in turn below.

4.8. Facies 5i. Mixed interbedded sandstones and siltstones with desiccation casts, ironstone and roots.

These sediments are found proximal to channel sandstones and within multistorey sand bodies (Facies 4iii, Type III). They are most commonly found overlying lateral accretion surfaces but they are not present in all such cases, and most Facies 4i channels show no evidence of these sediments. They are found in both the Saltwick Formation and Sycarham Member but none are recorded from the Gristhorpe Member, although this is thought to be simply a function of random exposure. Their vertical thickness is limited to 3-4m and they show marked lateral impersistency. Fig. 4.15 shows marked lateral thinning of such a sequence, found overlying point bar deposits at West Cliff, Whitby.

Individual sandstone beds are thin and show gently climbing ripples, small scale trough cross stratification and plane beds, Small sandstone channels cut into earlier sediments and usually show deformation and flame structures (Fig. 4.15). The interbedded siltstones are flat laminated and show evidence of both soft sediment deformation and desiccation marks. Folded sandstone dykes show evidence of a desiccation origin and subsequent soft sediment deformation, indicating periods of waterlogging and drying. Ironstone nodules are common and roots are found in the upper horizons along with simple 'worm-type' bioturbation tubes without spriete. In an example from the Sycarham Member at Hawsker roots are truncated by continued deposition, suggesting periods of colonisation followed by renewed activity. Fig. 4.16 shows a typical development of this type of sequence, from the Sycarham Member at Rodger Trod.

From the evidence of alternate wetting and drying and their position associated with channel sandstones these sediments appear to result from intermittent flood deposition. They are similar to the sections described by Ray (1976) from Plaquemine Point, a Mississippi

Fig. 4.15 Facies 5i sediments in the Saltwick Formation at West Cliff, Whitby. Note the marked lateral thinning and the small channels in the right hand log.

FIG. 4.15

Facies 5i

West Cliff, Whitby

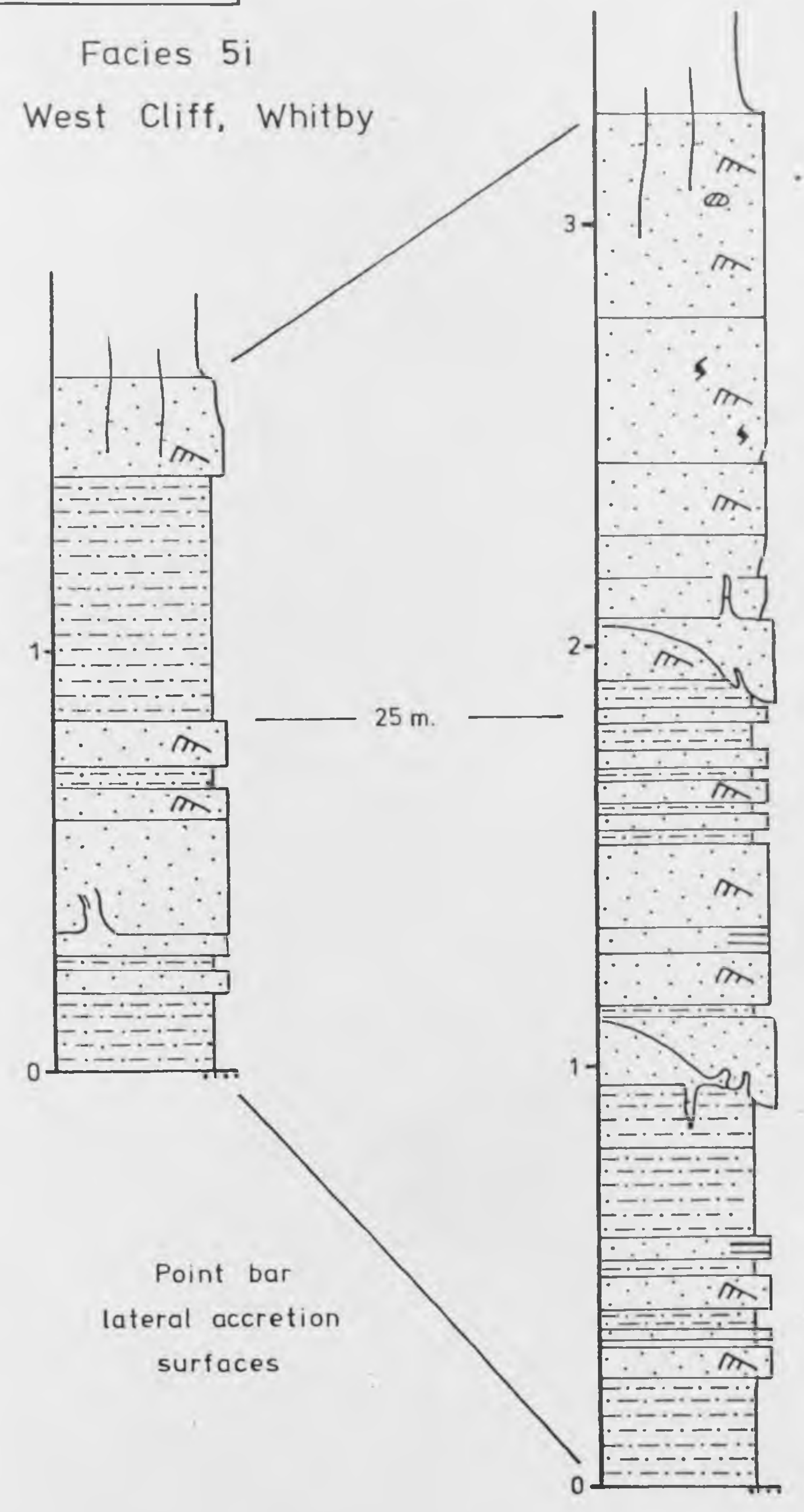


Fig. 4.16 Facies 5i sediments in the Sycarham Member, north of Cloughton Wyke. Interbedded sandstones and streaked siltstones with deformed sandstone dykes (above the lens cap) and ironstone nodules (arrow). Note the irregular, loaded, base of the central sandstone bed at the right of the figure.

Fig. 4.17 Scoured base of a Facies 5ii sheet sandstone bed at Cloughton Wyke showing linear gutter casts, infilled and overlain by plane bedded well sorted fine-grained sandstone. Upside down block, lens cap on left for scale.


Canon

river point bar. He demonstrated vertical sequences of interbedded sands and silts associated with periods of flooding. Interbedded muds and sand with desiccation marks, soft sediment deformation and plant growth are ascribed to levee deposits in Gomti river sediments (Reineck & Singh 1973, p. 246, Singh, 1972). These sediments show evidence of fluctuating stage and are commonly cut by small channels. The coarsest sediment is deposited closest to the source river channel and fines away giving triangular cross sections as shown in the example in Fig. 4.15, which Fisher and Brown (1972) site as a criterion for the recognition of levee deposits.

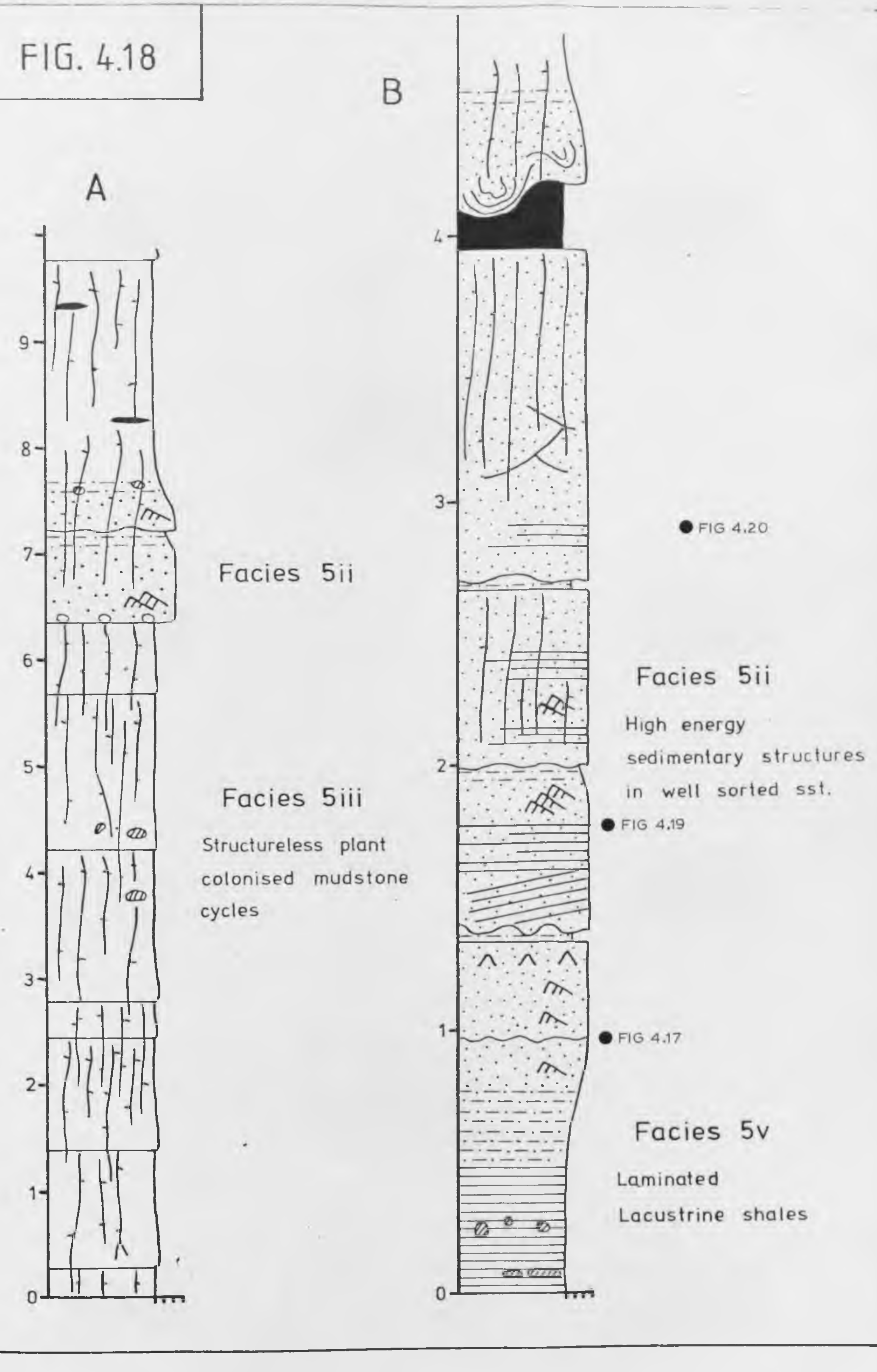
These sediments appear to represent point bar top and levee sediments with a distinction between the two difficult to apply. Their preservation is favoured by formation on inner meander banks, away from later cut bank erosion, and explains their local associations with point bar sediments.

4.9. Facies 5ii. Sharp based sheet sandstones with high energy sedimentary structures.

These sandstones can make up 15 - 20% of any one non-marine section as at Cloughton Wyke and Goathland in the Gristhorpe Member and at East Cliff, Whitby in the Saltwick Formation. They are usually 1-2m thick with scoured, sharp bases showing guttercasts, linear scours (Fig. 4.17) or flute marks. The sandstones are well sorted, fine-grained or very fine-grained and tend to include silt laminae in their upper parts. Although they usually occur as solitary beds, at Cloughton Wyke a number of such sandstones merge to give a single sheet sand body shown in Fig. 4.18. Individual beds show evidence of lateral impersistency but this whole sequence can be traced along the

Fig. 4.18 Examples of Facies 5ii, 5iii, and 5v sediments. A - the base of the Saltwick Formation at Whitby East Cliff. B - part of the Gristhorpe Member at Cloughton Wyke. Facies 5ii sediments in log B are of composite form, including several individual crevasse splays.

FIG. 4.18


A
B
Facies 5ii
Facies 5iii
Structureless plant colonised mudstone cycles
FIG 4.20
Facies 5ii
High energy sedimentary structures in well sorted sst.
FIG 4.19
FIG 4.17
Facies 5v
Laminated Lacustrine shales
0
1
2
3
4
5
6
7
8
9

coast from Common Cliff to Cloughton Wyke and a sandstone in a similar stratigraphic position occurs at Yons Nab, dying out within this outcrop. This represents a north-south extent of approximately 19km but is of unique extent within the Ravenscar Group.

The Cloughton Wyke section shows a number of features typical of these deposits. Basal low angle sedimentary structures with primary current lineation give way vertically to parallel laminated plane beds. These also show lineations suggesting an upper plane origin and give way vertically in turn to climbing ripples (Fig. 4.19). This type of sequence indicates initial high energy conditions, waning to include silt laminae at the top. Repeated deposition gives a further sequence usually eroding parts of the previous one. In between repetitions there are well marked rooted horizons (Fig. 4.20) and in some cases logs up to 25cm in diameter were recorded above these. The thickness of these roots (2cm) suggest major periods of plant colonisation with time gaps in-between sand deposition of the order of 10-100 yrs.

The tops of individual sheet sandstones show oscillation ripples suggesting that they were reworked by wind driven waves in a standing water body, and in many cases these sandstones may have been deposited into a submerged area. Harms (1975) suggests that the formation of primary current lineation is enhanced by deposition in shallow water. Mudflake clasts are occasionally found in these sediments testifying to their erosive contacts with earlier sediments. Apart from the Cloughton Wyke section the maximum lateral extent recorded for one sandstone was 500m at East Cliff, Whitby (taken from cliff photographs).

Fig. 4.19 Facies 5ii in the Gristhorpe Member at Cloughton Wyke. The top of an individual crevasse splay showing climbing ripples overlying upper phase plane beds with marked primary current lineation. Current flowed from right to left. This sequence indicates decelerating flows. Final abandonment is marked by plant colonisation indicated by the weathered out roots in the upper part of the block.

Fig. 4.20 Facies 5ii sediments in the Gristhorpe Member at Cloughton Wyke. Composite sandstone unit built up by repeated crevasse splay deposits. Note the truncated roots in the centre of the figure and the upper phase plane beds to climbing ripple junction (arrowed). Vertical scale is 3m.


Canon

A comparable present day mode of formation of these types of sediment is recorded from the Mississippi (Fisk, 1947). Major periods of overbank flooding occur when river water overtops channel margins cutting through levees and forming crevasse splays. Flood water flows through crevasse channels and fans out giving broad lobate sheets of sand supporting a radiating series of channels. Saxena (1976) shows the progressive development of such a crevasse system with associated channels. The sheet sand had a lateral extent of about $\frac{1}{3}$ of a mile (500-600m) and thinned from 8ft (2.5m) at the channel breach to 3ft. (1m) at its distal margin. The system was abandoned after 15 months and colonised by vegetation. In this example the channels show a meandering pattern and it is possible that Facies 4i channels seen in the Saltwick Formation at Whitby associated with sheet sandstones had a similar origin. To produce a set of epsilon cross stratification however they would have to have a longer duration than Saxena's example. Most of the channels recorded in association with these sheet sandstones are infilled by massive sandstones (see Fig. 4.6) of Facies 4ii, Type II.

Coleman (1969) demonstrates a number of crevasse splays from the Brahmaputra river, including ones that coalesce to form a multiple sand body. This could be a model for the formation of the section at Cloughton Wyke where repeated splay and colonisation occurred with little other overbank fines deposited. These sandstones correspond to the presence of marine microfossils in overbank sediments in the Gristhorpe Member (Hancock and Fisher, in press). Coleman and Wright (1975) also record that overbank splay in the Burdekin delta (a wave-fluvial-tidal delta) is commonest at the limit of tidal inundation. It may be that a sharp rise in sea level with concommitant introduction of marine fauna on to the delta top provided a mechanism for major overbank deposition.

The low angle sedimentary structures seen at Cloughton Wyke have also been recorded from similar sequences (Moore, 1979). He suggested that they formed as a result of bed roughness features such as scours. This is backed up by the findings at this locality where these structures are restricted to the very base of the section.

Actual deposition rates of these sandstones can be inferred from the plane bed to climbing ripple junctions described above using the following equation (after Allen, 1971).

$$R_* = \frac{K.\tan\zeta . D_*^{3/2}}{H}$$

H is the ripple height, ζ the angle of climb, D_* the grain sixe and K, a constant comprised of 4 variables (taken as = 51). R_* is the rate of deposition. From one well exposed transition at Cloughton Wyke a value of c.11 x 10^{-3} gm.cm^{-2}.sec^{-1} was obtained (H = 2.5cm, D_* = .24mm, $\zeta = 8^o$). Assuming an initial 40% porosity and a grain density of quartz this gives a vertical accretion rate of approximately 25cm/hr.

This very rapid rate of deposition can be contrasted with the periods of plant colonisation and with the much lower deposition rates associated with finer grained overbank sediments described below.

4.10. Facies 5iii. Structureless grey mudstones

These are volumetrically the most important overbank sediments and they can be divided into two types, those with well developed roots, and thoseshowing only poor evidence of plant colonisation.

The first type are well developed at the base of the Saltwick Formation (Fig. 4.18) and in the basal parts of the Gristhorpe Member especially in inland sections. They show cyclicity from pale grey silty mudstones grading into dark carbonaceous mudstones with thick root systems, and each cycle is approximately 1m thick. At Hawsker one of these cycles terminates in a thin coal. Hemingway (1974) describes a similar cyclicity associated with basal sandstones which he attributed to fluvial incursions and sediment spill. The ones at the base of the Saltwick Formation are without these sandstones but do show an upward fining of grain size. They show no evidence of desiccation marks and are completely unlaminated possibly due to bioturbation by infauna or roots, although there is no evidence of individual burrows. Ironstone nodules are sometimes present but generally rare and show no evidence of leaching or other pedogenic features. They appear to represent periods of medial to distal deposition of suspended sediment from freshwater fluvial sources, introduced during flooding. The cyclicity may relate to periods of avulsion with renewed sediment input from more proximal sources depositing the coarser basal parts.

The second type are homogeneous and medium grey but show little evidence of cyclicity. Plant colonisation is rarer but a large amount of plant debris is found within these mudstones. They are particularly common at the top of the Saltwick Formation and are the source rocks of the Hayburn Wyke plant beds. Spherulitic siderite and ironstone nodules are also particularly common from these horizons and they show major soft sediment deformation features. This type of overbank mudstone is similar to that found in the Scalby Formation (Nami, 1976) where plant colonisation is rare.

Both types were deposited from suspension in presumably waterlogged swamp conditions. They are not true soil horizons and show no evidence of extensive leaching or capillary action to form mineral enrichment or pans. They must have been reasonably firm to have supported the weight of dinosaurs, footprints of which are preserved (Sarjent, 1970).

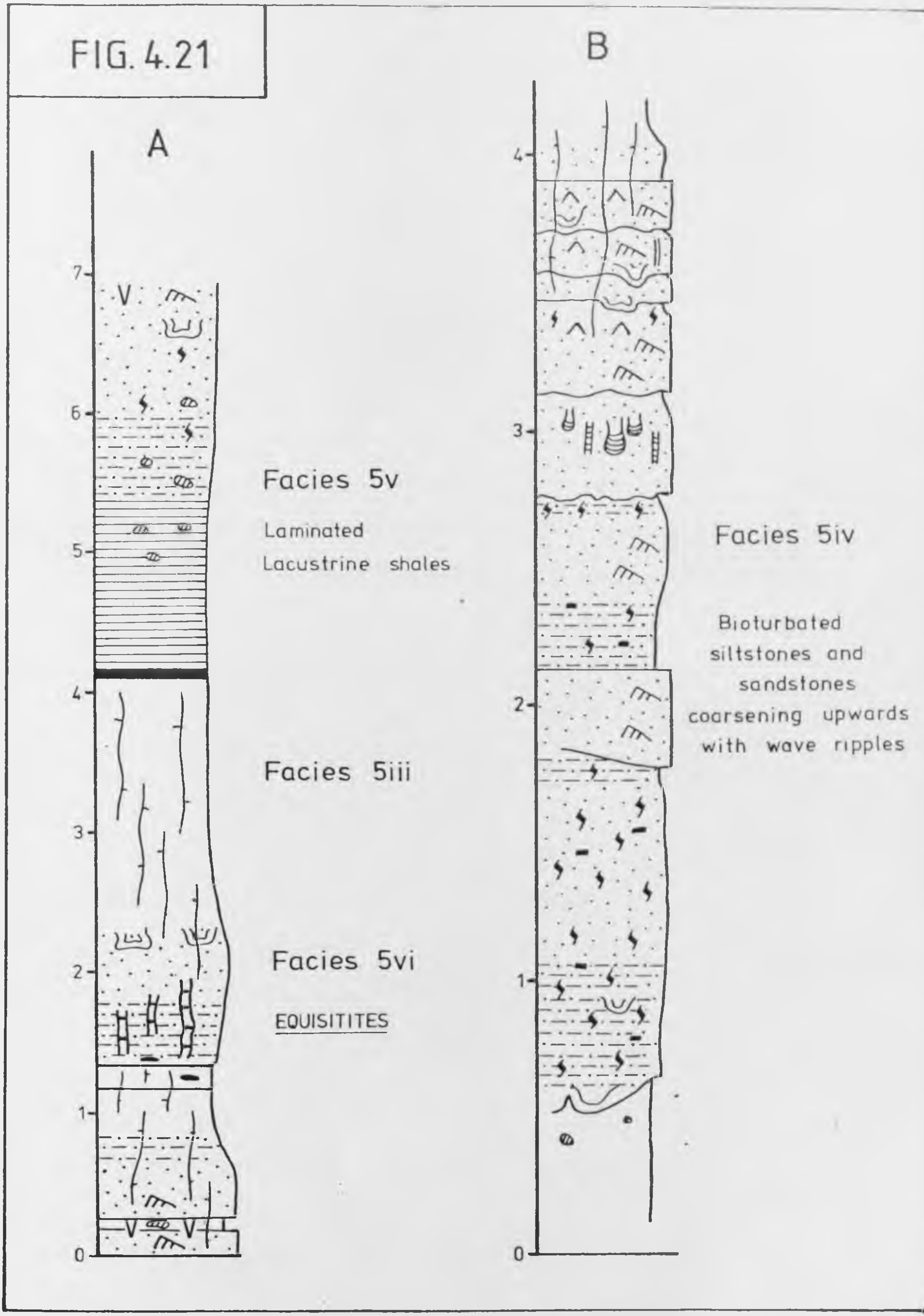
4.11. Facies 5iv. Extensively bioturbated silty sandstones with oscillation ripple marks.

These are found at the base of the Gristhorpe Member and bear a close resemblance to Facies 3c. They are best exposed at Cloughton Wyke (Fig. 4.21), where they overlie the Yons Nab Beds, but can be traced as far as Hawsker. Laevycyclus and Diplocraterion bioturbation forms are well developed and some beds are completely reworked by a variety of unidentifiable burrows. This complex bioturbation is in contrast to the simpler, commonly monotypic, forms seen in other non-marine horizons. Hudson (1979) suggests that increased salinity creates a greater diversity of fauna and this may explain the observations in Facies 5iv.

The sandier beds at Cloughton Wyke show oscillation ripples and soft sediment deformation and the upper parts are cut into by a siltstone and sandstone filled channel. The sequence was colonised by plants on abandonment and is overlain by root bound grey mudstones of Facies 5iii. It would appear that Facies 5iv represents a continuation of the lagoonal environments seen in the Yons Nab Beds and marks deposition in brackish water away from marked tidal activity and drained by small channels.

Fig. 4.21 Examples of Facies 5iii, 5iv, 5v and 5vi sediments.
A - Saltwick Formation at Hayburn Wyke (Fig. 4.1).
B - base of the Gristhorpe Member at Cloughton Wyke.
Discussion in text.

FIG. 4.21


A
B
Facies 5v
Laminated
Lacustrine shales
Facies 5iii
Facies 5vi
EQUISITITES
Facies 5iv
Bioturbated
siltstones and
sandstones
coarsening upwards
with wave ripples

4.12. Facies 5v. Laminated siltstones and shales with ironstones grading upwards into slightly bioturbated siltstones and very fine-grained sandstones.

These sediments are particularly common in the middle parts of the Saltwick Formation (overlying the cycles of Facies 5iii) and in certain horizons of the Gristhorpe Member. Fig. 4.21 shows one such sequence at Hayburn Wyke and Fig. 4.18 another at Cloughton Wyke. Both show well laminated unbioturbated siltstones and mudstones. Several examples from the Saltwick Formation show marked couplets of paler siltstone and mudstone with up to 13 per 2cm. These may represent seasonal deposition and if so this slow deposition is in marked contrast to that seen in Facies 5ii. Ironstone nodules and thin beds are well developed in the upper parts and formed before compaction. The sequences usually terminate in siltstones and silty sandstones with bioturbation, desiccation marks and drifted plant debris. One such horizon in the Saltwick Formation contains the freshwater mussel Unio (Hemingway, 1968).

This facies appears to represent deposits of shallow lakes with varied, (seasonal ?) inputs of suspended sediment. On infill or drainage, sandier lake edge sediments are deposited with evidence of variable water table levels giving desiccation marks and soft sediment deformation. The upper parts were usually colonised by plants.

4.13. Facies 5vi. Laminated sandstones and siltstones with well developed Equisitites stems in situ.

These are found in the lower and middle parts of the Saltwick Formation and at the base of the Sycarham Member. They were not recorded from the Gristhorpe Member. Fig. 4.21 shows one such horizon at Hayburn Wyke and demonstrates the common association with Facies 5v. These stands of sediment filled Equisetum columnare are well documented and have been known for a long time (Murchison, 1832). The Equisitites appears to have served as a sediment trap, and there are marked scour pits on the downcurrent side of their stems. The sediments appear to coarsen upwards in these horizons. They are associated with drifted plant debris and are frequently mudcracked (Fig. 4.22). The Equisitites probably grew in freshwater from modern analogues, in shallow pools, possibly lake margins. Their presence decelerated the flow of incoming suspended sediment from floodwaters enhancing deposition.

4.14. Facies 5vii. Coals

A number of thin coals have been worked from the Ravenscar Group, probably since Roman times (Owen, 1970). No true coals were recorded from inland outcrops but their positions can be roughly gauged from large areas of bell pit spoil heaps such as at Rosedale Head. Recent papers on historical records (Hemingway and Owen, 1975) also give valuable information on their thicknesses and approximate situation. The thickest coals recorded (.9 - 1.2m, Fox-Strangways, 1892) were worked in the south-east of the area around Coxwold and Gilling in the 18th century but no longer outcrop. Thin coals have been found from a number of horizons in the coastal outcrops associated with a variety of overbank sediments.

A thin (7cm) coal was found associated with root cycles (Facies 5iii) at Maw Wyke Hole, Hawsker, adjacent to Gnipe Howe where it was once worked. This coal bearing facies and stratigraphic horizon appears

Fig. 4.22 Facies 5vi sediments in the Saltwick Formation at Hayburn Wyke. Equisetum bed with casts arrowed, showing a drifted Bennettitalean leaf Zamites gigas. Minor bioturbation (monotypic) at the top of the photograph, desiccation cracks by the hammer tip and soft sediment deformation to the bottom right.

to extend over large areas of the basin and Wandless and Slater (1938) undertook a full chemical analysis of one inland deposit. The Sycarham Member at Hawsker also bears a thin coal found within thick root bearing mudstones just above the Eller Beck Formation. In the Gristhorpe Member coals are found associated with Facies 5. crevasse splay sandstones at Common Cliff. At Commondale a very shaly coal shows similar relationships to sheet sandstones and the deposit worked at Danby during the 18th and 19th centuries probably came from this horizon. This latter coal was 41cm thick (Hemingway and Owen, op. cit.) and was heavily worked on a fairly large scale. At Cloughton Wyke this horizon is marked by black shales and it would appear that actual coal formation in this association is patchy, with local thicker developments.

A thin coal also occurs at Cloughton Wyke/Roger Trod associated with the abandonment of the Yons Nab Beds, but it is of poor quality and thins away to dark shales within the outcrop. Previous workers have tended to place these coals into two broad categories, drifted and in situ (Muir, 1964) depending on their root base. It would appear however that most of the coals include a large amount of material exotic to the depositional site, and Equisitites is frequently the most abundant constituent (Hemingway, 1974).

None of the coals found can be traced throughout the region and most show patchy development.

4.15. Non-Marine Facies within the stratigraphic sequence

A. The Saltwick Formation

This is the thickest of the non-marine sequences and although 32m. is the maximum recorded (Fig. 4.23 E) Hemingway and Wilson (1963) estimated the Ravenscar exposure at 170-190 feet (51-58m). There is rather an abrupt passage from marine Dogger Formation sediments to the Saltwick Formation, with roots penetrating the former and widespread erosion preceding non-marine deposition (see Section 2.4a). In the south-west of the Yorkshire basin basal Saltwick Formation sediments contain marine microfossils (Muir, 1964) and the distinctive plant fossil Pachypteris papillosa (Harris, 1964). This plant was thought to have resembled species of modern mangroves and along with Brachyphyllum crucis was probably tolerant to salinity. Pachypteris papillosa and marine microfossils only occur in the lower few metres of the Hasty Bank section (Hill, 1974) and these lower sediments are overlain by a freshwater coal. Hill discusses the possibility that the marine microfossils could have been scoured from erosion of the Dogger Formation. The channel sandstones in this area show no evidence of tidal activity and are completely unbioturbated, with unidirectional palaeocurrents recorded from well sorted sandstones.

In coastal exposures the basal parts of the Saltwick Formation show well developed root cycles (see Fig. 4.18) in association with thin coals and Equisitites rich plant beds. At West Cliff, Whitby, overbank mudstones overlying lateral accretion deposits show no evidence of marine influence (Hancock & Fisher, in press). Meandering rivers dominate the basal parts of the Saltwick Formation and the coastal sections appear to resemble a fluvial dominated coastal plain sequence. There appears to have been an initial saline influence in the western exposures with a rapid progradation of freshwater sediments from the coast towards the south-south-west in the dominant palaeocurrent direction.

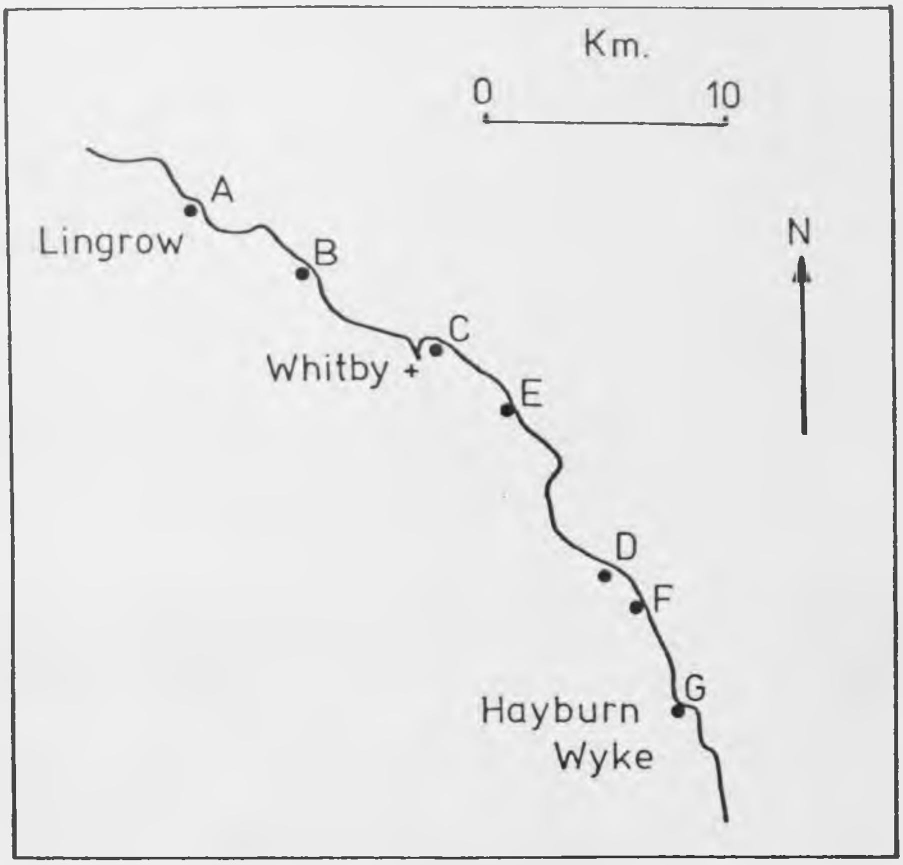


Fig. 4.23 Representative logs of the Saltwick Formation, with locations shown above (see also Fig. 4.1). Dominant overbank deposits (Facies 5) indicated. Note that log C is at the base of the formation and that log F occurs in the middle.

A - Lingrow Howe
B - Overdale Wyke
C - East Cliff, Whitby
D - Peak Alum Quarries
E - Hawsker
F - Beast Cliff
G - Hayburn Wyke

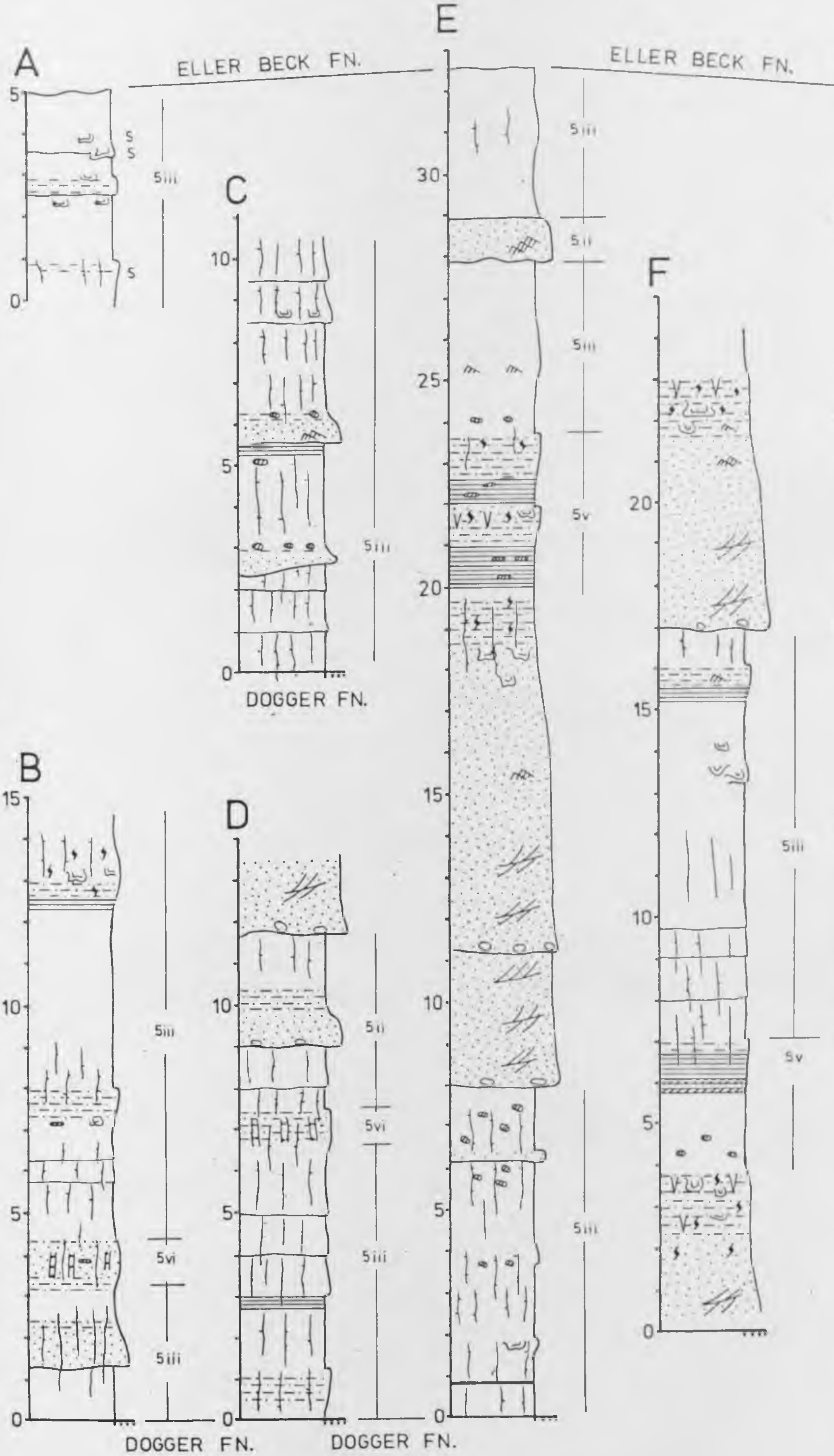

A
B
C
D
E
F
G
ELLER BECK FN.
ELLER BECK FN.
DOGGER FN.
DOGGER FN.
DOGGER FN.
5iii
5ii
5v
5vi

FIG. 4.23

Knox (1969) suggested that extensive channelling began after the deposition of 10' (3m) of shales, but at Kettleness an extensive sand body directly overlies the Dogger Formation (Fig. 4.8). He also implied that two separate phases of channelling could be discerned from this formation but again a consideration of the whole outcrop makes this seem unlikely. Leeder (1978) discusses the problem of random exposure in such sequences and warns against placing too much weight on scanty evidence.

The middle parts of the Saltwick Formation show a great deal of variety and include a freshwater mussel-bearing sandstone at Saltwick (Hemingway, 1968). Well laminated shales and siltstones of inferred lacustrine origin occur interbedded with Equisitites plant beds and root-bearing claystones (Fig. 4.23,E). Sheet sandstones of crevasse-splay origin also occur and support a number of small channels. Ironstone nodules and bioturbation, usually of simple form, also occur in overbank siltstones and vertically accreted channel top sediments. Desiccation casts indicate periods of drying and lowering of the water table below the sediment surface. The channel sandstones in the middle of the Saltwick Formation tend to be of Facies 4iii types with large scale sheet and multistorey bodies at Loftus, Whitby West Cliff and Aislaby (Knox, 1969). These channels probably had a prolonged life span dominating sedimentation and confining river flow.

The upper parts of the Saltwick Formation show a noticable decrease in size and frequency of channels (Fig. 4.24, after Knox, 1969). Figure 4.24 demonstrates this from the Peak to Iron Scar cliff section, but it can also be seen south of Whitby in the Hawsker sections. At Hayburn Wyke Facies 4ii Type I channels with major basal soft sediment deformation occur just below the Eller Beck Formation indicating waterlogged

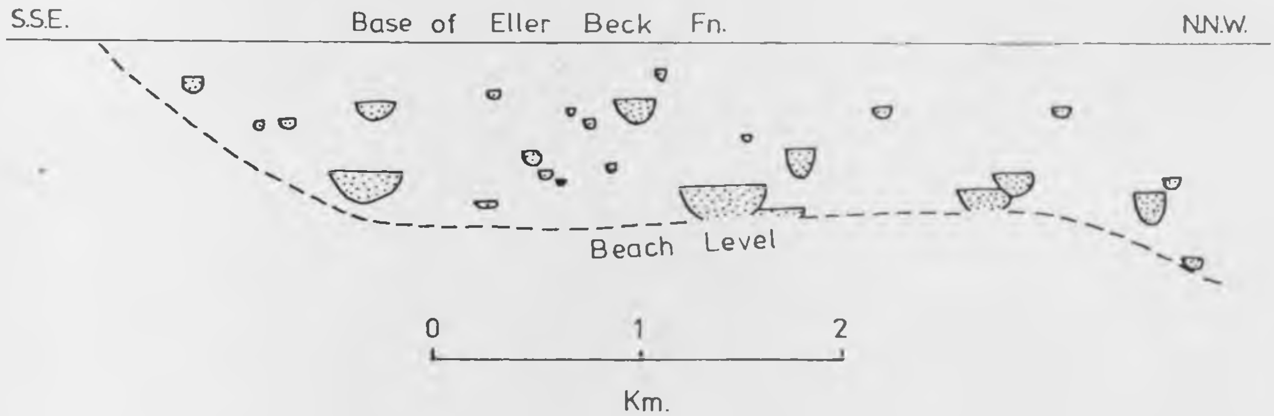


Fig. 4.24 Distribution of channel sand bodies in the Saltwick Formation, Peak (N.N.W.) to Iron Scar (S.S.E.), after Knox (1969). Note the paucity of such bodies at the top of the formation, below the Eller Beck Formation.

conditions. The vertical variation in the overbank sediments of the Saltwick Formation is probably more spectacular than that seen in the channels. At the top of the formation (Fig. 4.23 A,G) roots are rare and the sequence is dominated by structureless mudstones all along the coastal outcrops. Sphaerosiderite (spherulitic fine-grained ironstone nodules) is common, and probably results from precipitation under local stagnant overbank conditions. Hancock and Fisher (in press) report marine microfossils from the Hayburn Wyke section which contrasts with their above mentioned absence at Whitby West cliff. The overbank sediments at the top of the Saltwick Formation are very similar to those of the Scalby Formation (Nami, 1976) and rather different to the other non-marine associations (the Hawsker Member).

There appears to be an evolutionary trend in the sedimentary history of the Saltwick Formation involving a gradual decrease in coarse clastic input and a concommitant increase in waterlogged overbank material. The basal sediments resemble alluvial plain cycles whilst the middle parts show a much more varied series of overbank deposits one would normally expect from deltaic environments.

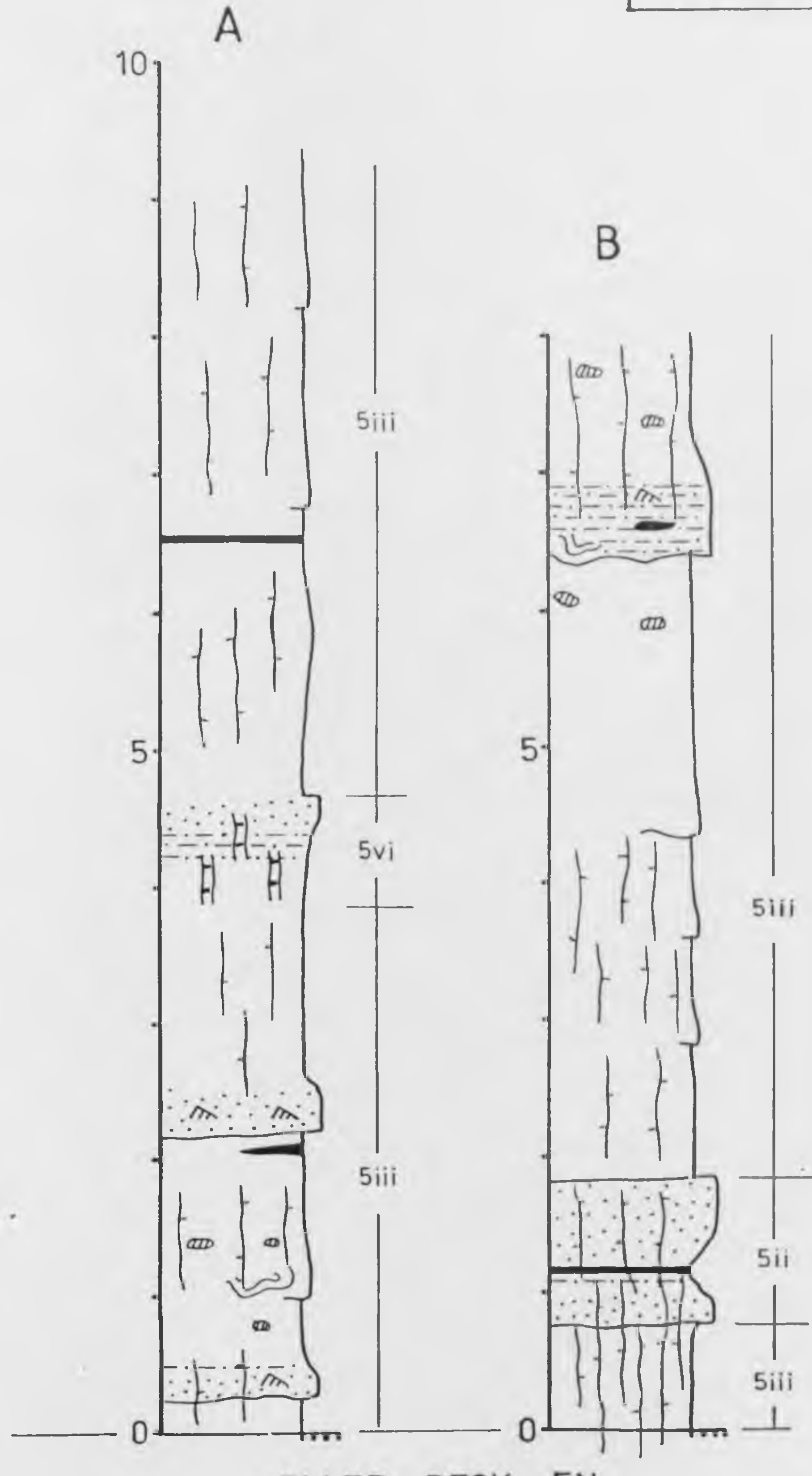
It is interesting to speculate on the cause of this vertical variation. Coarse clastic sediment supply has decreased but this appears to be an effect confined to the upper parts of the Saltwick Formation. The Eller Beck Formation and the succeeding units in the Ravenscar Group all contain substantial amounts of coarser clastic material suggesting that there was no dramatic changes in the hinterland source sediments. The variation is unlikely to be a climatic effect due to the relatively short time span involved in the deposition of the Formation (see Fig. 1.6). Deltas are complex systems of sediment deposition and when overextended tend to be abandoned as distributaries seek gradient advantages. Major abandonments concentrate deposition in new areas giving the formation of delta lobes, such as in the Mississippi (Fisher et al. 1969) and the Rhone (Scruton, 1960). This could explain the sequences seen in the Saltwick Formation with a delta being gradually abandoned to dominantly fine-grained sediment under the influence of saline water incursions with most of the coarse sediment introduced to an adjacent area. This would leave a waterlogged coastal plain of low, even relief which was eventually inundated by the sea during the Eller Beck Formation transgression. The Eller Beck Formation shows remarkable lateral uniformity of thickness as a result.

There is no evidence of tidal influence or of delta front sediments within the Saltwick Formation. The progradation of this sequence was as sudden as its final termination to fully marine sediments. If the concept of delta lobe abandonment is accepted one can postulate further non-marine sedimentation beyond the present limits of outcrop of the Yorkshire Basin. The Saltwick Formation thins to the south-west and is represented by 13m of root bearing mudstones and sandstones at Brown Moor borehole.

B. The Sycarham Member

This non-marine sequence is poorly exposed and where the regional southerly dip brings it down to sea level it is obscured by a large cliff failure at Roger Trod. Hancock and Fisher (in press) have found marine microfossils from both the basal and upper parts of the Member, but the presence of Equisitites in situ at the base (Fig. 4.25) suggests freshwater conditions as well. There is an abrupt break from foreshore sediments of the Eller Beck Formation to thick root bound mudstones with a thin coal (Fig. 4.25) at Hawsker, and this transition can be

FIG. 4.25



noted throughout the outcrop of the Ravenscar Group at this horizon.

At Ravenscar a major multistorey channel dominates the Sycarham Member and is directly overlain by the Millepore Bed. This channel sandstone represents a river which dominated Sycarham Member sedimentation, for the channel sandstones to the south are much smaller and of dominantly Facies 4i and 4ii form. At Yons Nab and Roger Trod laterally accreted channel sandstones occur in the upper parts of the Sycarham Member indicating small scale meandering rivers. There appears to have been a heirarchy of channel sizes in the Sycarham Member and these sandstones were probably deposited simultaneously.

The top of this sequence at Roger Trod includes 7m of pale grey mudstones with roots, cut into by three Facies 4ii Type I channels. Inland the only major outcrop of the Sycarham Member occurs at Darnholme where thick (6m) black shales are cut into by a crevasse channel. There is no evidence of tidal or wave influence in any of the sediments in this member and it appears to have formed by the vertical accretion of channel and overbank sediments. The overlying Millepore Bed has a sharp erosive contact with these sediments suggesting a discontinuity, rather than a gradation from non-marine to marine environments.

In the south-west of the basin Hemingway and Knox (1973) record shales with a marine fauna overlying the Eller Beck Formation. The correlation of this Blowgill Member with the coastal sections 40km to the east is impossible but the western region appears to have subsided with the deposition of fine-grained marine sediment. It may be that during Sycarham Member times the edge of the non-marine sediments was close to the present coastal outcrops. At Brown Moor 7.5m of silty sandstones were recorded between the Blowgill Member and the Lebberston Member but this part of the core was heavily broken up. The erosive base of the Lebberston

Member makes it difficult to assess how much the Sycarham Member thins towards the south-west.

C. The Gristhorpe Member

This non-marine sequence has a maximum recorded thickness of 23m at Darnholme (Fig. 4.26), thinning towards the south-east to nearly 11m at Yons Nab. The coastal exposures (at Cloughton Wyke and Yons Nab) show evidence of brackish water deposition (Facies 5iv), with marked bioturbation. This appears to be a continuation of the lagoonal environments seen in the Yons Nab Beds immediately below. Inland the Millepore Bed is directly overlain by thin coals and root bound mudstones at Darnholme, delimiting the geographical extent of the basal saline influence. At Yons Nab a meandering stream deposit cuts through the basal bioturbated sediments and is overlain by fissile grey shales containing the Gristhorpe Plant Bed (Fig. 4.26).

At Cloughton Wyke and Darnholme the initial brackish water sediments are overlain by grey mudstones with thin coals and numerous truncated root horizons (Harris, 1953). Hancock and Fisher's work (in press) found no marine influence in this horizon, which can be traced as far as Commondale (Fig. 4.26D), and indicates widespread freshwater environments associated with the meandering stream deposit at Yons Nab. These mudstones are 5m thick at Cloughton Wyke and are overlain by laminated lacustrine sediments which include marine microplankton (Hancock and Fisher). This horizon can be traced as far north as Blea Wyke (a distance of 7km.) which gives some indication as to the size of these standing water bodies. The middle parts of the Gristhorpe Member are dominated by crevasse splay sandstones (Section 4.8), especially on the coast. At Cloughton Wyke these are cut into by a large scale composite channel sandstone. The sheet sandstones will greatly

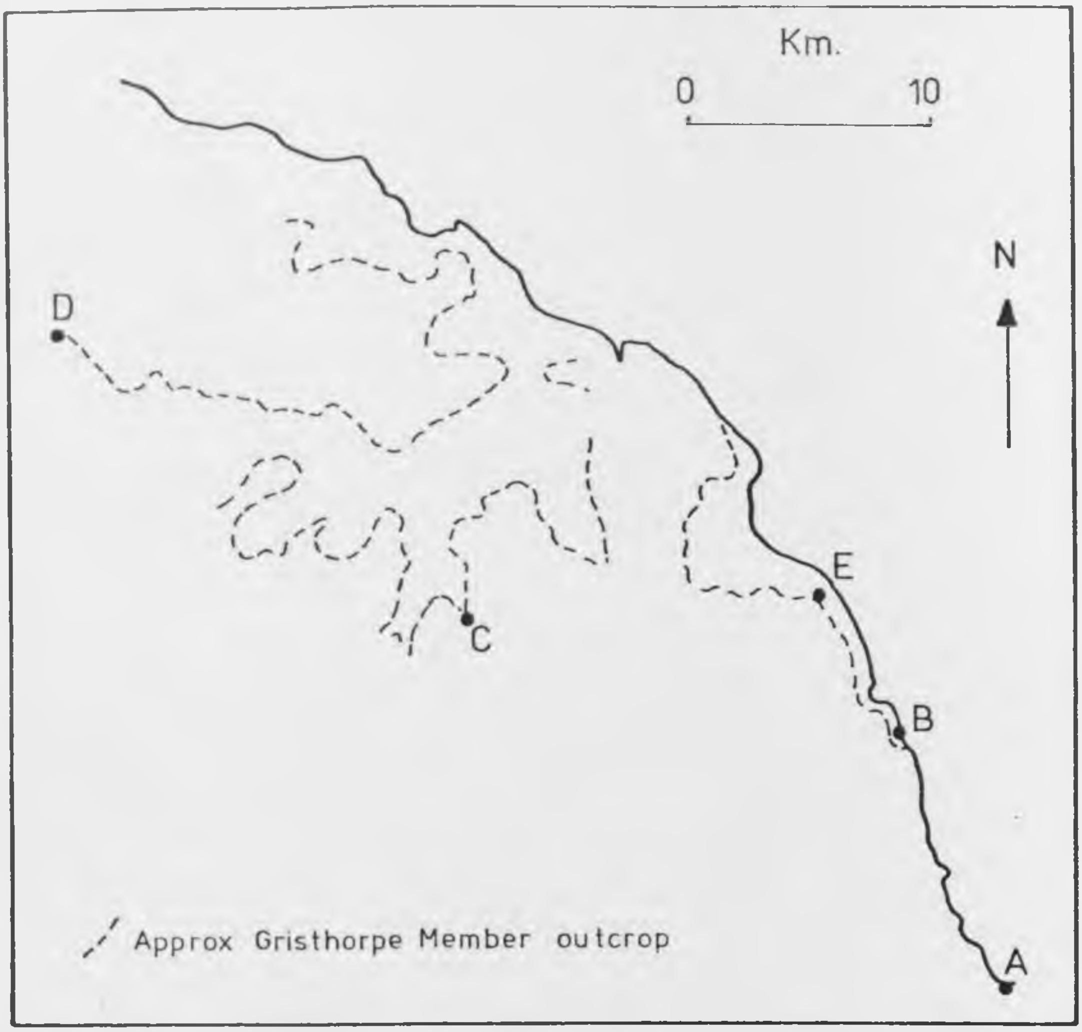
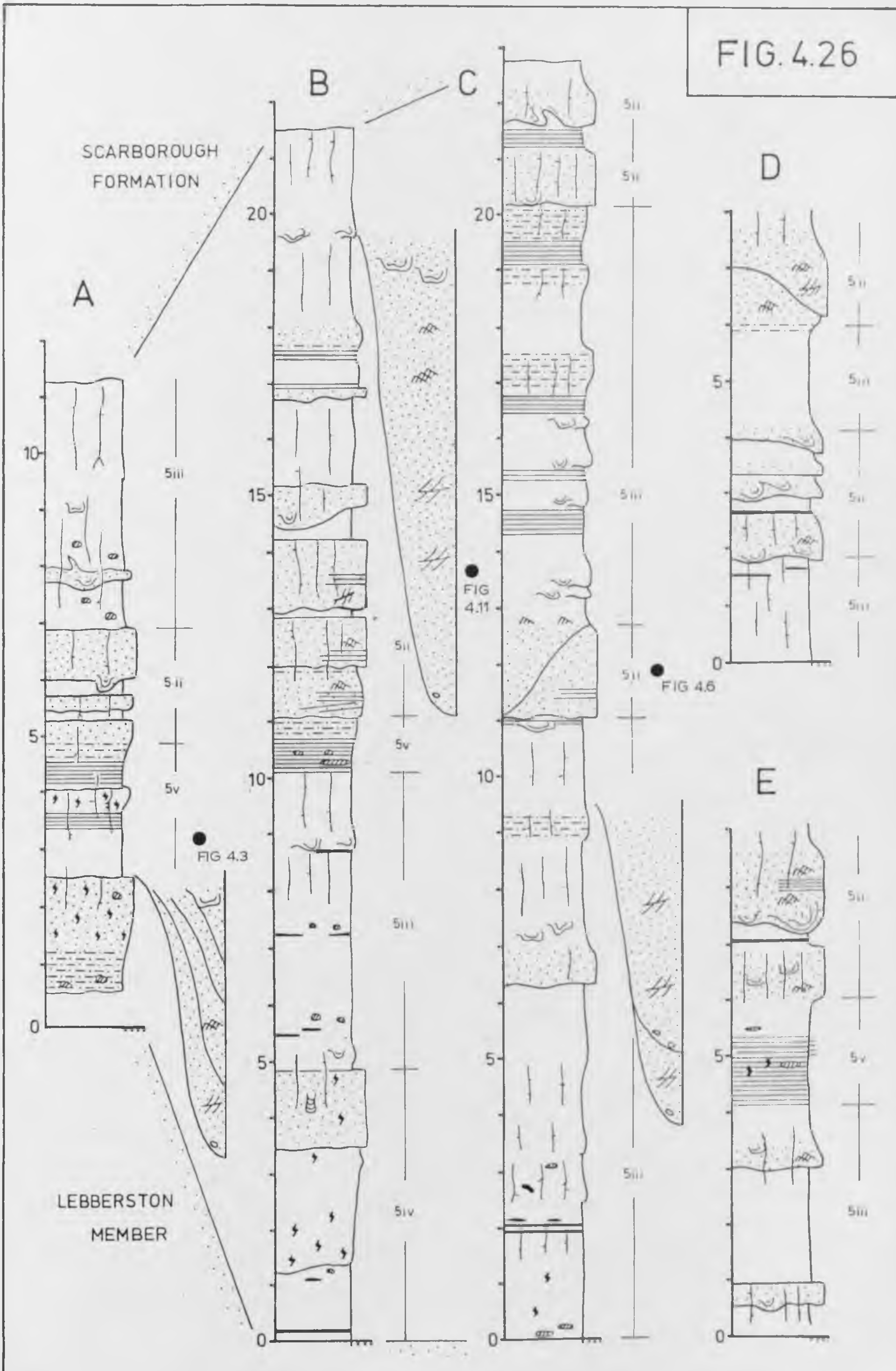


Fig. 4.26 Representative logs of the Gristhorpe Member, with locations shown above (see also Fig. 4.1). Dominant overbank deposits (Facies 5) indicated. Note that logs D and E come from the middle of the member.

A - Yons Nab
B - Cloughton Wyke
C - Darnholme-Goathland
D - Commondale
E - Blea Wyke

FIG. 4.26



SCARBOROUGH FORMATION
LEBBERSTON MEMBER
A
B
C
D
E
FIG 4.3
FIG 4.11
FIG 4.6
5iii
5ii
5v
5iv
0
5
10
15
20

increase the lateral permeability connections within this section of the Ravenscar Group. The upper parts of the Gristhorpe Member consist of pale grey mudstones with roots and ironstone nodules, and include marine microplankton (Hancock and Fisher).

At the top of the Gristhorpe Member on the coast Facies 4ii Type III channels indicate fine-grained suspension load rivers. At Kilton Beck (Fig. 3.1) medium-grained sandstone occurs in multistorey channels just below the Scarborough Formation. It would appear that coarse sediment was being transported through the central parts of the Yorkshire Basin whilst the coastal outcrops south of Ravenscar show signs of abandonment. This may have been the result of gradual subsidence of the eastern area with salt water incursions prior to the transgression that formed the coarsening upward sequence at the base of the Scarborough Formation. (Facies 1a).

The coastal sections therefore give a story of rapid freshwater sediment progradation over the last remnants of the Yons Nab Beds delta front system. After a considerable period of deposition there were saline incursions on to the coastal plain which probably resulted in major overbank deposition of crevasse splay sandstones. The majority of the coarse-grained sediment was finally deposited in the middle parts of the basin, the present day coastal outcrops showing evidence of abandonment rather similar to that seen in the Saltwick Formation. The Brown Moor borehole recorded 4.2m of bioturbated sandstones beneath the Scarborough Formation but correlation with outcrops is impossible.

Palaeocurrents taken from the Hawsker Member (Gristhorpe and Sycarham Members) show a strong south-south-westerly palaeoflow which would suggest progradation in this direction. None of the channels show any evidence of tidal sedimentation, fluvial or distributary flow being dominant.

CHAPTER 5

DEPOSITIONAL PALAEOGEOGRAPHY, PALAEOCURRENT ANALYSES AND THE HISTORY OF SEDIMENTATION OF THE RAVENSCAR GROUP

CHAPTER 5

DEPOSITIONAL PALAEOGEOGRAPHY, PALAEOCURRENT ANALYSES AND THE HISTORY OF SEDIMENTATION OF THE RAVENSCAR GROUP

This chapter attempts to synthesise the palaeoenvironments of the facies described in Chapters 2, 3 and 4, considering the sedimentary evolution and depositional palaeogeographies of the Yorkshire Basin Middle Jurassic deposits. Nearly 1500 palaeocurrent readings were taken during the study. These represent a broad stratigraphic and facies range and were processed using a computer programme written by A.R. Gardiner. The results are tabulated in stratigraphic order in Appendix 1.

5.1. The initiation of Middle Jurassic sedimentation and the murchisonae Dogger Formation.

The Dogger Formation overlies Upper Liassic Whitbian and Yeovilian sediments, mainly shales, the contact being marked by slight unconformity. Gentle pre-Dogger folding preserves some of the youngest Liassic sediments (the Yeovilian of the Upper Toarcian) in a series of structural basins below this unconformity, as in Rosedale (Rastall and Hemingway, 1949). The Liassic sediments must have been eroded and peneplained prior to the deposition of the Middle Jurassic. Hemingway (1974) suggests that the Upper Lias sequence in Yorkshire represents a gently shallowing marine environment with an increase in the oxygenation of the sediment. This shallowing is reflected in the heavily bioturbated Yeovilian Blea Wyke Sands which grade into opalinum age Dogger Formation sandstones and ironstones at Blea Wyke.

The coarsening upwards Liassic-Aalenian boundary seen at Blea Wyke is typical of the 'basin' and 'swell' sedimentary patterns that Sellwood and Jenkyns (1974) have recognised in the Pleinsbachian and Toarcian throughout Great Britain. During the Toarcian the Yorkshire area acted as a 'basin' for the offshore deposition of bituminous shales and bioturbated clay. Gradual shallowing marked the development of a 'swell' and resulted in the deposition of Aalenian ironstones. Vertical sedimentation rates were slower and the *opalinum* Dogger Formation represents a condensed sequence. Sellwood and Jenkyns (op. cit.) attribute this Yorkshire sedimentary pattern to the influence of the Market Weighton area, one of several regions in Great Britain that showed variable amounts of subsidence during the Lias.

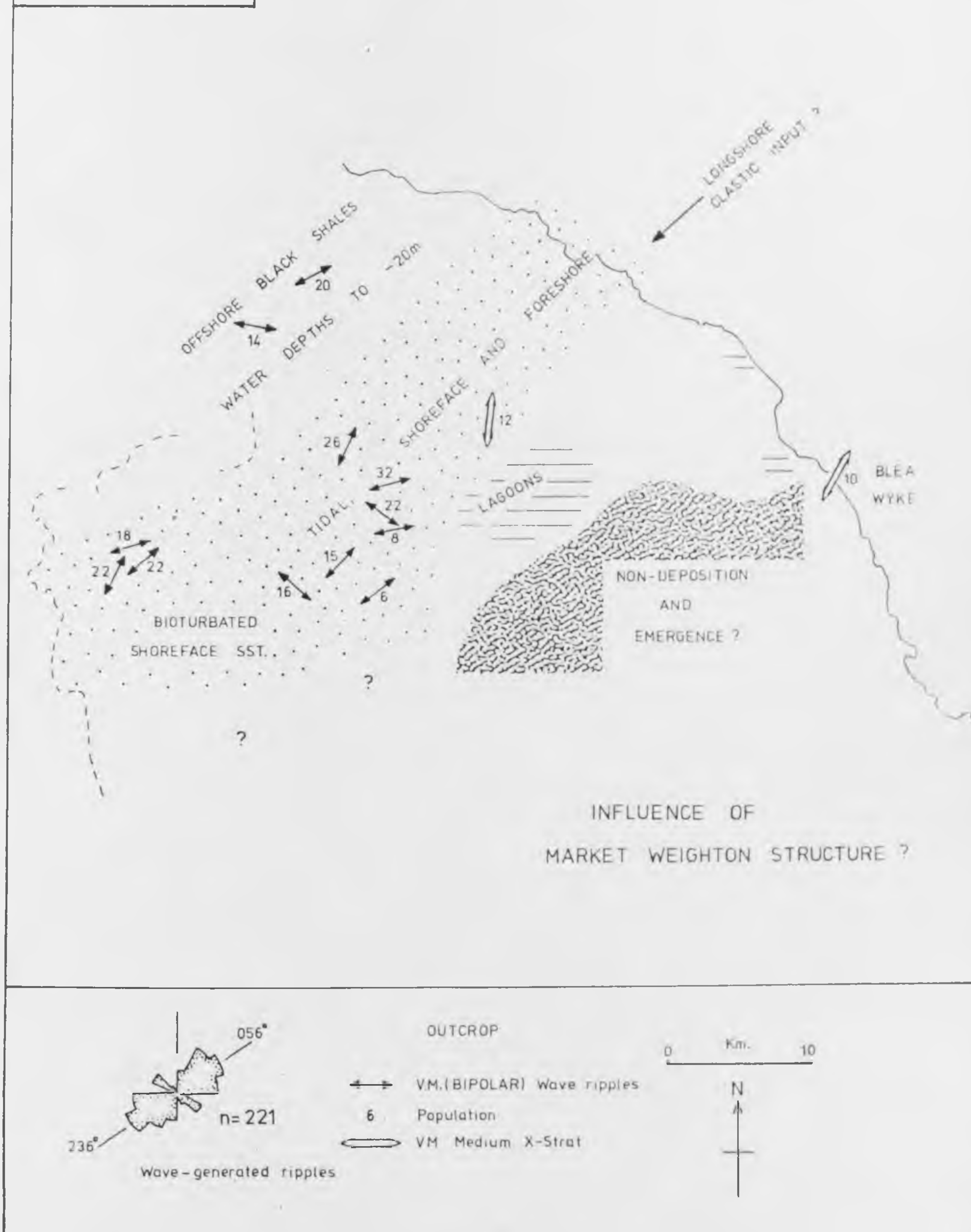
Although the outcrop at Blea Wyke is unique in the Yorkshire Basin it appears to imply that there was no major time gap involved between topmost Liassic and Middle Jurassic sedimentation. Elsewhere in Yorkshire the Lias was uplifted and gently folded before erosion and the deposition of the Dogger Formation. The *opalinum* ironstones contain a number of phosphatised Liassic fossils and concretions that appear to originate mainly from the Whitbian Alum Shales.

The *opalinum* zone Dogger Formation was deposited over large areas of the south-eastern Yorkshire Basin and may be continuous over the Market Weighton area into Humberside (Neale, 1958). These Aalenian sediments include oolitic ironstones and demonstrate intense bioturbation by shallow marine faunas, notably *Diplocraterion*. The Blea Wyke exposure shows low angle planar cross stratification and bipolar 'herringbone' sets (Fig. 5.1) indicative of shallow tidal activity and emergence. This exposure also shows sideritisation of chamositic sediments, a diagenetic effect that appears to have been widespread in these Dogger ironstones. The sideritisation may well have been an early effect associated with emergence shortly after deposition. To the north-west there is noticable thinning of the ironstones as they pass into a thin pebble lag zone (Fig. 2.20B). A younger series of limestones is found in the western parts of the Yorkshire Basin (Black, 1934) and from their coarseness and shallow marine fauna they appear to represent littoral deposition. Unfortunately these limestones are concentrated into localised erosional hollows and are now poorly exposed.

The coarsening upwards sequence (Facies 1c) that terminates the Dogger Formation contains dominantly clastic rather than carbonate sediment. The sequence indicates a different palaeogeography to the earlier Aalenian one in that Facies 1c is restricted to the north-western parts of the Yorkshire Basin (Fig. 5.1, see Fig. 2.21). Figure 5.1 shows a coastal sequence with a north-east/south-westerly orientated linear sandbody. To the north-west offshore black shales were deposited contemporaneously with a coastal barrier sequence. Behind this coastal barrier to the south east there were large areas of non-deposition and emergence with minor lagoonal sedimentation. Palaeocurrents taken from oscillation ripple form sets give a strong preferred orientation parallel to the sandbody. Much of the sediment in Facies 1c probably derived from the reworking of earlier Aalenian deposits, but the shoreface sandstones are petrographically similar to those in the Ravenscar Group. They are quartz arenites and are generally better sorted than the underlying Lower Jurassic sandstones. There is little evidence to suggest a large scale erosion of an earlier quartz

Fig. 5.1 Depositional palaeogeography of northeast Yorkshire during *murchisonae* times (Facies 1c). Note the area of non-deposition to the southeast. Discussion in text.

FIG. 5.1


LONGSHORE CLASTIC INPUT ?
OFFSHORE BLACK SHALES
WATER DEPTHS TO ~20m
SHOREFACE AND FORESHORE
TIDAL
LAGOONS
BLEA WYKE
NON-DEPOSITION AND EMERGENCE ?
BIOTURBATED SHOREFACE SST.
INFLUENCE OF MARKET WEIGHTON STRUCTURE ?
20
14
12
26
32
22
8
10
18
22
22
15
16
6
?
?
056°
236°
n= 221
Wave-generated ripples
OUTCROP
VM.(BIPOLAR) Wave ripples
6 Population
VM Medium X-Strat
0 Km. 10
N

arenite source within the Yorkshire Basin. Part of the sediment was probably introduced by longshore drift as indicated in Fig. 5.1, and may represent the first clastic material brought into the area from the source region of the Ravenscar Group, discussed in Chapter 7.

The palaeogeographic interpretation in Fig. 5.1 is similar to that of Black (1934), which was rejected by Knox (1969) and Hemingway (1974) who both speculated that the Dogger Formation shorelines lay to the north-west. There is no evidence for this interpretation from the murchisonae Dogger sediments. The Market Weighton area appears to have been a 'high' at this time, with no murchisonae sediments deposited in this region. Only the older iron rich Dogger Formation was proved in the Brown Moor borehole.

The Lower Jurassic - Middle Jurassic transition described above marks a major change in depositional environments from shallow marine clastics (Sellwood, 1970) and ironstones (Hallam, 1975) of the Lias to coastal and coastal plain sediments of the Ravenscar Group, discussed below.

5.2. Coastal plain progradation and the Saltwick Formation.

Palaeocurrents taken from medium to large scale cross stratification within channel sandstone bodies show a strong south-westerly transport direction (Fig. 5.2) as an alluvial coastal plain prograded rapidly over an abandoned coastal sequence. Roots penetrate and colonised the offshore marine sediments of the murchisonae Dogger in the north-west of the basin and bearing in mind the water depths indicated in Fig. 5.1 this appears to suggest uplift or major sea level fall. Gradual progradation into a marine area would probably have been marked by some form of tidal or wave influenced sandstone in-between the offshore shales and the non-marine beds. Most of the

Fig. 5.2 Palaeocurrents from the non-marine Saltwick Formation and Hawsker Member horizons. Note the similarity between the two stratigraphic levels. See Appendix I for locality and statistical details.

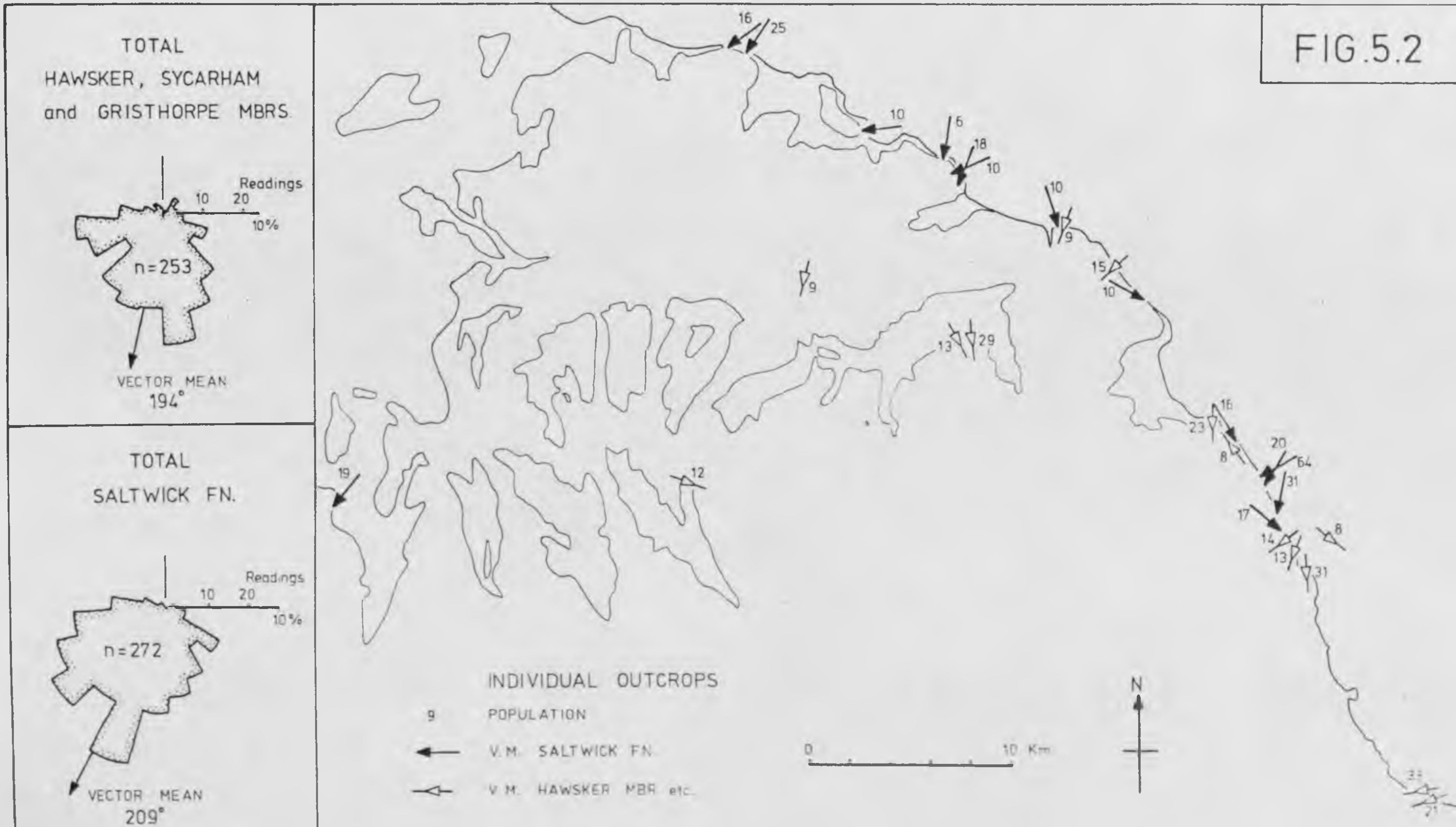

TOTAL
HAWSKER, SYCARHAM
and GRISTHORPE MBRS.
Readings
10
20
10%
n=253
VECTOR MEAN
194°
TOTAL
SALTWICK FN.
Readings
10
20
10%
n=272
VECTOR MEAN
209°
INDIVIDUAL OUTCROPS
9
POPULATION
V.M. SALTWICK FN.
V.M. HAWSKER MBR etc.
0
10 Km
N

FIG.5.2

palaeocurrents in Fig. 5.2 were taken from the lower parts of the Saltwick Formation and seem to indicate sediment input along the Dogger Formation coastline. Clearly there was a radical change in the palaeogeographies of these two formations.

In the south-west of the area initial Saltwick Formation sedimentation is marked by channel incision and brackish water deposition suggested by the presence of marine microfossils. Although there is still the possibility that these microfossils were reworked from the underlying Dogger Formation both the paucity of roots and the presence of bioturbation seem to indicate a marine influence. Evidence for tidal and wave modification is negligible and the depositional sequence was dominated by fluvial processes. The coastal outcrops show no marine influence and represent the deposition of freshwater, dominantly alluvial, sediments seen around Whitby. A variety of channel sizes cut through the early coastal plain sediments and include a multilateral sandbody at Kettleness and a single meandering stream at Whitby. The middle parts of the Saltwick Formation demonstrate a complex interbedding of varied coastal plain sediments, including extensive lacustrine sequences. Randomly avulsing rivers cut into and reworked these overbank deposits. Some rivers remained at the same site for a long period and formed sand dominant (braided/anastomosing?) bodies up to 1km wide. There is no evidence of any seaward margin sediments within the outcrop area and these non-marine deposits extended to the south of Brown Moor. However this borehole does indicate that the Saltwick Formation thins towards the Market Weighton area. The dominant palaeocurrent direction is towards the south-west and the main sediment transport route probably by-passed the Market Weighton region to the north towards the Vale of York (Fig. 1.2).

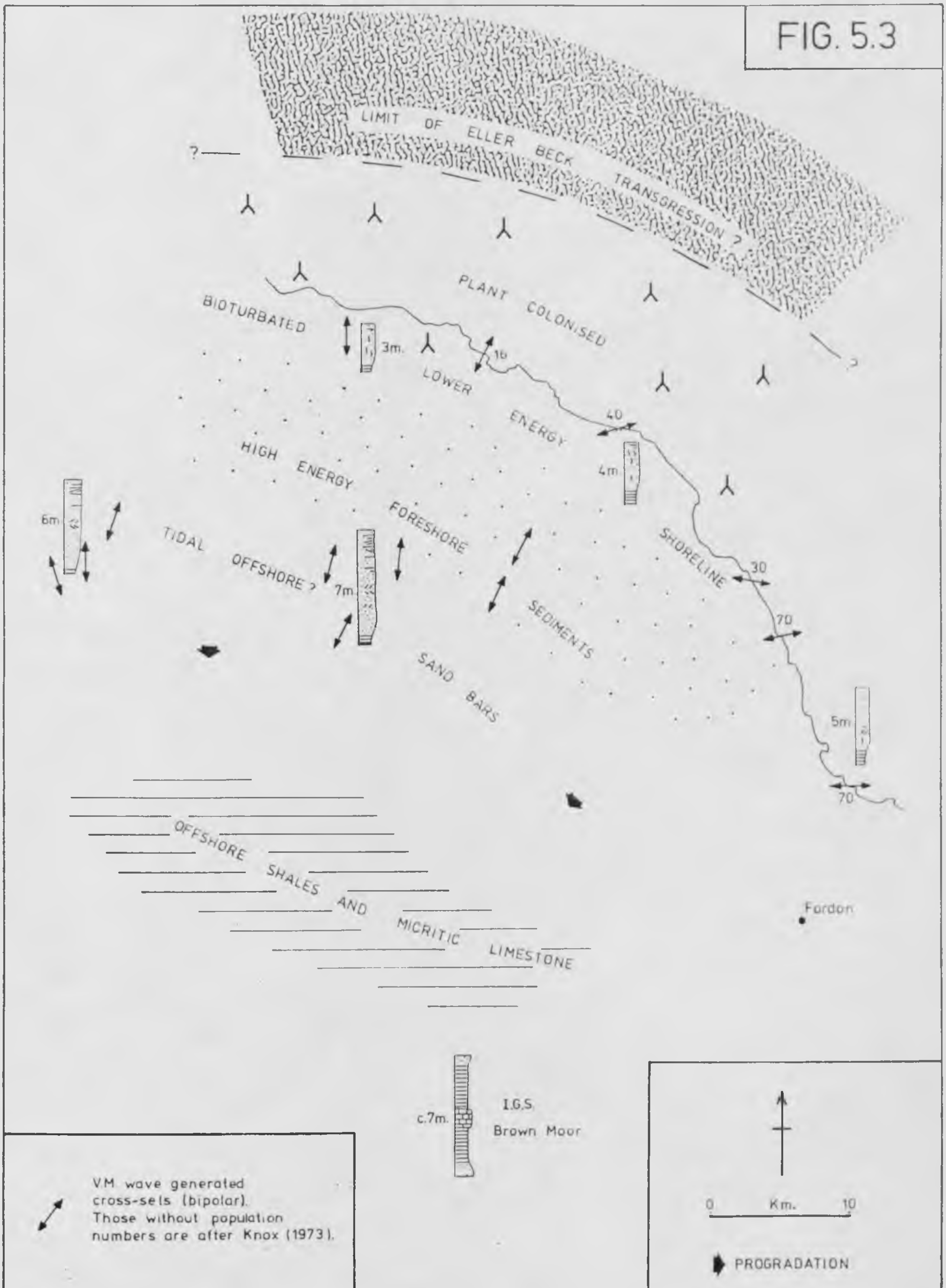
Towards the top of the Saltwick Formation the coastal plain was abandoned by the rivers carrying the coarsest sediment and overbank fines dominate the sequence. The deposition of marine microplankton marks the influence of marine incursions, probably in the form of tidal backup. Evidence from the upper parts of the Saltwick Formation suggest a relative rise in sea level as the coastal plain subsided under compaction of the underlying sediments. This subsidence was accompanied by the deposition of muds and silts as the area gradually became a low marsh region of even relief at, or near to, sea level.

5.3. The Eller Beck Formation transgression-regression.

After a period of gradual sea level rise there was a sudden transgression which left the whole of the depositional area under water to depths of 4 - 10m. Based on the grain size distributions in the basal ironstones Knox (1973) suggested that the transgression came from the south-west and south-east, and deposited chamosite oolites with a fully marine fauna. The transgression extended northwards and eastwards beyond the present outcrop of the Yorkshire Basin (Fig. 5.3). The main part of the Eller Beck Formation was deposited as a prograding shoreline sequence from offshore shales to foreshore sediments (Fig. 5.3). Northern and eastern exposures indicate a low wave energy shoreline, possibly due to protection by offshore tidal sand bars. In the central parts of the basin this protective effect was lost and a high wave energy beach zone formed as the coastline prograded. The increase in the shale:sandstone

Fig. 5.3 Depositional palaeogeography of northeast Yorkshire during Eller Beck Formation times. Discussion in text.

FIG. 5.3


LIMIT OF ELLER BECK TRANSGRESSION ?
?
PLANT COLONISED
BIOTURBATED
3m.
16
LOWER ENERGY
40
4m
HIGH ENERGY FORESHORE
SHORELINE
30
6m
TIDAL OFFSHORE ?
7m
SEDIMENTS
70
SAND BARS
5m
70
OFFSHORE SHALES AND MICRITIC LIMESTONE
Fordon
c.7m.
I.G.S.
Brown Moor
V.M wave generated cross-sets (bipolar). Those without population numbers are after Knox (1973).
0
Km.
10
PROGRADATION

ratio towards the south-west and the palaeocurrent evidence (Fig. 5.3) indicate a general north-east to south-west direction of progradation. Bates (1967) palaeogeographic reconstruction for the Eller Beck Formation indicates a Pennine land area in the south west of the Yorkshire Basin region which is clearly contradicted by the depositional palaeoenvironments indicated in Fig. 5.3. The exposure at Cornelian Bay indicates that the coarsening upwards sequence was deposited much further to the south than previous workers (Knox, 1973, Hemingway, 1974) have indicated. The Eller Beck Formation was not recorded from Fordon borehole (Fig. 5.3) but since the section was logged from chips it is possible that this horizon was missed (see Falcon and Kent, 1960).

All the indications seem to point to deeper water towards the south-west, the Brown Moor borehole proving nearly 7m of marine mudstones and micritic carbonates at this horizon (Fig. 5.3.) The bioclastic micritic carbonates from what was formerly termed the Hydraulic Limestone (Fox-Strangways et al. 1886) and re-named the Blowgill Member by Hemingway and Knox (1973). These latter authors named the Blowgill Member after an exposure of shales with a marine fauna found overlying the Eller Beck Formation in the south-west of the area. Hemingway and Knox correlated these shales with the Hydraulic Limestone ignoring the palaeogeographic considerations of the Eller Beck Formation. The Blowgill Member at Brown Moor directly overlies non-marine Saltwick Formation sediments and the majority of this marine sequence is probably laterally equivalent to the Eller Beck Formation as suggested in Fig. 5.3.

The depositional palaeogeography drawn in Fig. 5.3. indicates that the Eller Beck Formation sea extended beyond the present outcrop of the Ravenscar Group to the west, north and east of the area. Much of the sediment was probably introduced by longshore drift as there is no evidence of contemporary distributaries within the Yorkshire Basin. Both Bate (1967) and Knox (1973) suggested that a Pennine landmass existed during Eller Beck Formation times. If the Pennines were upstanding during this period they did not influence sedimentation and were not proximal to the depositional area. Later erosion of much of the Ravenscar Group over the Market Weighton area complicates the picture but further south the laterally equivalent Lower Lincolnshire Limestone demonstrates dominantly carbonate deposition. These discites age limestones represent lagoonal and tidal flat environments (Ashton, 1980).

5.4. Non-marine progradation and the Sycarham Member

Behind the Eller Beck Formation coastline there was rapid progradation of marsh sediment with vegetation colonising and fixing the beach deposits below. There appears to have been a period of slow deposition between the Eller Beck Formation progradation and the onset of major coastal plain deposition which allowed dense plant colonisation with associated minor coal formation. The coal is especially represented in the region of the present day coastal sections where exposures show mixed freshwater (with Equisitites) and marine influenced sediments at the base of the Sycarham Member. To the south-west marine macrofossils were introduced in shales with carbonate concretions (The Blowgill Member) on to the coastal plain. The exact correlation between the coastal sections and those in the south-west is impossible for they are separated by 40km of non-exposure. Much of the Sycarham Member was probably deposited very close to sea level with the result that the coastal plain was prone to the marine influences and the deposition of the marine microfossils recorded by Hancock and Fisher (in press).

At Ravenscar the sandbody that dominates the Sycarham Member gives south-westerly palaeocurrent directions and the Cloughton Formation channels as a whole show similar fluvial transport trends to the Saltwick Formation (Fig. 5.2). In the coastal outcrops the upper parts of the Sycarham Member show meandering stream deposits and thick-rooted overbank sediments. These sediments give no indication of the marine transgression that followed.

5.5. The Lebberston Member transgression

This marine transgression has a sharp erosive base in the coastal sections but in large areas of the south west there was initial mud deposition. The transgression only partially covered the coastal plain area of the Sycarham Member and its northern limits can be defined with some accuracy (Fig. 5.4). Present day coastal exposures demonstrate a low wave energy bioturbated shoreline sequence lying to the north of a complex offshore tidal carbonate sand belt area (Fig. 5.4). Carbonate grain coatings indicate fully marine clear water conditions and the adjacent coastal plain must have been inactive. The shoreline was unstable and sensitive to minor subsidence giving repeated bioturbated and cross-bedded horizons seen at Cloughton Wyke. Minor conglomerates were deposited on the shoreline marking the introduction of offshore derived oolitic clasts under violent storm conditions. The shoreline can probably be traced across the Yorkshire Basin to Kirby Knowle from where Hemingway (1974) describes thin sandstones with carbonate concretions. This exposure no longer exists but clearly

Fig. 5.4 Depositional palaeogeography of northeast Yorkshire during the lower Lebberston Member times. Note the variable but generally bipolar palaeocurrent roses shown below. The letters by the roses refer to their position on Fig. 5.4 and the lines on the roses refer to recalculated (for bipolarity) vector means. See Appendix I for statistical details.

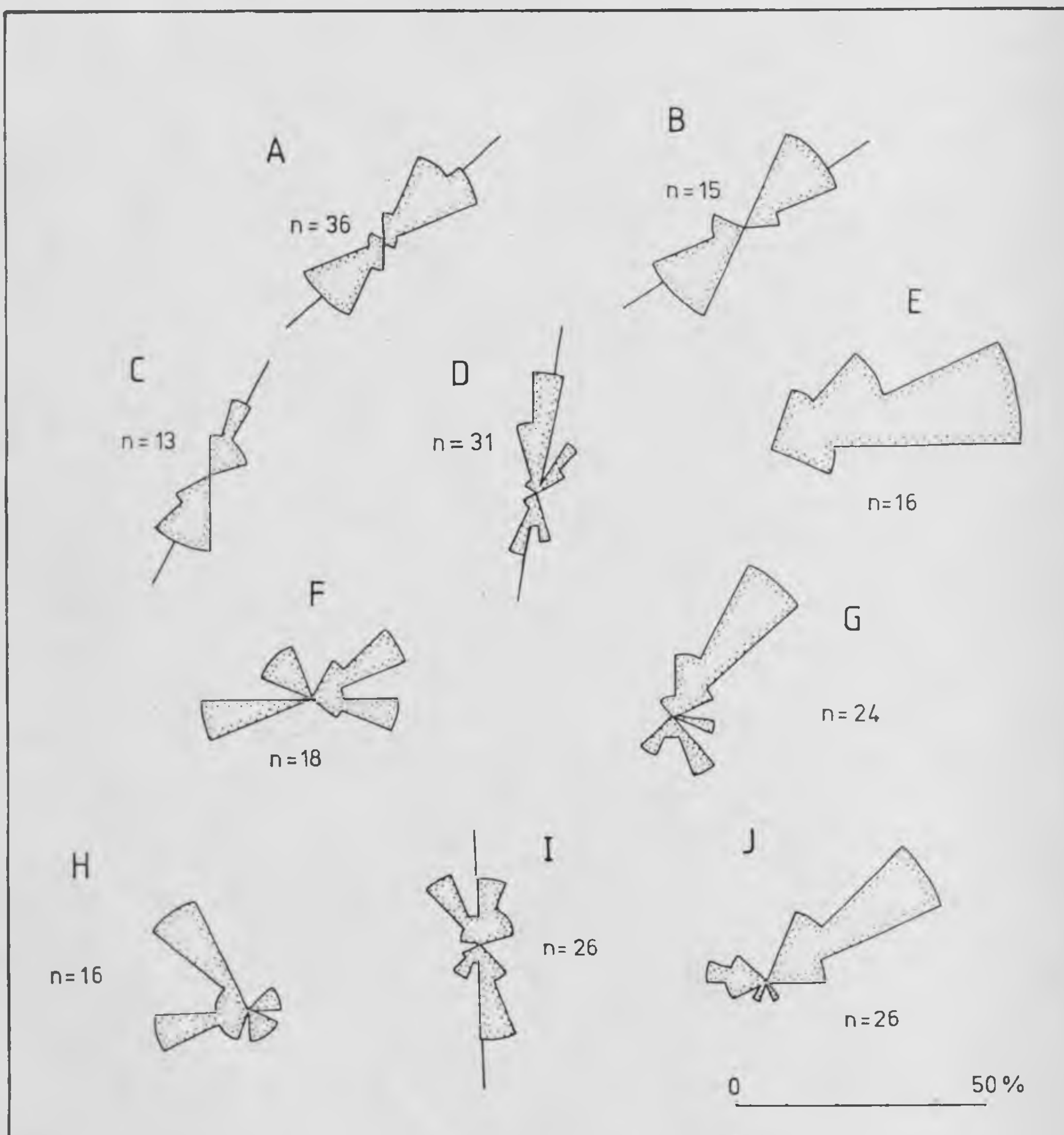
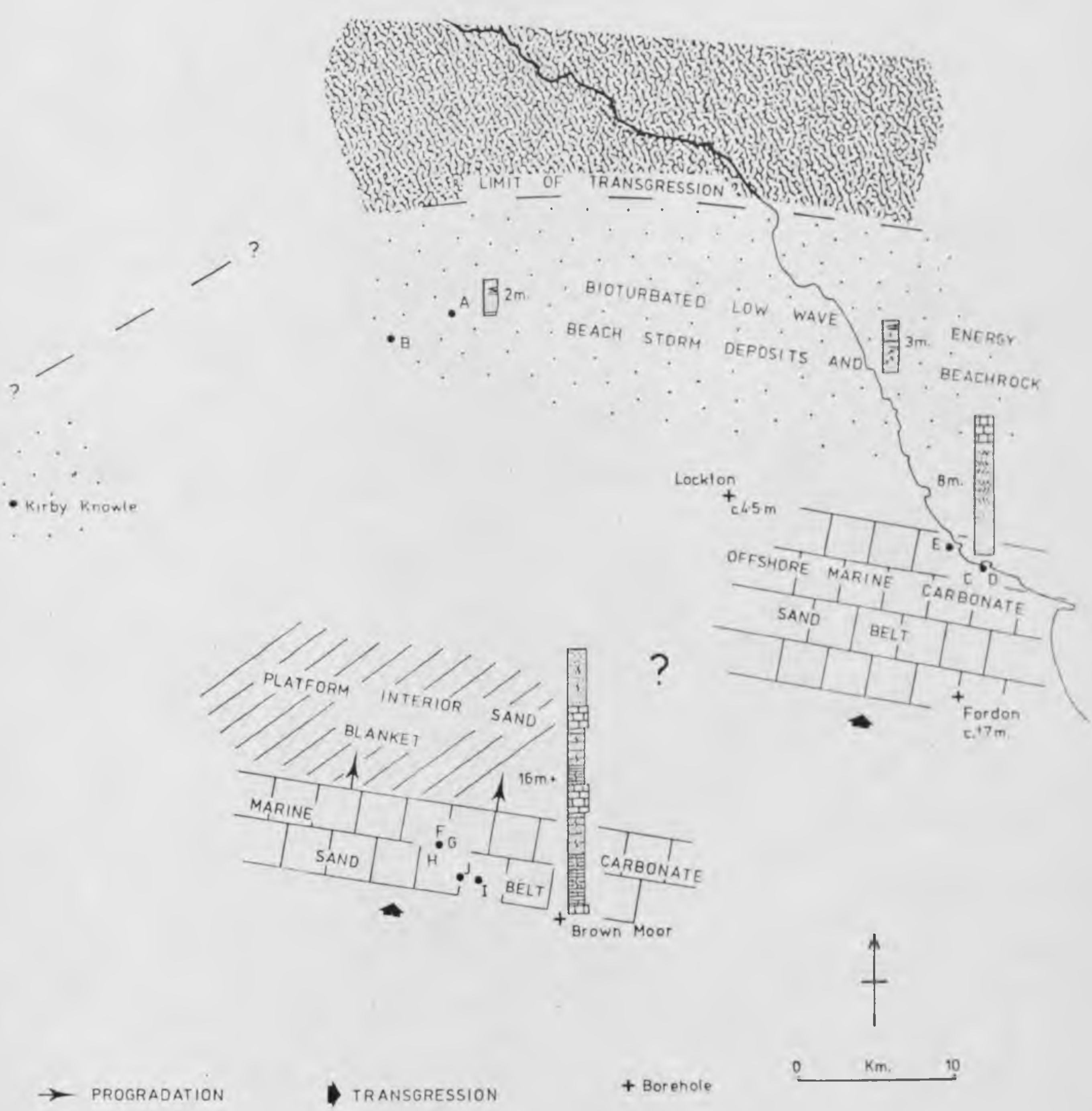


FIG. 5.4


LIMIT OF TRANSGRESSION ?
BIOTURBATED LOW WAVE ENERGY
BEACH STORM DEPOSITS AND BEACHROCK
2m.
3m.
8m.
A
B
Kirby Knowle
Lockton
c.45m
E
C D
OFFSHORE MARINE CARBONATE SAND BELT
Fordon
c.17m.
PLATFORM INTERIOR SAND BLANKET
16m+
MARINE SAND BELT
CARBONATE
F
G
H
J
I
Brown Moor
?
PROGRADATION
TRANSGRESSION
+ Borehole
0 Km. 10

the transgression extended further north than indicated in Bates (1967) palaeogeographic reconstruction.

Palaeocurrents taken from medium scale cross-bedding (Fig. 5.4) suggest a north/north east to south/south west tidal oscillation in the offshore area. As sea level rose the underlying sediments were reworked to form a sand belt area. This sediment reworking ceased as sea level stabilised and sand grains started to act as nuclei for carbonate deposition under the motion of tidal currents. The overall offshore environment is analagous to the present day Lily Bank, Bahamas with the concentration of tidal flow along well defined channels showing a dominant landward (north) energy flux. Areas of patchy submarine lithification were reworked and redistributed into the low energy troughs in-between the sand waves that constituted this sand belt environment. The sand waves were periodically flattened, presumably under storm conditions with waning flows producing thick clay drapes overlying wave-ripple cross-sets.

In the south-west of the Yorkshire Basin the lower Lebberston Member is represented by two oolitic limestones separated by fine-grained clastic sediments. Correlation with the coastal outcrops at Yons Nab is complicated by the 40km gap between exposures. The present study favours a correlation between the upper oolite in the south west and the Millepore Bed which would explain the reworked ooids seen at Yons Nab and Osgodby Point. Any such correlation is circumstantial and the one stated above disagrees with that of Hemingway (1974).

The oolitic limestones of the south-west were deposited under the influence of tidal currents which produced bipolar foreset orientations indicating similar palaeocurrent trends to the Millepore

Bed exposures (Fig. 5.4). Both limestones in the south west appear to have prograded over protected and bioturbated platform interior sediments (Fig. 5.4). The oolites correlate with the Upper Lincolnshire Limestone indicating a broad spread of shallow marine carbonate sedimentation across the Market Weighton area.

The general palaeocurrent readings and the relatively uniform sediment thicknesses across the basin militate against the idea of a Pennine landmass directly adjacent to the present outcrop area as suggested by Bate (1967).

5.6. The Yons Nabs Beds and Gristhorpe Member delta front progradation.

The Yons Nab Beds and the lower Gristhorpe Member represent the only true delta front deposits found in the Ravenscar Group and are vital to the understanding of the sequence as a whole. The Yons Nab Beds mark the sudden end of the carbonate sedimentation seen in the lower Lebberston Member and the renewal of major clastic input into the coastal plain area. One would expect to find evidence of abandonment in the coastal plain sediments to the north of the lower Lebberston Member shoreline but there is insufficient exposure to prove this hypothesis.

The Yons Nab Beds sequence prograded rapidly southwards but the two dimensional ribbon outcrop seen in the coastal sections makes an exact direction difficult to assess. There is insufficient palaeocurrent evidence available to accurately orientate the palaeocoastline drawn schematically in Fig. 5.5. From offshore marine shales the sequence passes into shoreface sandstones and wave/tidal moulded sand ridges and bars. The latter are separated by

FIG. 5.5

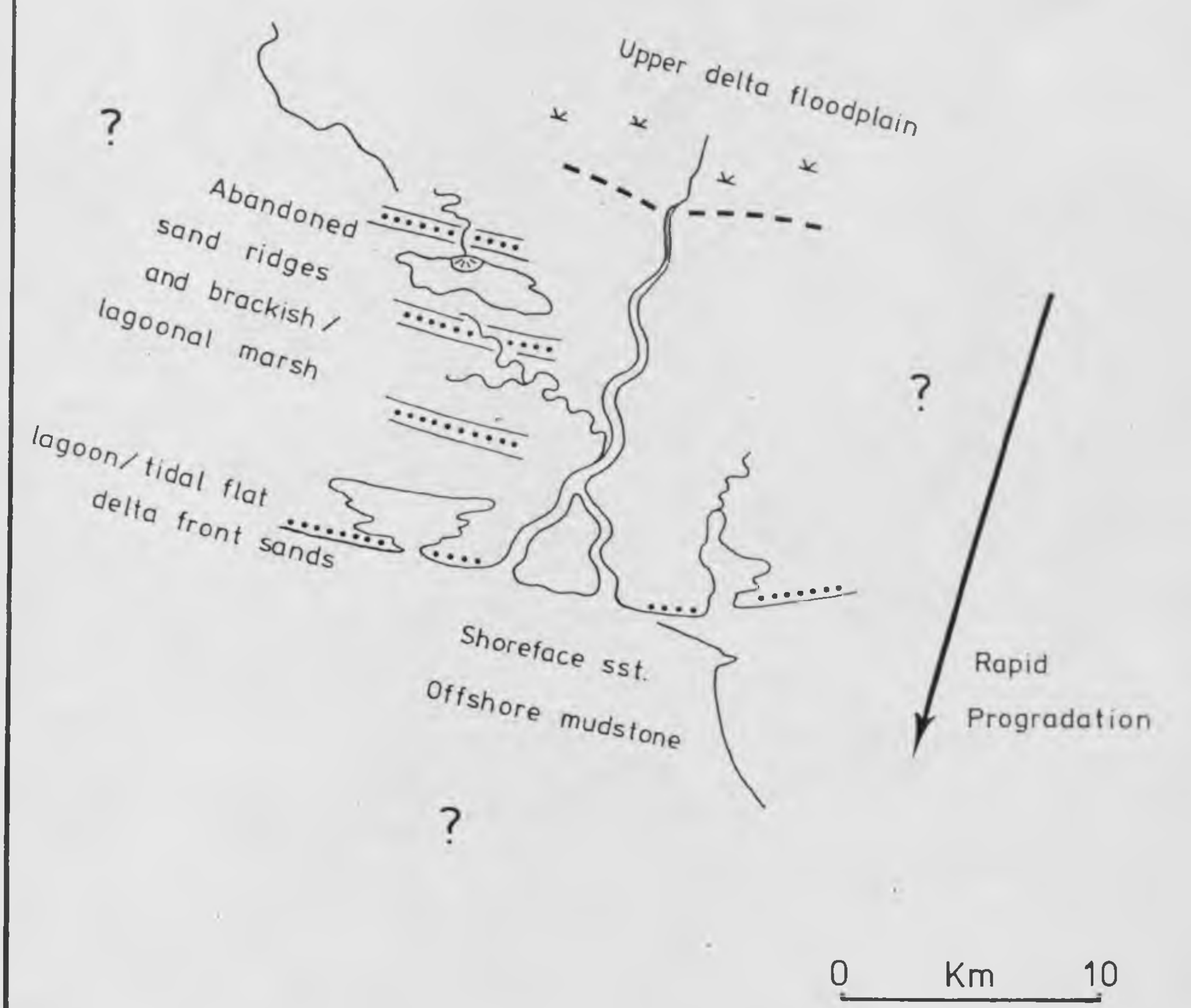


Fig. 5.5 Schematic reconstruction of the Yons Nab Beds palaeogeography showing generalised environments associated with a prograding wave/tide/fluvial delta. The exact orientation of the system is unknown.

lagoonal and brackish marsh sediments (Fig. 5.5) and the lower deltaic plain was cut into and reworked by a heirarchy of tidally influenced meandering channels. At the base of the Gristhorpe Member there is evidence of continued brackish environment deposition including thin, possibly tidal flat, sandstones. The final phase of the delta front progradational sequence is the deposition of fresh-water shales with thick roots and meandering stream deposits. The overall sequence therefore shows the rapid superposition of upper deltaic floodplain sediments on coastal and lower deltaic plain deposits. An analogy can be drawn between the Yons Nab Beds and the modern Niger Delta but the scale of the Ravenscar Group system is similar to the smaller Burdekin delta of Australia. One can conclude that the Yons Nab Beds-lower Gristhorpe Member sediments represent a wave/tide/fluvial delta system that prograded rapidly over a gently sloping coastal plain. Away from the ribbon exposure on the Yorkshire coast only one locality has been tentatively correlated with the above sequence. This one locality, at Oulston, appears to indicate a local dominance of fluvial processes with a river crevassing into an interdistributary bay environment. There was, however, sufficient wave energy to rework the abandoned crevasse channel into a coquina.

The middle and upper parts of the Gristhorpe Member shows varied overbank deposition including sheet sandstones and shales. The sheet-like bodies consist of a coalescing sequence of crevasse splay sandstones which occur in-between shales containing marine microfauna.

As in the modern Burdekin delta (Coleman and Wright, 1975) a correlation can be made between major overbank sedimentation and the limit of tidal inundation. At the top of the Gristhorpe Member Facies 4ii Type III channel fills indicate the presence of sluggish low energy rivers which cut into marine influenced overbank shales. The present day coastal sections appear to show localised abandonment of the Gristhorpe Member delta plain.

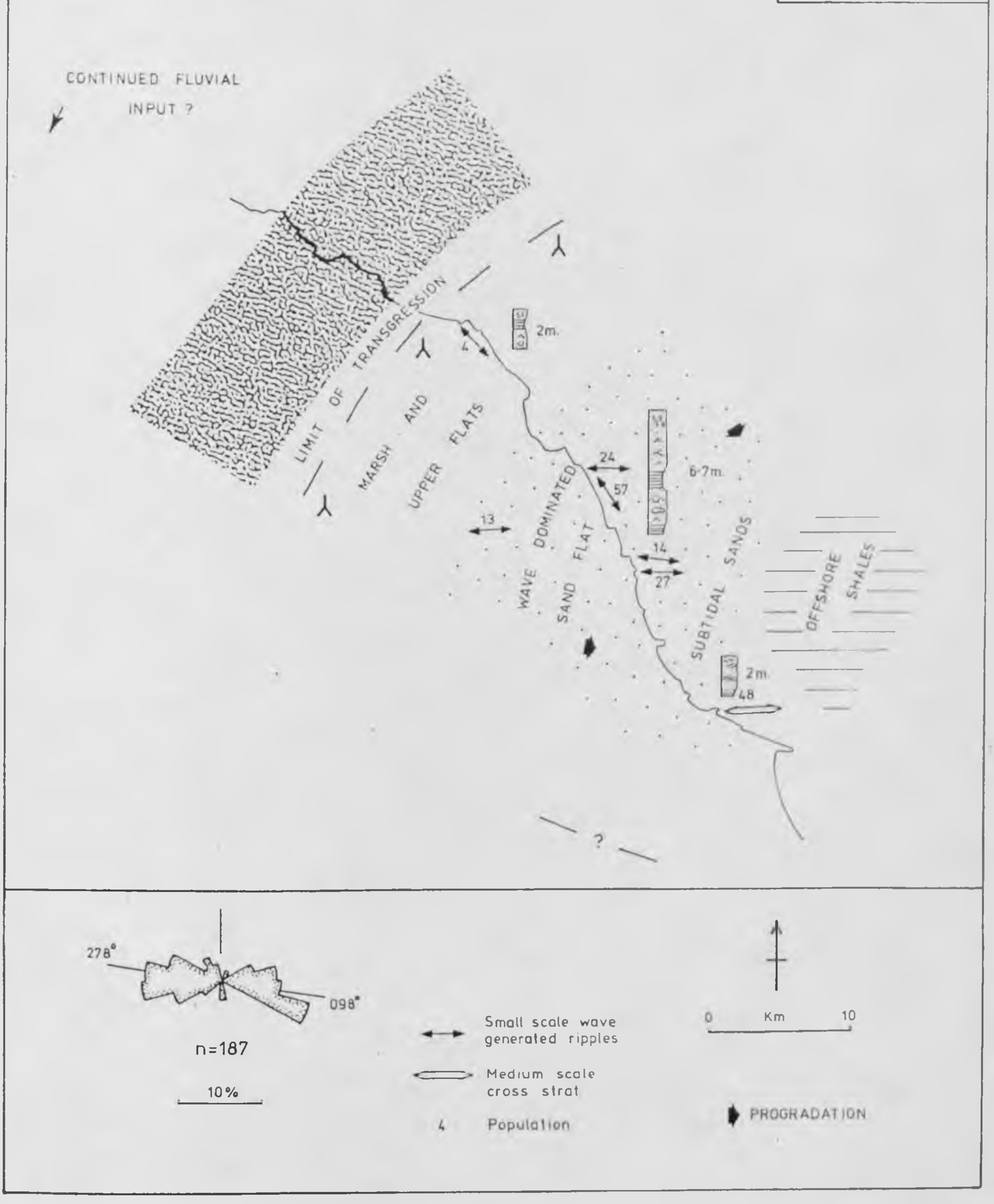
5.7. The lower Scarborough Formation transgression

The abandoned eastern area of the Yorkshire Basin coastal plain formed a low topography region very near to sea level. A sudden, but partial transgression occurred over the eastern region with the deposition of offshore shales directly on to coastal plain sediments. Major soft sediment deformation occurs in the ensuing marine deposits (Facies 1a) as a result of inferred earthquake shock. Whether or not this indicates a tectonic, fault movement, cause for the rapid transgression is open to discussion. Gradual transgression under coastal plain subsidence would probably have produced a noticable lag deposit.

The lower Scarborough Formation sandstone was deposited as a coarsening upward sequence resulting from the progradation of a tidal sand flat (Fig. 5.6). The source of the clastic material found in Facies 1a was probably from longshore sediment transport along the coastline, which can be delimited with some accuracy (Fig. 5.6). Wave generated currents and tidal motions reworked the sediment into tidal flat sandbodies, which prograded seawards as more clastic material was provided to the depocentre. Continued subsidence during progradation is the likely cause of the double coarsening upward profiles seen in Fig. 5.6. This subsidence caused a minor transgression which in turn led to shoreline retreat. Palaeocurrents indicate a strong north-west to south-east wave and current motion and the system prograded in the latter direction. Bate (1965) found a restricted distribution of the ostracod Glyptocythere polita from sediments immediately overlying Facies 1a which caused him to infer the existence of a small bay open to the east at the base of the Scarborough Formation. Apart

Fig. 5.6 Depositional palaeogeography of northeast Yorkshire during lower Scarborough Formation times. Discussion in text. Palaeocurrent statistical details are in Appendix I.

FIG. 5.6


CONTINUED FLUVIAL
INPUT ?
LIMIT OF TRANSGRESSION
MARSH AND UPPER FLATS
WAVE DOMINATED SAND FLAT
SUBTIDAL SANDS
OFFSHORE SHALES
2m.
6-7m.
2m.
4
24
57
13
14
27
48
?
278°
098°
n=187
10%
Small scale wave generated ripples
Medium scale cross strat
4 Population
0 Km 10
PROGRADATION

from Bates information there is little evidence on which to define a southern boundary to Facies 1a.

In the central parts of the Yorkshire Basin the Scarborough Formation overlies coarse and medium-grained channel fill sediments at Kilton Beck (NZ 703172). At this locality the Scarborough Formation is represented by the Crinoid Grit (Richardson, 1912) which is found 3m above Facies 1a at Cloughton Wyke. The coarseness of the channel sediment at Kilton Beck and its apparent position laterally equivalent to Facies 1a is interesting. It may be that the coastal plain was undergoing rapid sedimentation as a result of the sea level rise, with channel alluviation occurring adjacent to tidal flat deposition.

5.8. A comparison with the Scarborough and Scalby Formations

The Scarborough Formation is a thick (max. 32m) marine sequence with a large proportion of offshore shales in its middle and upper parts. Immediately above the Blea Wyke Member (Facies 1a) are thin sandy limestones and shales overlain by the littoral Crinoid Grit, which thickens to the north and is continuous beyond the present day Ravenscar Group outcrop. The fossiliferous bioturbated Crinoid Grit is overlain by shales with ammonites (Parsons, 1977) and the whole marine episode is terminated by a coarsening upwards sequence described by Nami (1976). Nami interpreted the top of the Scarborough Formation as a wave dominated shoreline, which can be traced northwards across the basin to Kilton Beck. South of Ravenscar large parts of the Scarborough Formation appears to have been removed by erosion at the base of the overlying Scalby Formation. As such the Scarborough Formation thins southwards towards Market Weighton in marked contrast to the general north to south increase in bathymetry discerned by

Farrow (1966) from a study of trace fossils. The erosion at the base of the Scalby Formation led Leeder and Nami (1979) to suggest that the discontinuity marked a period of hiatus. Such a hypothesis would explain the unreasonably long time period between the mid-Bajocian Scarborough Formation and the Callovian Cornbrash sediments (see Fig. 1.6) that could not be represented by normal deposition rates for an alluvial sequence such as the Scalby Formation. Leeder and Nami postulated a mid-Bajocian to late Bathonian uplift that may have extended across the Market Weighton 'axis', and they related this hiatus to North Sea rifting processes.

The Scalby Formation includes a low sinuosity unit (the braided Moor Grit Member) at its base, overlain by high and low sinuosity channels set in a matrix of overbank fines (Nami, 1976, Nami and Leeder, 1978). The fine-grained overbank material shows similar lithofacies types to the upper parts of the Saltwick Formation and both horizons contain a comparable flora (Harris, 1952) rather distinct from the Hawsker Member. The palaeobotanical evidence suggests that the upper parts of the Saltwick and Scalby Formations were deposited in similar environments.

The vertical change from low to high sinuosity alluvial plain sediments seen in the Scalby Formation is comparable with the Mississippi valley sequence (Nami and Leeder, 1978) where coarse-grained braided stream deposits are succeeded by finer-grained alluvium deposited after the early Holocene sea level rise. Although Nami and Leeder inferred a tectonic (North Sea fault movement) cause for the vertical changes seen in the Scalby Formation they did not entirely discount the type of climatic glacio-eustatic variation responsible for the Mississippi valley sequence.

There is no direct evidence however for any large scale climatic variation within the whole Ravenscar Group. The Middle Jurassic is terminated by the Callovian Cornbrash marine deposits that mark a complete abandonment of the Ravenscar Group coastal plain environments (Nami, 1976, Wright, 1977).

5.9. Discussion

Volumetrically the dominant sediments preserved in the sequence studied are non-marine delta top and coastal plain deposits of the Saltwick Formation and Hawsker Member. Within the outcrop area these deposits are fluvial-dominated and formed on low coastal plains of shallow gradient. Palaeocurrents and the overall similarity of both of the non-marine horizons suggest that they were deposited from different periods of progradation of the same deltaic system sourcing from the north and north-east. The repeated periods of marine incursions and coastal plain progradation may relate to tectonic uplift in the source area allied to delta lobe abandonment. It is difficult to prove that either process was dominant during any one period of Ravenscar Group deposition.

Although the non-marine beds show fluvial dominance there is evidence from the intercalated marine horizons for substantial wave and tidal activity in the adjacent nearshore and coastlines. Wave influence is marked in the Eller Beck Formation, the Dogger Formation and at the base and top of the Scarborough Formation. Protection by offshore and nearshore tidal sand deposits had a moderating effect on the shoreline wave activity in the Lebberston Member and parts of the Eller Beck Formation. All the marine horizons demonstrate the effects of tidal motions. From the heights of the coarsening upwards marine units (especially

Facies 1a) and from the presence of oolites in the lower Lebberston Member one can roughly estimate a micro-mesotidal range (after Hayes, 1975), probably in the region of 1-3m., for the Ravenscar Group sediments. The range would obviously vary depending on the orientation and morphology of the coastline (Hayes, op. cit.) and any figure presented would be, at best, an approximation. In view of the evidence from the marine horizons it is not surprising that the only delta front sediments found in the Ravenscar Group indicate a mixture of wave, tidal and fluvial conditions. If ever exposed the Saltwick Formation, Sycarham Member and the Scalby Formation coastal margins would probably show similar sediments to those seen in the Yons Nab Beds.

The tectonic controls on sedimentation in the Middle Jurassic are well documented (Hallam and Sellwood, 1976) and relate to North Sea rifting and fault block movement. This tectonic activity was probably the cause of the sudden marine transgressions (Facies 1) and the mixed marine and non-marine periods of deposition seen in the Ravenscar Group. A fuller discussion on the structural evolution of the North Sea area and its effects on the regional sedimentary patterns in the Middle Jurassic of north-western Europe is given in Chapter 7. The Market Weighton area influenced sedimentation throughout the Middle Jurassic and there is a marked thinning of the Yorkshire Basin sediments against this structure. Marked erosion at the base of the Lebberston Member appears to suggest uplift of the Market Weighton region as inferred by Leeder and Nami (1979) for the Scarborough Formation/Scalby Formation junction. Other horizons thin towards Market Weighton by non-deposition as if this region was acting as a rigid block. The Liassic sediments in the Yorkshire Basin thin southwards as a result of the basin and swell influences discussed in Section 5.1. (Sellwood and Jenkyns, 1974). As the Liassic sediments compacted the Yorkshire Basin would become a favourable depocentre for the accumulation of Middle Jurassic clastics. As a result the Yorkshire Basin would have been partly self propagating, explaining the non-depositional thinning noted above.

Only the southernmost limits of the Ravenscar Group can be defined with any confidence. These lie in the Market Weighton area. In all other directions there is little evidence of marked lateral sedimentary variation especially in the Scarborough, Eller Beck and Saltwick Formations up to the present day outcrop limits. Previous workers, notably Bate (1965, 1967) and Smithson (1942) have tended to draw the margins of the depositional area adjacent to the present outcrop limits when sedimentological evidence suggests that the Yorkshire Basin had a greater lateral extent.

Unlike the upper parts of the Ravenscar Group the Dogger Formation to Scarborough Formation sequence in the basin appears to show evidence for essentially continuous deposition. The biostratigraphic evidence (Fig. 1.6) suggests a time span of five ammonite zones from the murchisonae Dogger Formation to the humphriesianum Scarborough Formation. Following the arguments of Leeder and Nami (1979) that one Jurassic ammonite zone approximates to an average duration of one million years it is possible to postulate a continuous period of coastal plain and marine sedimentation lasting about five million years. This time span is also borne out by a consideration of van Hintes (1976) approximate dates for the Jurassic system (Fig. 1.6).

Five million years is ample time for major climatic change to occur in a region if one considers the Holocene period of glaciation. However there is little direct evidence of climatic controls on sedimentation in any of the Ravenscar Group studied. Hallam (1975) finds little indication for the existence of polar ice caps during Jurassic times, and in general the climates pertaining during this period were more uniform than today. Inferred periods of tectonic instability are more likely explanations for the varied Middle Jurassic sediments described in this chapter. Recent isotope research and palaeomagnetic evidence give a general clue as to the overall climatic conditions pertaining during the Bajocian period in Great Britain. Marshall and Ashton (1980) estimated shallow marine palaeotemperatures using oxygen isotopes from Bajocian oysters from Lincolnshire and produced a range of 22-25^{o}C. A similar range of 20-25^{o}C was estimated by Tan and Hudson (1974) for Bathonian shallow marine faunas in north-east Scotland. Palaeomagnetic work by Smith et al. (1973) indicates that Great Britain was in low latitudes (c.30^{o}N) during the Jurassic which, using modern analogues, would be pre-requisite for the formation of the Lebberston Member ooids. Coastal plain conditions seem to indicate a warm wet climate ideal for the formation of kaolinite under overbank leaching (see Section 6.4). There is little evidence of pedogenesis in any of the non-marine sequences although the cyclic horizonation of shales at the base of the Saltwick Formation implies sufficiently variable deposition rates to allow soil formation. In arid climates with slow overbank deposition rates pedogenic carbonate is common, resulting from evaporation and the concentration of minerals near to the sediment surface (see Leeder, 1975, for discussion). The coastal plains of the Ravenscar Group were probably formed in a climate where precipitation was too high to allow continued periods of evaporation and mineral concentration in the overbank sediments. Only the possible varves in the lacustrine sediments imply any seasonal variation within the climate as a whole.

CHAPTER 6

PETROGRAPHY AND DIAGENESIS

CHAPTER 6

PETROGRAPHY AND DIAGENESIS

Part 1. Clastic Sediments

6.1. Grain Size Analysis of coarse clastic sediments

Forty-nine samples were taken from a variety of facies and stratigraphic horizons within the Ravenscar Group. Sample locations are given in Appendix II. Thirty-seven loosely consolidated sandstones were disaggregated and sieved (see Appendix III for sample preparation and sieve techniques). For the twelve indurated samples a standard point counting method was employed with approximately three hundred measurements taken from thin sections using a calibrated mechanical stage. It was found to be easier and quicker to measure grain long axes rather than the variations recommended by Kellerhals et al. (1975) which give only small increases in accuracy. Friedman's (1958) regression line equation was used in an attempt to convert this thin section data to equivalent sieve values.

Statistical measurements were computed for the graphical parameters of Inman (1952) and Folk and Ward (1957) as well as the moment parameters of Friedman (1961). Equations for the calculation of mean, sorting, skewness and kurtosis are presented in Table 6.1. A computer program written by A.R. Gardiner was used to calculate these statistics and to produce drawings of cumulative curves and histograms for each sieved sample. An additional program was written to apply Friedmans (op. cit.) correction to the relevant percentiles and groupings of the thin section data. Table 6.2a is a presentation of the sieve analysis results and the thin section data are shown in

TABLE 6.1

Formulas used for the computation of grain size graphical and moment parameters.

INMAN

MEAN	$M\phi = (\phi16 + \phi84)/2$
SORTING	$\sigma\phi = (\phi84 - \phi16)/2$
SKEWNESS	$\alpha2\phi = (\frac{1}{2}(\phi5 + \phi95) - \phi50)/\sigma\phi$
KURTOSIS	$\beta\phi = (\frac{1}{2}(\phi95 - \phi5) - \sigma\phi)/\sigma\phi$

FOLK and WARD

MEAN	$Mz = (\phi16 + \phi50 + \phi84)/3$
SORTING	$\sigma_I = (\phi84 - \phi16)/4 + (\phi95 - \phi5)/6.6$
SKEWNESS	$Sk_I = (\phi16 + \phi84 - 2\phi50)/(2\phi84 - 2\phi16) + (\phi5 + \phi95 - 2\phi50)/(2\phi95 - 2\phi5)$
KURTOSIS	$K_G = (\phi95 - \phi5)/2.44(\phi75 - \phi25)$

MOMENTS

MEAN	$\bar{X}\phi = 1/100.\sum Fm\phi$
SORTING	$\delta\phi = (\sum F(m\phi - \bar{X}\phi)^2 /100)^{\frac{1}{2}}$
SKEWNESS	$\alpha3\phi = 1/100.\delta\phi^{-3}\sum F(m\phi - \bar{X}\phi)^3$
KURTOSIS	$\alpha4\phi = 1/100.\delta\phi^{-4}\sum F(m\phi - \bar{X}\phi)^4$

$\phi5$, $\phi16$, $\phi50$, $\phi84$, $\phi95$ refer to the grain size in ϕ at the 5^{th}, 16^{th}, 50^{th}, 84^{th} and 95^{th} percentile values from the cumulative curves. F is the weight percent in each grain size grade (0.25ϕ intervals), m is the midpoint of each grain size grade (ϕ values).

TABLE 6.2a

Sample No.	Facies	INMAN				FOLK				MOMENTS				FOLK'S CLASS		
		MEAN	SORT.	SKEW.	KURT.	MEAN	SORT.	SKEW.	KURT.	MEAN	SORT.	SKEW.	KURT.	SORT.	SKEW.	KURT.
1	2b	2.75	0.41	0.34	0.56	2.70	0.40	0.37	0.98	2.70	0.42	0.82	3.82	W.S.	F.Sk.	MS.
2	2b	2.16	0.37	-0.02	0.98	2.17	0.40	0.07	1.54	2.20	0.42	0.75	4.93	W.S.	N.Sy.	VLK.
3	2a	2.52	0.31	-0.09	1.11	2.53	0.35	0.00	1.42	2.55	0.41	0.70	5.38	W.S.	N.Sy.	LK.
4	2a	2.71	0.28	0.23	0.91	2.69	0.30	0.21	1.49	2.69	0.34	0.91	5.44	V.W.S.	F.Sk.	LK.
18	2b	2.37	0.23	0.03	1.41	2.37	0.26	0.15	1.19	2.38	0.33	1.30	7.56	V.W.S.	F.Sk.	LK.
29	2b	2.71	0.57	0.40	0.71	2.63	0.58	0.34	1.28	2.60	0.58	0.71	3.10	M.W.S.	S.F.Sk.	LK.
30	2b	2.44	0.44	-0.01	0.97	2.44	0.49	0	1.41	2.46	0.50	0.25	3.51	W.S.	N.Sy.	LK.
31	2b	2.53	0.26	0.06	1.00	2.52	0.29	0.14	1.16	2.54	0.35	0.78	5.31	V.W.S.	F.Sk.	LK.
32	2b	2.83	0.33	0.10	1.09	2.82	0.38	0.10	1.22	2.82	0.42	0.16	4.11	W.S.	N.Sy.	LK.
5	3b	2.36	0.27	0.01	1.43	2.36	0.33	0.10	1.38	2.38	0.37	0.75	4.85	V.W.S.	N.Sy.	LK.
6	3b	2.64	0.38	0.40	0.84	2.59	0.40	0.46	1.60	2.59	0.44	1.39	5.17	W.S.	S.F.Sk.	LK.
15	5ii	2.37	0.23	0.03	1.11	2.37	0.26	0.15	1.19	2.39	0.33	1.30	7.56	V.W.S.	F.Sk.	LK.
16	5ii	2.48	0.31	0.01	0.81	2.48	0.32	0.12	1.07	2.51	0.32	0.85	4.93	V.W.S.	F.Sk.	MK.
19	5ii	2.42	0.23	0.03	1.22	2.42	0.26	0.12	1.33	2.44	0.32	0.91	6.63	V.W.S.	F.Sk.	LK.

TABLE 6.2a. (continued)

Sample No.	Facies	INMAN				FOLK				MOMENTS				FOLK'S CLASS		
		MEAN	SORT.	SKEW.	KURT.	MEAN	SORT.	SKEW.	KURT.	MEAN	SORT.	SKEW.	KURT.	SORT.	SKEW.	KURT.
20	4	1.90	0.41	0.13	0.56	1.88	0.39	0.17	0.86	1.91	0.46	1.08	5.46	W.S.	F.Sk.	PK.
22	4	1.90	0.40	0.18	0.76	1.87	0.41	0.22	1.03	1.90	0.47	1.19	5.60	W.S.	F.Sk.	MK.
23	4	2.02	0.46	-0.04	0.69	2.02	0.47	0.04	0.96	2.05	0.51	0.72	4.43	W.S.	N.Sy.	MK.
24	4	1.90	0.33	-0.12	0.83	1.92	0.34	0.01	1.02	1.96	0.45	1.77	8.74	V.W.S.	N.Sy.	MK.
25	4	0.97	0.38	0.05	0.86	0.97	0.41	0.12	1.08	1.01	0.51	1.47	8.21	W.S.	F.Sk.	MK.
26	4	1.27	0.60	0.15	0.80	1.24	0.63	0.19	1.19	1.27	0.70	0.93	4.85	M.W.S.	F.Sk.	LK.
28	4	2.10	0.40	-0.02	0.84	2.10	0.42	0.11	1.19	2.15	0.47	1.23	5.98	W.S.	F.Sk.	LK.
7	4	2.20	0.33	0.02	0.93	2.20	0.35	0.07	1.28	2.23	0.41	1.17	6.53	W.S.	N.Sy.	LK.
8	4	2.74	0.37	0.32	0.67	2.70	0.37	0.32	1.15	2.69	0.40	0.85	4.10	W.S.	S.F.Sk.	LK.
9	4	2.03	0.23	-0.18	0.83	2.04	0.24	-0.09	1.20	2.07	0.33	1.96	12.17	V.W.S.	N.Sy.	LK.
10	4	2.34	0.26	0.00	1.80	2.34	0.35	0.10	1.72	2.37	0.41	1.30	6.61	W.S.	N.Sy.	V.LK.
12	4	1.88	0.35	0.32	1.06	1.84	0.39	0.42	1.23	1.89	0.47	1.71	7.00	W.S.	S.F.Sk.	LK.
14	4	2.18	0.40	-0.14	0.75	2.20	0.41	-0.09	1.20	2.23	0.44	0.43	4.59	W.S.	N.Sy.	LK.
17	4	2.77	0.44	0.13	0.64	2.75	0.44	0.07	0.95	2.74	0.47	-0.06	3.32	W.S.	N.Sy.	MK.
34	4	0.23	0.91	1.54	5.73	0.19	0.78	0.34	1.67	0.29	0.91	1.54	5.73	M.S.	S.F.Sk.	V.LK.
35	4	0.11	0.59	0.12	1.47	0.09	0.73	0.28	1.65	0.19	0.86	1.60	6.46	M.S.	F.Sk.	V.LK.
36	4	1.40	0.85	0.11	0.68	1.36	0.86	0.12	1.01	1.37	0.87	0.30	3.09	M.S.	F.Sk.	MK.
37	4	1.30	0.89	0.09	1.03	1.28	0.88	0.11	1.03	1.28	0.89	0.34	3.08	M.S.	F.Sk.	MK.
11	4	2.19	0.44	-0.27	0.87	2.23	0.47	-0.13	1.40	2.29	0.49	0.48	4.27	W.S.	C.Sk.	LK.
13	4	2.56	0.33	0.09	0.84	2.55	0.35	0.18	1.19	2.57	0.39	0.95	4.76	W.S.	F.Sk.	LK.
21	4	1.62	0.37	0.23	0.87	1.59	0.39	0.24	1.24	1.61	0.45	1.47	7.50	W.S.	F.Sk.	LK.
27	4	1.71	0.30	0.24	0.73	1.68	0.30	0.27	1.17	1.70	0.39	2.02	10.43	V.W.S.	F.Sk.	LK.

TABLE 6.2b.

Sample No.	Facies	INMAN				FOLK				MOMENTS				FOLK'S CLASS		
		MEAN	SORT.	SKEW.	KURT.	MEAN	SORT.	SKEW.	KURT.	MEAN	SORT.	SKEW.	KURT.	SORT.	SKEW.	KUR
58	2b	1.62	0.29	0.06	0.86	2.61	0.31	0.15	1.13	1.63	0.34	0.71	4.06	V.W.S.	F.Sk.	LK
57	3b	1.97	0.40	0.02	0.80	1.97	0.41	0.08	1.03	1.98	0.42	0.43	2.91	W.S.	N.Sy.	MK
50	1	3.21	0.50	0.15	0.77	3.18	0.51	0.15	1.07	3.20	0.53	0.48	3.13	M.W.S.	F.Sk.	MK
51	1	3.42	0.47	0.13	0.69	3.40	0.48	0.16	1.02	3.42	0.49	0.51	3.25	W.S.	F.Sk.	MK
52	5ii	2.33	0.54	0.17	0.65	2.30	0.54	0.18	0.95	2.31	0.56	0.45	3.08	M.W.S.	F.Sk.	MK
53	5ii	2.62	0.50	0.14	0.70	2.60	0.51	0.17	1.08	2.62	0.53	0.62	3.55	M.W.S.	F.Sk.	MK
54	5ii	2.13	0.46	0.18	0.63	2.11	0.46	0.17	1.02	2.10	0.47	0.49	3.18	W.S.	F.Sk.	MK
56	5ii	2.07	0.46	0.19	0.62	2.05	0.45	0.21	0.96	2.06	0.48	0.64	3.45	W.S.	F.Sk.	MK
100	4	1.57	0.49	-0.02	0.91	1.58	0.55	0.04	1.20	1.60	0.54	0.32	3.18	M.W.S.	N.Sy.	LK
55	4	1.60	0.46	0.22	0.79	1.56	0.48	0.29	1.16	1.58	0.51	1.00	4.28	W.S.	F.Sk.	LK
59	4	2.04	0.51	0.21	0.75	2.01	0.52	0.24	1.15	2.02	0.53	0.79	3.52	M.W.S.	F.Sk.	LK
60	4	1.81	0.42	0	0.87	1.81	0.44	0.08	1.16	1.83	0.46	0.57	3.77	W.S.	N.Sy.	LK

KEY TO TABLES 6.2a, b.

SORT.	Sorting
SKEW.	Skewness
KURT.	Kurtosis

FOLK'S CLASSIFICATION

V.W.S.	Very well sorted
W.S.	Well sorted
M.W.S.	Moderately well sorted
S.F.Sk.	Strongly fine-skewed
F.Sk.	Fine-skewed
N.Sy.	Near symmetrical
V.LK.	Very leptokurtic
LK.	Leptokurtic
MK.	Mesokurtic
PK.	Platykurtic

Table 6.2b.

Two samples were subjected to both thin section and sieve analyses and compared. After correction for sectioning the mean values corresponded well but the sorting, skewness and kurtosis results were inaccurate (e.g. samples 9 and 59 Table 6.2). All the thin section analyses produced a closer grouping of skewness and kurtosis values than seen in the sieve results. The corrections suggested by Adams (1977) did little to improve these findings and following the observations of Harrell and Eriksson (1979) the thin section data in Table 6.2b are presented as rough estimates only. Only the sieve experiment results were therefore used in comparing the grain size distributions between facies and stratigraphic horizons involving sorting, skewness and kurtosis.

6.1a. Results

i. Facies 2b. Shallow marine tidal sand belts

These marine sandstones all show broadly similar results with mean grain size varying from 2.17 to 2.82 Ø (Folks graphical parameters). They are moderately to very well sorted and near symmetrical to fine-skewed. Figure 6.3a sample 31 demonstrates the high degree of sorting and all the samples taken from this facies in the Lebberston Member give very comparable results (Table 6.2a) reflecting their high energy environment of deposition. Facies 2a (Fig. 6.3a, sample 3) sediments show a similar grain size distribution as do those of Facies 3b. Both these facies represent littoral environments and it would be impossible to separate them from Facies 2b samples using grain size analysis.

Fig. 6.3 Graphical representation of grain size data. Histograms and cumulative frequency curves for six varied sieved samples. Note how well sorted the marine examples (samples 3, 31) are. Laterally accreted sandstones of point bar origin (samples 13, 7) are much better sorted and finer-grained than lag deposits at the base of the channels. Statistical results of the analyses are in Table 6.2a.

Sample	
3	Millepore Bed, Common Cliff
31	Lebberston Member, Crambeck
13	Sycarham Member, Yons Nab
7	Gristhorpe Member, Yons Nab
26	Saltwick Formation, Petard Point
34	Hawsker Member, Kilton Beck

FIG. 6.3a

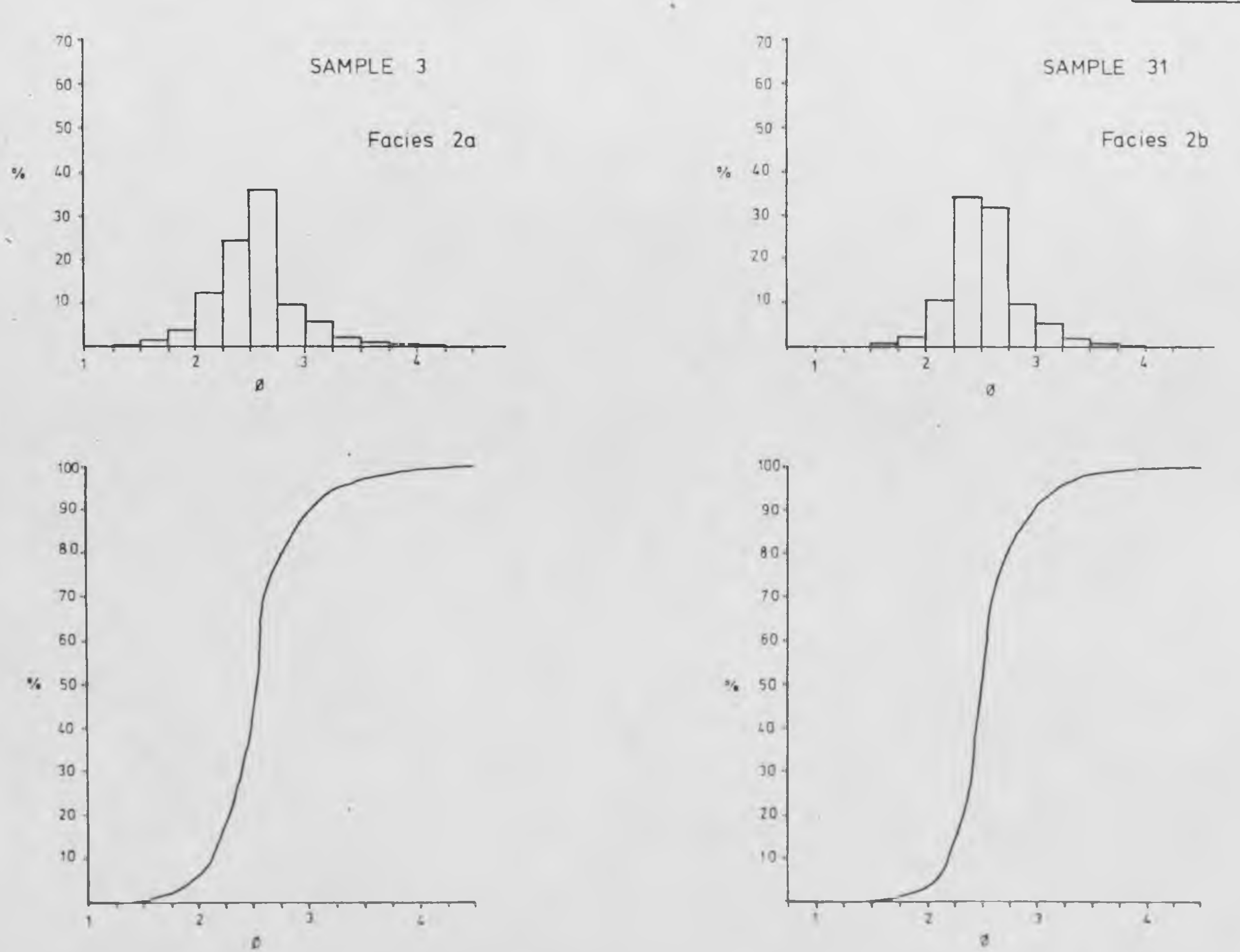
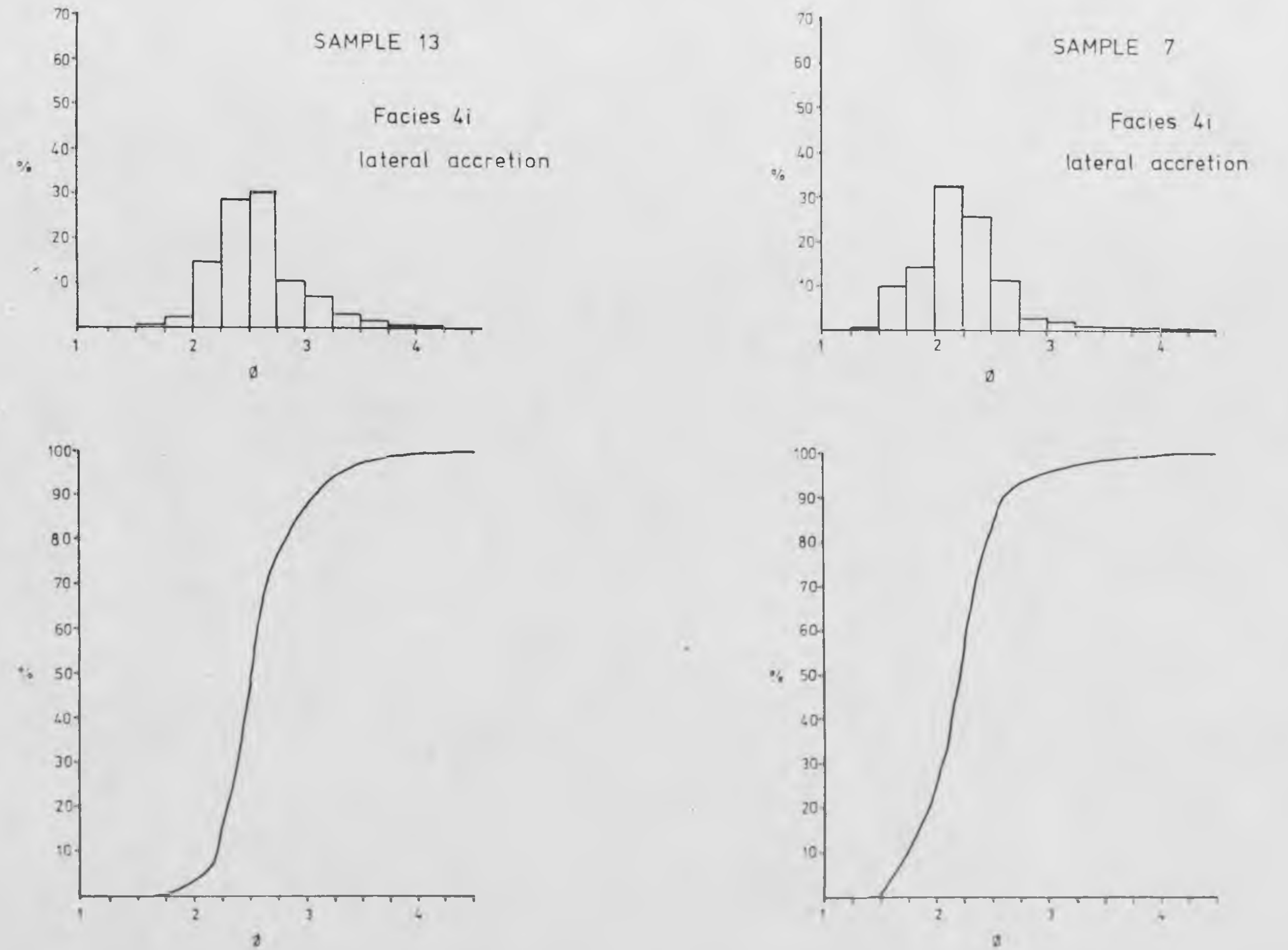
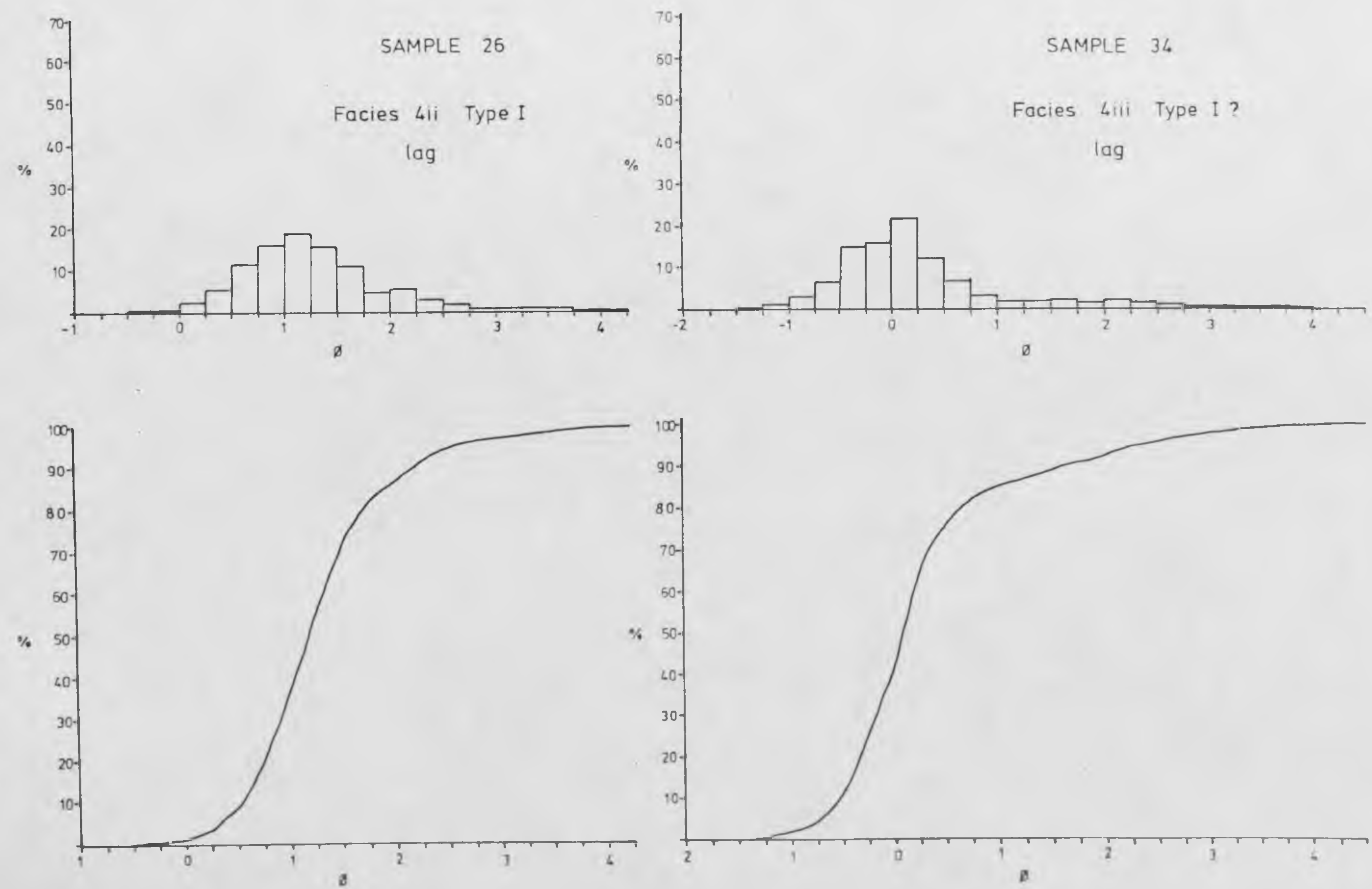

SAMPLE 3
Facies 2a
SAMPLE 31
Facies 2b
%
ø
70
60
50
40
30
20
10
100
90
80
1
2
3
4

FIG. 6.3b



SAMPLE 13
Facies 4i
lateral accretion
SAMPLE 7
Facies 4i
lateral accretion
%
Ø

FIG. 6.3c



SAMPLE 26
Facies 4ii Type I
lag
SAMPLE 34
Facies 4iii Type I ?
lag
%
Ø

ii. Facies 4. Non-marine channel deposits

Channel sandstones show a greater variation in grain size parameters than any other environments. Channel lags are generally fine-skewed and show poorer sorting than laterally accreted sandstones (Fig. 6.3b, c). Mean grain size is highest in the lags and the coarsest sediment found was in samples at the top of the Cloughton Formation in Kilton Beck and Stonegate Gill. Marked vertical variation in grain size was only noted in the Saltwick Formation, and in the Gristhorpe Member on the coast.

iii. Facies 5ii. Crevasse splay sandstones

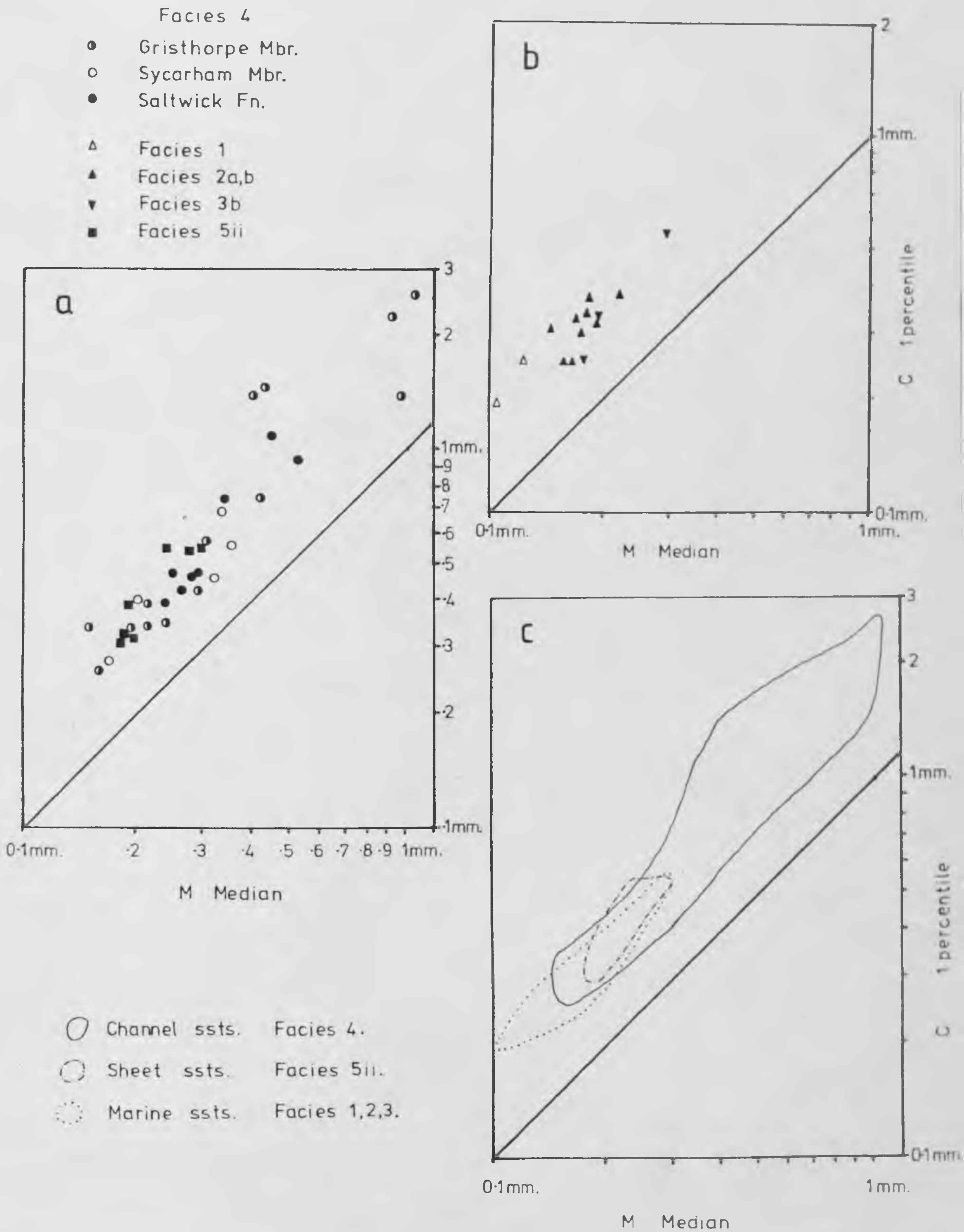
These sandstones are usually very well sorted and fine-skewed. Mean grain size varies from 2.05ϕ to 2.60ϕ. Towards the top of each crevasse splay there is an increased silt content, and only the basal and middle parts were subjected to grain size analysis. The sorting is a direct result of the high energy nature of their deposition, usually associated with upper phase plane bedding.

6.1b. Comparison of facies by grain size statistics

1. C-M diagrams (after Passega, 1957). Harrell and Eriksson (1979) found that it was possible to convert percentile values from thin section to equivalent sieve values with reasonable accuracy. It was therefore possible to plot all the samples shown in Table 6.2 on one diagram, and compare them irrespective of the method used in grain size determination. Fig. 6.4 shows a series of such plots, with C (1 percentile) against M (50 percentile) on logarithmic scales. As an environmental discriminant this type of plot appears to have only limited use when applied to the sediments analysed. However the much

Fig. 6.4 Representation of grain size data on CM diagrams. The results include all the samples analysed by both sieve and thin section techniques. Discussion in text.

FIG. 6.4


Facies 4
Gristhorpe Mbr.
Sycarham Mbr.
Saltwick Fn.
Facies 1
Facies 2a,b
Facies 3b
Facies 5ii
a
b
c
M Median
C 1 percentile
0·1mm.
1mm.
Channel ssts. Facies 4.
Sheet ssts. Facies 5ii.
Marine ssts. Facies 1,2,3.

larger field of the channel sandstone is readily discerned (Fig. 6.4c). Both the marine and crevasse splay samples plot in similar fields. As they both occur as sheet forms it would be possible to consider them as one homogeneous type on a large scale grain size distribution study of such a mixed series of deposits as found in the Ravenscar Group.

2. Graphical Statistic Parameters. (Folk & Ward, 1957). Mason and Folk (1958) used these parameters as a means of distinguishing environments at Mustang Island, Texas. The tails of the grain size distributions are strongly influenced by the environment of deposition, with skewness and kurtosis particularly effected in their study. The sieved samples were therefore plotted in Fig. 6.5 using these two graphical parameters. The results were unfortunately inconclusive.

3. Moment Statistical Parameters (Friedman, 1961). Moment parameters are rather more sensitive than graphical parameters and have the added value in that they are computed on a larger proportion of the distributions. A variety of Friedmans (op. cit.) plots were used in an attempt to similarly distinguish between dune, beach and river sands. The only satisfactory results were for plots of skewness against standard deviation (Fig. 6.6A) and all the others suggested by Friedman were of little value.

4. Discussion. The methods described above were similar to those of Nami (1976) who worked on overlying deposits in the Ravenscar Group, in order to facilitate comparisons. Nami also found that a Friedman plot of standard deviation against skewness was useful in discriminating marine and non-marine deposits. The results outlined above confirm

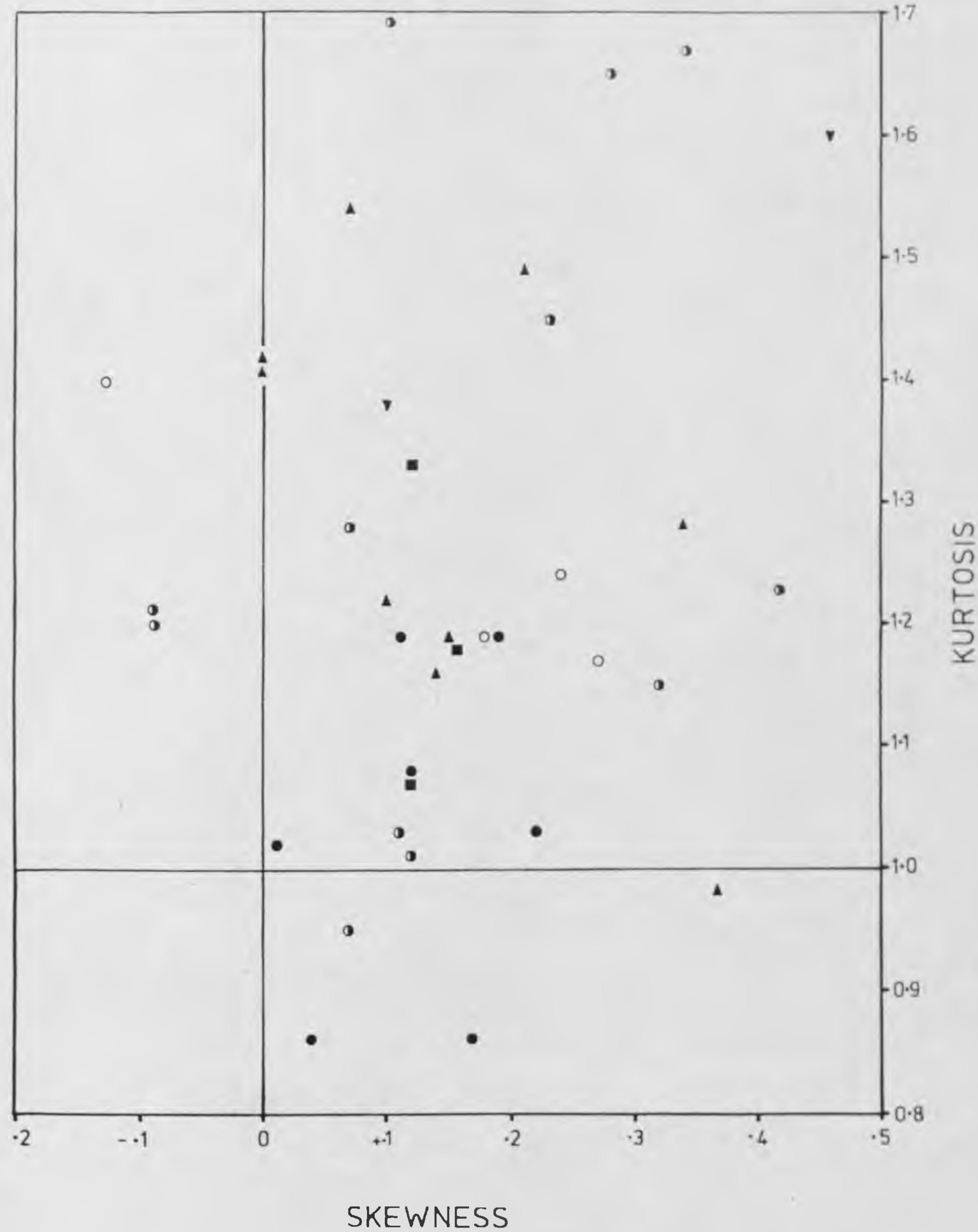


FIG. 6.5 Plot of the graphical parameters skewness against kurtosis for the sieved results only. Lines indicate normal curves. Note the wide scatter of sample points. Symbols as in Fig. 6.4.

FIG. 6.6A

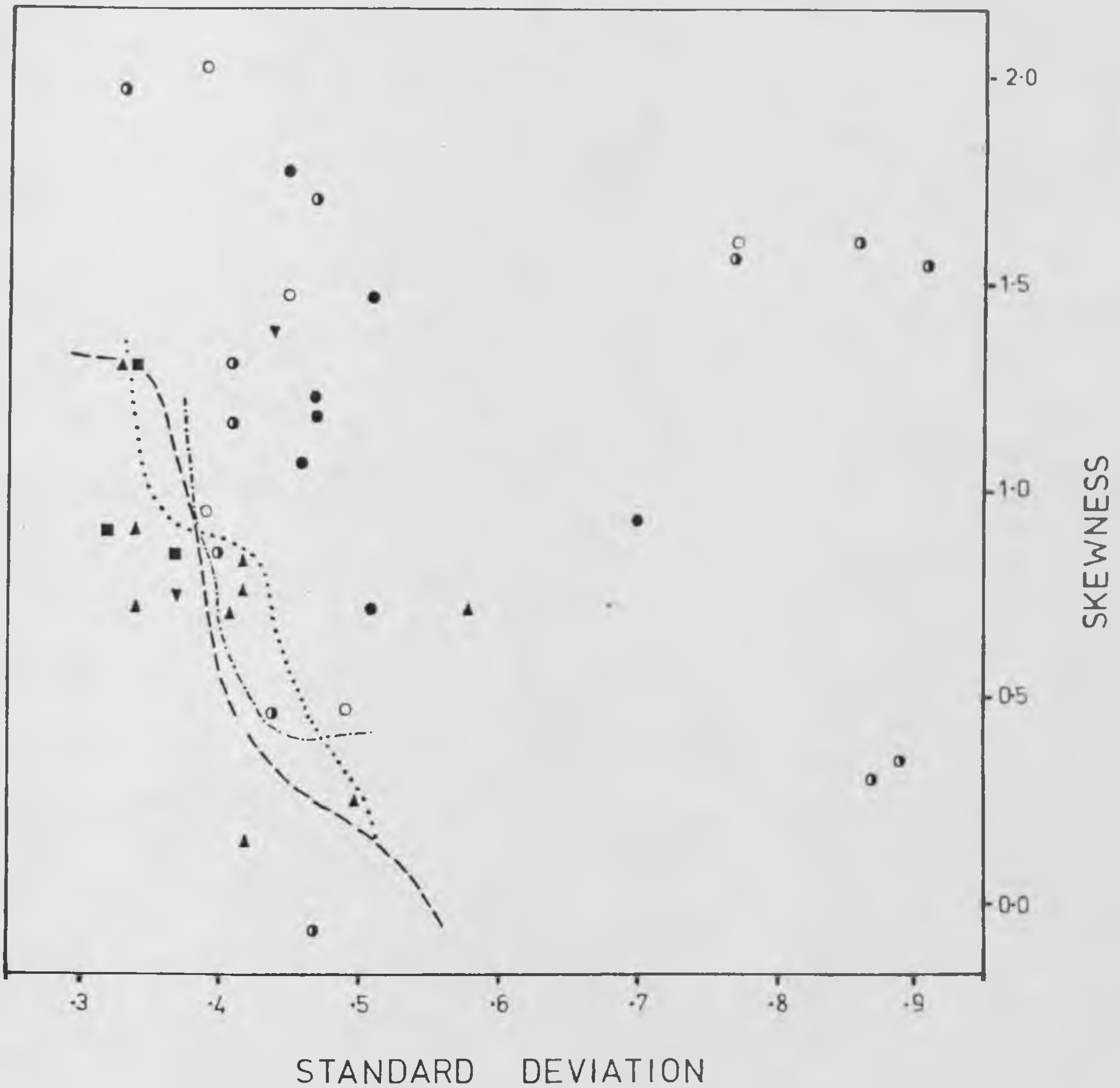


Fig. 6.6A Plot of the moment parameters standard deviation against skewness for the results in Table 6.2a.

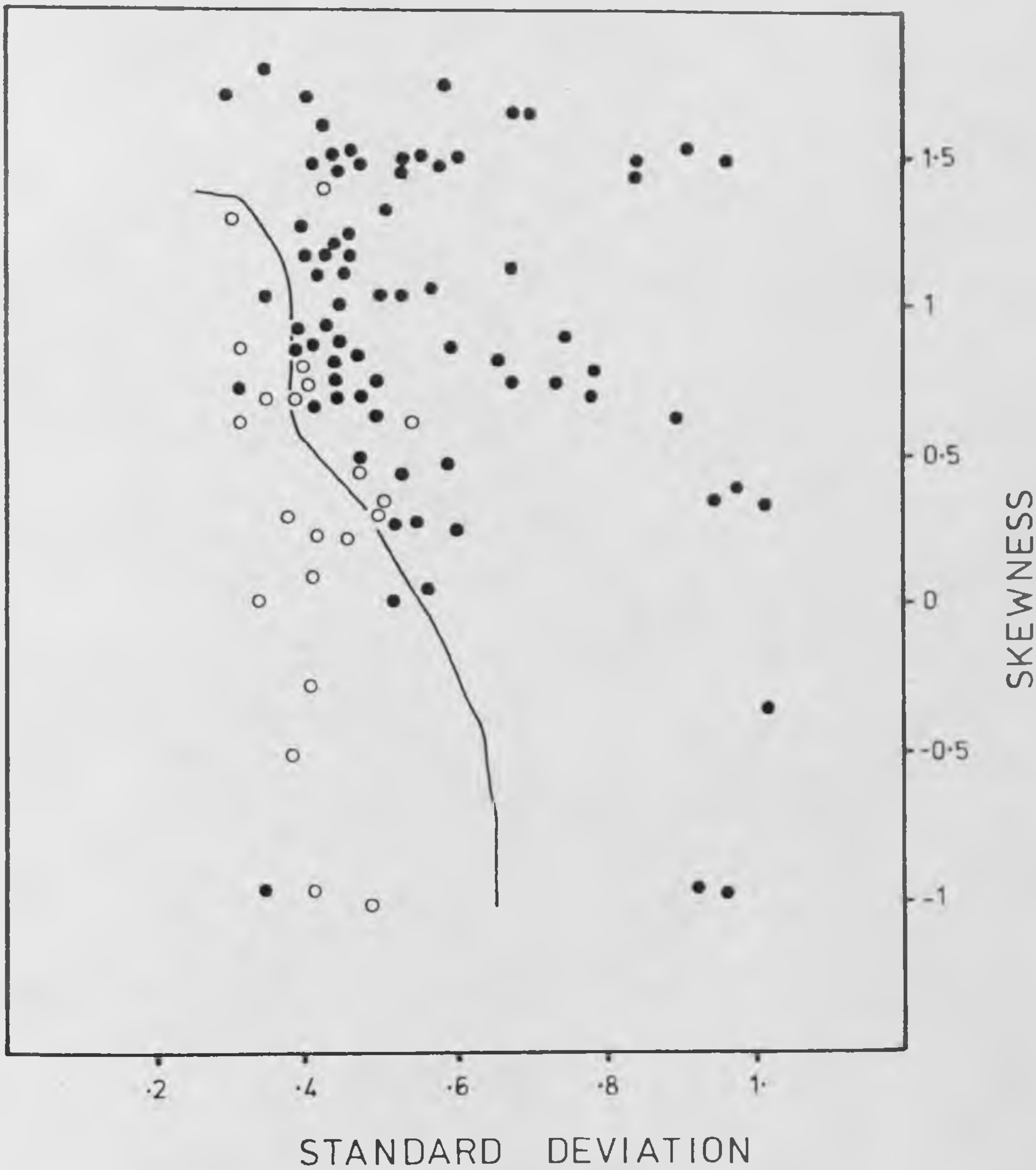
— — Friedmans (1961) discriminant line

· · · · Limit of the plot of non-marine samples (ignoring 1)

—·—·— Limit of the plot of marine samples (ignoring 2)

Symbols as in Fig. 6.4.

FIG. 6.6B



o Marine

• Non-marine

Fig. 6.6B Plot of moment parameters standard deviation against skewness for the samples in this study plus those of Nami (1976). The plot represents a widespread selection of sandstones from throughout the Ravenscar Group.

Friedmans discriminant line indicated

these findings and it would appear that such a plot would provide good results in any test for environments carried out on Ravenscar Group sediments. Figure 6.6B shows both Nami's results plus those from the present study to illustrate this point.

There is very little difference in the broad grain sizes of the different stratigraphic horizon in the Ravenscar Group as a whole suggesting a general uniformity of source area throughout the depositional history of this Middle Jurassic sequence. Furthermore the majority of the coarse clastic sediment is fine-grained with rather less medium and coarse-grained sandstone present. No extraformational conglomerates occur in any part of the Ravenscar Group and the grain sizes found are probably a function of provenance, discussed in Chapter 7.

6.2. Sandstone Classification and Framework Constituents

The framework constituents of nineteen samples representing a variety of facies and stratigraphic horizons within the Ravenscar Group were analysed. The aim was to classify these sandstones and to use the study for indications of provenance. A mechanical stage was used and approximately four hundred counts taken from each thin section using random traverses. The results are shown in Table 6.7. McBride's (1963) classification was used with the modification of plotting stretched metamorphic quartzite with lithic fragments at the L-pole. If this had not been done all the plots shown in Fig. 6.8 would have lain on the quartz-feldspar line due to the paucity of detrital rock fragments in the samples. The majority of the sandstones lie in the subarkose field, although a few are quartzarenites. This is confirmation of Selley's (1978) inclusion of the Yorkshire area in his North Sea

TABLE 6.7

Point count data taken from sandstone samples. Thin section number refers to Leeds University Earth Science department records. The ternary values F, L, and Qtz. are plotted in Fig. 6.8. The final three columns refer to quartz extinction angles as a percentage of the whole section.

Section No.		Count	F	L	Qtz.	Mica	Str.	< 5°	> 5°
1	Sa39865	444	8.06	5.06	86.88	1.15	40.99	19.82	19.37
2	Sa39864	311	6.95	9.93	83.12	1.93	30.86	44.24	10.41
3	Sy40007	400	1.77	2.84	95.39	0.75	45.25	24.00	21.75
4	Sy40465	405	2.72	7.87	89.41	-	33.83	19.51	29.14
5	Sy39863	400	5.02	3.69	91.29	-	30.75	25.25	31.75
6	Sy39862	408	5.20	0.51	94.29	0.98	51.72	14.95	23.53
7	Sy40459	391	11.76	4.77	83.47	-	34.53	29.16	17.65
8	Sy41171	344	6.98	3.10	89.92	0.29	35.47	26.16	22.67
9	Le40467	400	7.03	0.52	92.45	0.25	44.50	21.00	23.00
10	Le40009	400	6.84	0.25	93.91	0.50	49.50	17.25	22.25
11	Le40466	400	8.10	0.55	91.35	1.00	37.75	22.25	27.25
12	Gr39860	405	8.04	4.61	87.35	1.73	40.99	15.56	26.42
13	Gr39859	400	4.51	2.36	93.13	0.25	44.75	18.75	27.75
14	Gr39861	419	8.11	0.99	90.90	2.63	45.82	14.32	27.21
15	Gr40008	420	1.87	0.97	97.16	-	39.76	22.86	26.67
16	Gr40464	318	8.49	2.20	89.31	0.31	31.45	31.76	22.33
17	Sc39857	400	7.65	-	92.35	4.50	50.75	17.00	19.00
18	Sc40005	400	6.71	1.94	91.35	3.00	49.00	15.75	23.75
19	Sc40006	400	6.64	1.37	91.99	1.75	54.25	12.00	24.00

Ternary values

F- Feldspar
L- Lithic
Qtz.- Quartz

Sa- Saltwick Fn.
Sy- Sycarham Mbr.
Le- Lebberston Mbr.
Gr- Gristhorpe Mbr.
Sc- Scarborough Fn.

Quartz classification

Str.- Straight extinction (expressed as % of whole section)

FIG. 6.8

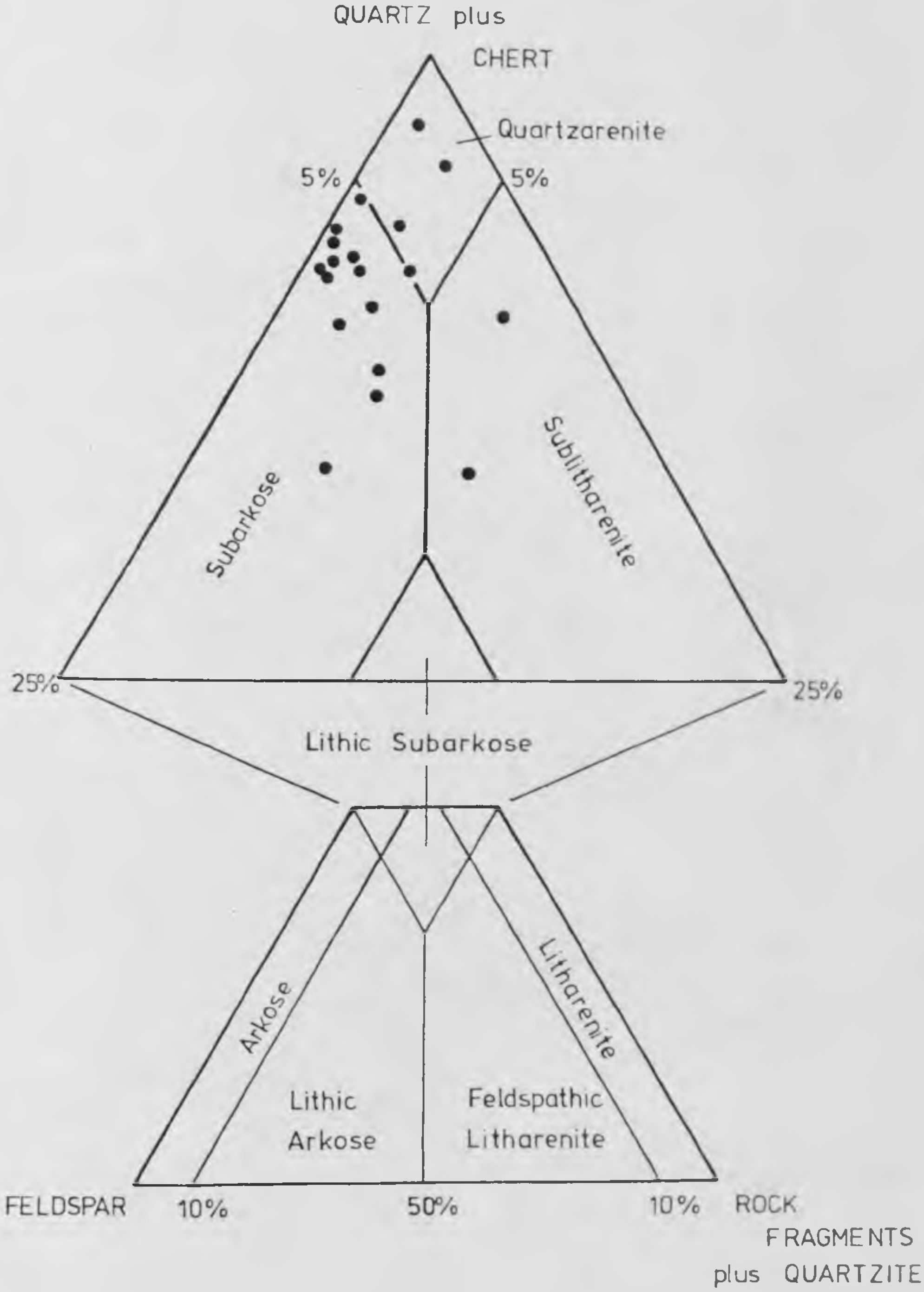


Fig. 6.8 Triangular classification diagram illustrating the framework petrography of the samples analysed (see Table 6.7). Modified from McBride (1963), discussion in text.

Mesozoic protoquartzite petrographic province.

6.2a. Framework constituents

1. Quartz - This is by far the most abundant detrital mineral in the samples analysed, varying from 88.24% to 98.13% (these figures include polycrystalline metamorphic quartzite). The quartz grains vary in roundness from subangular to well rounded, the majority lying in the region of 0.3 to 0.5 on Powers (1953) scale. Sphericity shows a similar variation. The majority of the quartz grains are clear and uniform, but a few notable exceptions show vacuoles and inclusions (see Fig. 6.18). Tourmaline and rutile as well as hornblende were recognised and these quartz grains appear to have been of igneous/hydrothermal origin.

The majority of the quartz grains show straight extinction (Table 6.7), with a variation from 30-51%. Slightly undulose ($< 5^{\circ}$ stage rotation) and strongly undulose ($> 5^{\circ}$) quartz grains were variably represented and occur in approximately equal proportions. Composite quartz grains (unstretched) make up about 1-8% of the sandstones. Stretched metamorphic quartz is present in all the slides with a maximum of 7.8%.

The use of Basu et al's (1975) discriminants for provenance interpretation based on undulatory extinction and polycrystallinity gave mixed results. From the amount of polycrystalline quartz present the source area would appear to be plutonic. Using undulatory extinction as a criteria these Ravenscar Group sandstones plot in a low-rank metamorphic field. This anomaly is easily explained by considerations of recycling quartz grains. Polycrystalline quartz will tend to be mechanically unstable during transport and will break down rather more readily than single crystal grains (Harrell and Blatt, 1978), with an ensuing bias towards an apparent plutonic source. Unfortunately Basu et al (op. cit.) and Young's (1976) criteria rely on the sediments being of first cycle origin. Only the metamorphic quartzite fragments and the quartz grains with inclusions give a clue as to their primary origin. It would appear from an analysis of the quartz grains present that an unspecified percentage has been recycled.

2. Feldspar. Feldspar is noticably present in all the samples analysed, with a maximum of 11.76% recorded. K-feldspar is more abundant than plagioclase, with an average ratio of approximately 6:1. The K-feldspar is recognised by its cloudier appearance adjacent to clearer quartz grains. Both untwinned orthoclase and microcline occur, with the former more abundant. Most of the feldspar recorded was surprisingly fresh, and this was confirmed when samples were cathodeluminesced for carbonate studies (see section 6.3). Many clear feldspar nuclei to ooids luminesced a bright blue colour. In some cases there was evidence for polycyclic feldspar with non-luminescing overgrowths formed prior to carbonate coating. It would appear that much of the weathering of the feldspars was a diagenetic process, especially prevalent in the coarser grained sandstones.

3. Mica. A maximum of 4.5% of mica was recorded in the samples analysed. Muscovite was by far the most abundant of the micas, with only rare biotite flakes seen. No detrital chlorite was recognised in the thin sections, but a few grains of glauconite were present in the lower Scarborough Formation sandstone (Facies 1a).

4. Rock fragments. Apart from quartzite, rock fragments are very rare in these sandstones. A maximum of less than 2% was recorded and

they appear to be restricted to very fine-grained basic volcanic fragments. The small grain size and later diagenetic alteration make this identification tenuous.

These sediments are rather mature with quartz and quartzite dominating the framework constituents. Some of this appears to have been derived from the recycling of earlier sediments giving inherited characteristics. Possible source areas are discussed in the provenance section in Chapter 7.

6.3. Sandstone Matrix and Diagenetic Material

A combination of X.R.D., thin section and S.E.M. techniques were used in an attempt to identify the fine-grained constituents and elucidate the diagenetic history of the coarser clastic sediments. To eliminate possible modern weathering effects seven fresh sandstones were taken from the I.G.S. Brown Moor borehole, representing a variety of facies types and stratigraphic horizons. Thin sections from outcrop samples were also studied to give a broader base to the study.

The clay sized matrix ($> 2\mu$) was removed from the samples by the techniques outlined in Appendix IV. Orientated mounts were prepared and analysed using a Phillips PW1310 diffractometer under fixed operating conditions to facilitate sample comparisons. A variety of heating and alcohol treatment was used to identify the clay mineral suites present (after Carroll, 1970), and some of the results are shown in Fig. 6.9. S.E.M. analysis was obtained using a Joel JXA-50A microprobe.

6.3a. Clay Mineralogy

1. Kaolinite. Kaolinite is distinctive and common to all the samples analysed. It is characterised by sharp peaks on the X.R.D. traces at

Fig. 6.9 Examples of the X.R.D. results for five samples taken from the I.G.S. Brown Moor borehole core. Numbers (e.g. 107.00) refer to depth of the sample in the core.

K - Kaolinite
I - Illite
I/S - Mixed layer illite/smectite
Ch - Chlorite
Ca - Calcite

Note the paucity of illite and illite/smectite in the two marine samples (Fig. 6.9D) and the presence of calcite. Discussion in text.

Operating conditions for all samples :-

Phillips PW1310 Diffractometer
CuK radiation, Nickel filtered with 1° scatter and divergence slits. Range 1×10^{3}, time constant 2. 40 Kv and 20 mA.

FIG. 6.9A

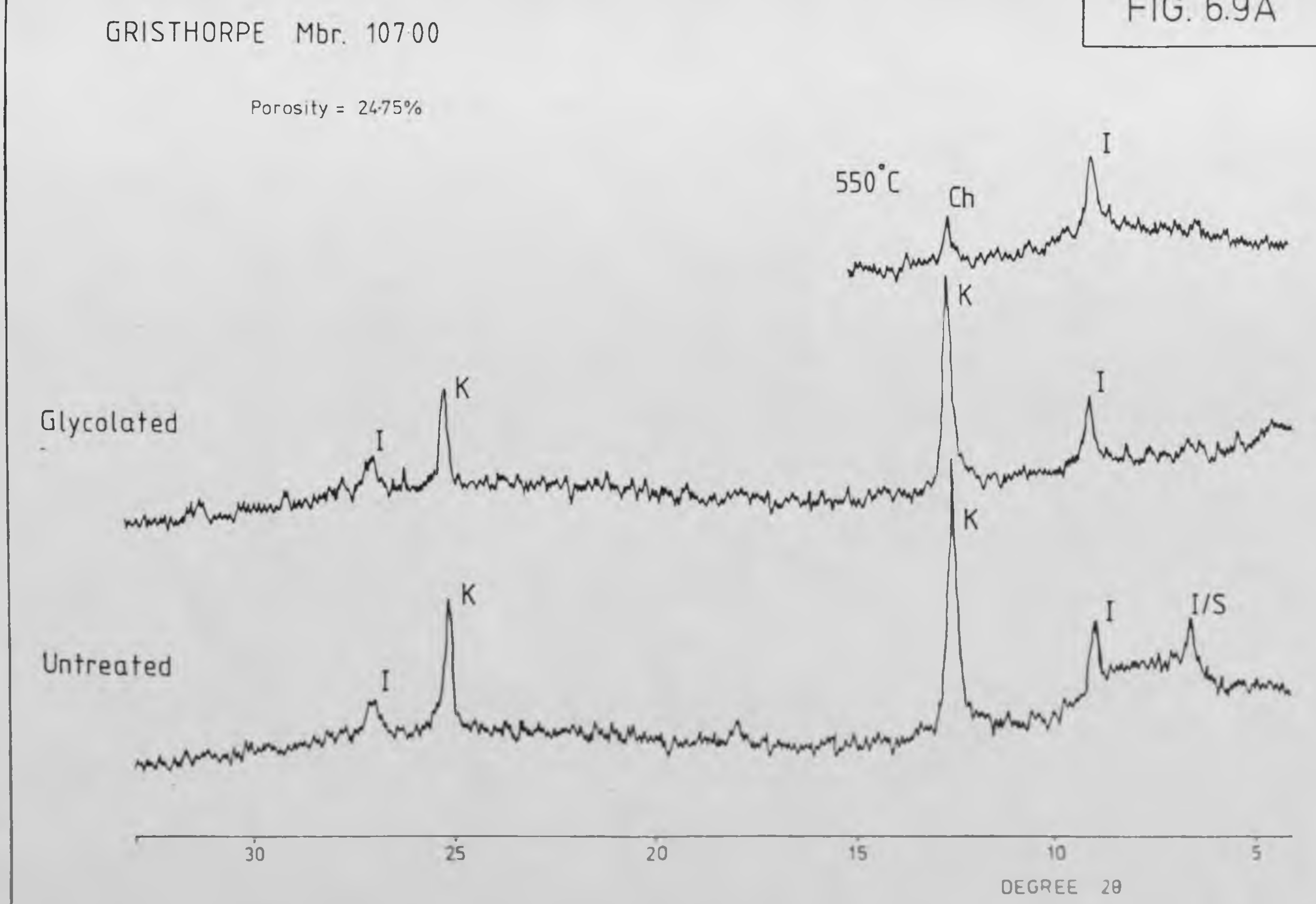
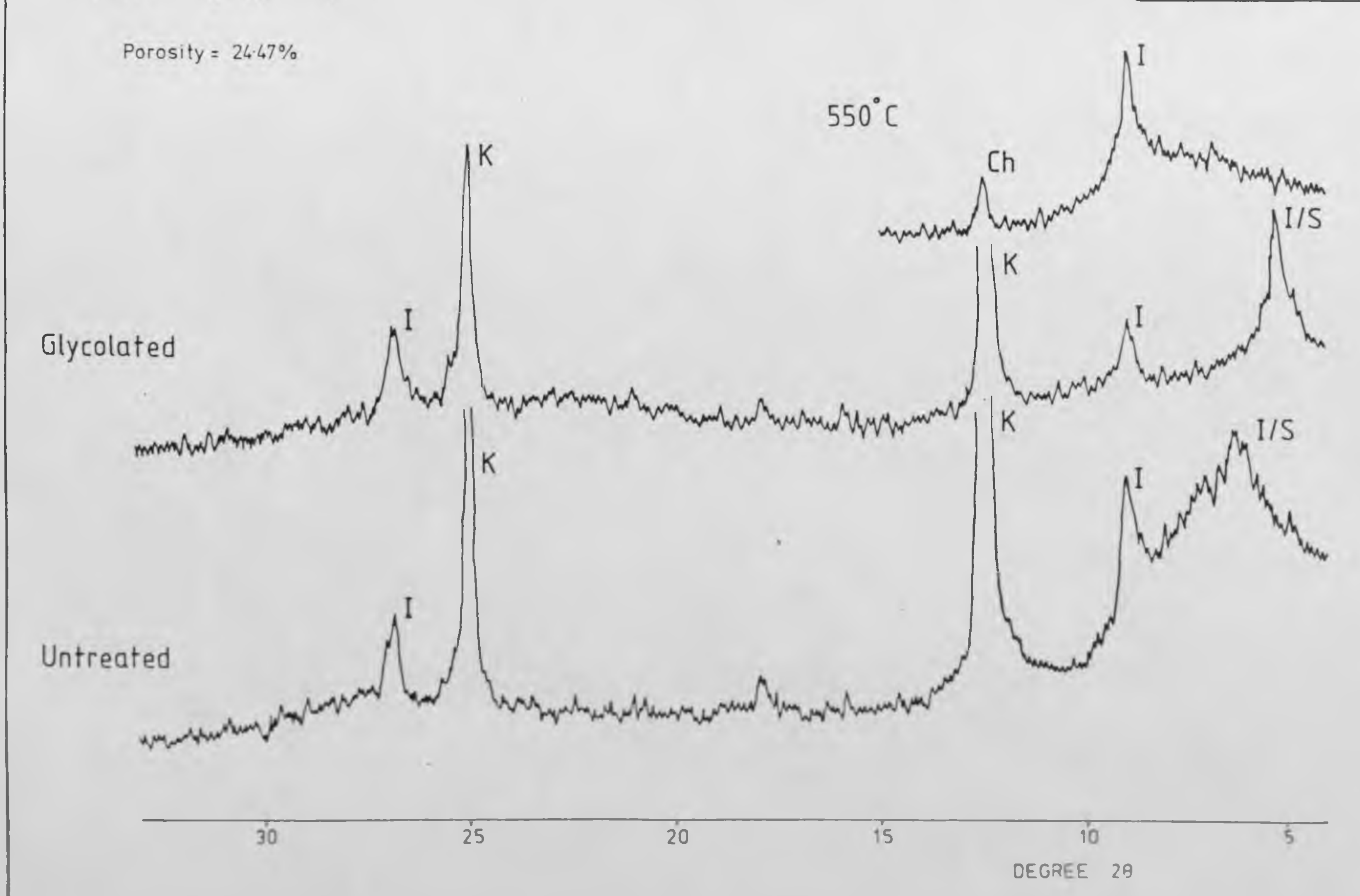
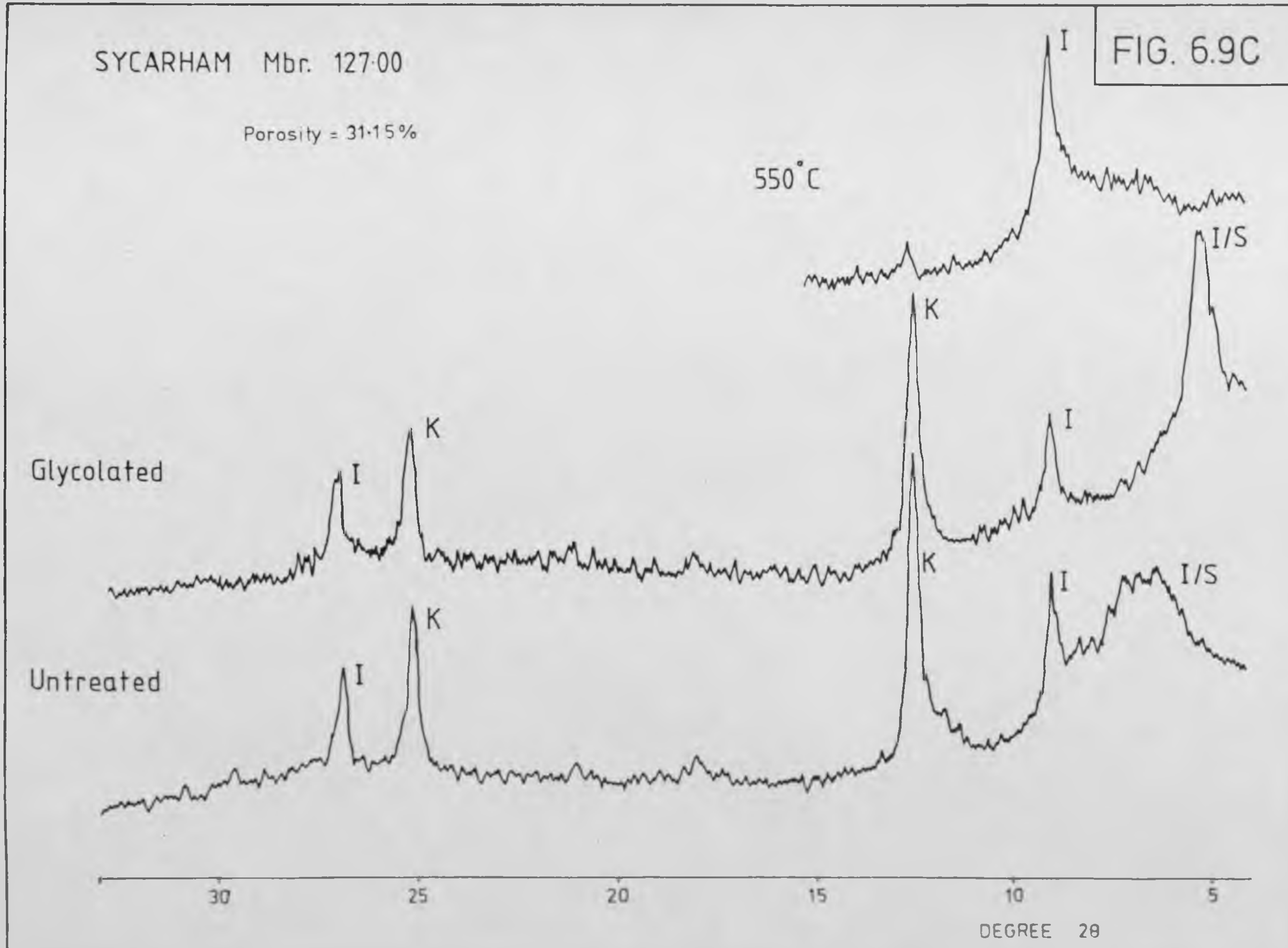

GRISTHORPE Mbr. 107·00
Porosity = 24·75%
550°C
Ch
I
K
I
K
Glycolated
I
K
I
K
Untreated
I
I/S
30
25
20
15
10
5
DEGREE 2θ

FIG. 6.9B



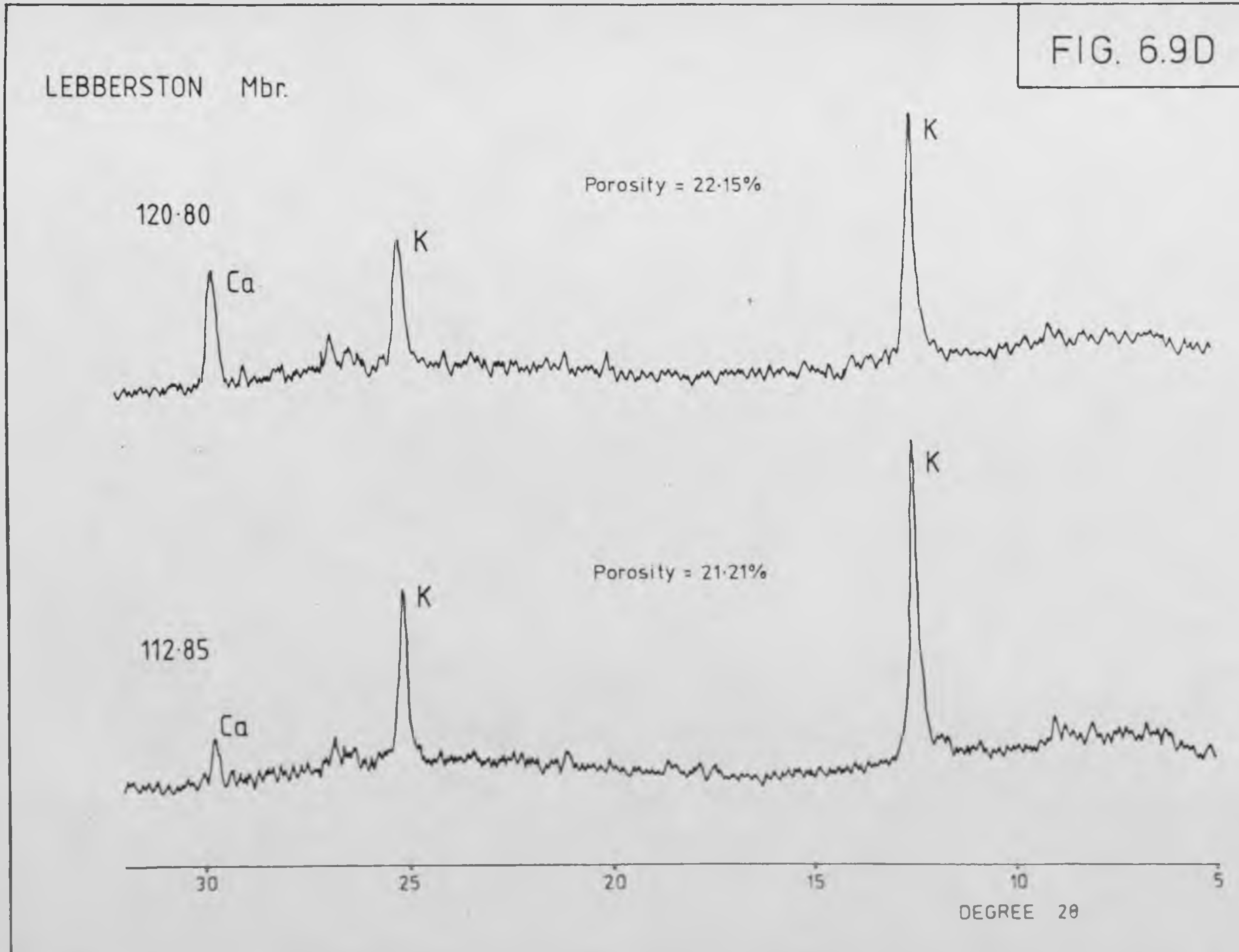
GRISTHORPE Mbr 109·00
Porosity = 24·47%
550°C
Glycolated
Untreated
K
I
Ch
I/S
30
25
20
15
10
5
DEGREE 2θ

FIG. 6.9C



SYCARHAM Mbr. 127·00
Porosity = 31·15%
550°C
Glycolated
Untreated
I
K
I/S
30
25
20
15
10
5
DEGREE 2θ

FIG. 6.9D


LEBBERSTON Mbr.
120·80
Porosity = 22·15%
Ca
K
K
112·85
Porosity = 21·21%
Ca
K
K
30
25
20
15
10
5
DEGREE 2θ

7.1Å (001) and 3.56Å (002) (Fig. 6.9). These peaks disappear on heating above 450°C when the kaolinite becomes amorphous (Lucas and Jehl, 1961). Under the S.E.M. kaolinite is easily recognised by its good pseudohexagonal crystal form and the stacking of individual plates in the form of 'booklets'. This good crystal form plus the fact that it is proportionally more common than other clay minerals in the sandstones as compared to the shales (Section 6.4) proves that it is, at least in part, of diagenetic origin. It occurs in the sandstones as a pore infill (Fig. 6.10) and is also found in between individual mica plates (Fig. 6.11).

Blanche and Whitaker (1978, after Bucke and Mankin, 1971) discuss several factors which are required for diagenetic kaolinite formation. Sufficient porosity and permeability is required to allow the migration of interstitial water, carrying ionic material, and to give growth space. This water breaks down detrital potash feldspar which acts as a source of the Al^{3+} and Si^{4+} ions and partly degraded illite is needed to act as an acceptor for the excess k^{+} ions. The presence of organic matter maintains a low pH and enables the chemical reactions to take place. Parker (1978) points out that detrital kaolinite also sources the ionic material needed for the formation of this diagenetic material, with mica acting as a further donator.

The leaching of detrital minerals to form kaolinite in North Sea Middle Jurassic rocks was produced by freshwater circulation following the Jurassic-Cretaceous Cimmerian uplift (Sommer, 1978). Its presence in all the sediments of the Ravenscar Group suggests an open system (Von Engelhardt, 1967) of acidic water circulation. The kaolinite seen in the samples was therefore probably produced by the leaching of detrital micas and feldspars from the sandstone framework plus the recrystallisation of detrital kaolinite. The relative proportions of diagenetic to detrital kaolinite was impossible to assess. Although ubiquitous, kaolinite is not abundant inmany of the samples, and porosity remains high in most of the sediments.

The kaolinite observed was always very fresh with no evidence of the illitisation recorded from the North Sea Brent Sand (Hancock and Taylor, 1978). In outcrop it is particularly abundant infilling shrinkage cracks in organic debris, where local acidic environments have presumably encouraged its formation.

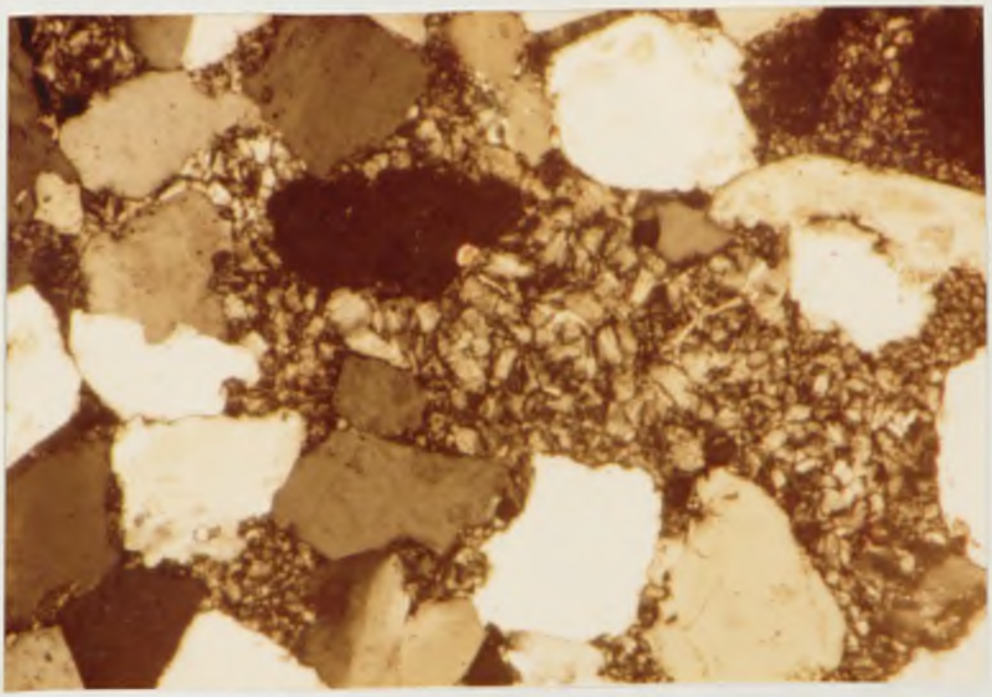
2. Illite. Illite is characterised by X.R.D. peaks at 10Å (001) and 3.3Å (002) and is thought to consist of fine-grained micas of variable chemical composition (Millot, 1970). It was found in all the non-marine samples but was noticably poorly represented in the marine sediments (Fig. 6.9D). These latter sediments appear to have been washed clean of detrital clay during deposition, and it would appear that much of the illite found in the non-marine samples was primary. The sharp peaks seen in the X.R.D. traces however probably result from the regeneration of detrital illites involving the addition of K^+ and Mg^{2+} given off during the breakdown of primary clastic material.

3. Mixed layer illite/smectite. These clay minerals occur in varying amounts in the samples analysed, and are characterised by broad peaks in the region of 11-14Å on the X.R.D. traces. Glycolation expands the smectite layers within the lattices, shifting the peaks to 14-15Å (Fig. 6.9C). Heating collapses the layers to 10Å and increases the illite peaks (Fig. 6.9B). This pattern of reaction to the various treatments suggests that the dominant smectite present is montmorillonite (Millot, 1970). The presence of illite within the lattices is proven by the restriction in swelling of the clays noted on glycolation.

Fig. 6.10 Photomicrograph of kaolinite booklets completely infilling pore space in-between framework grains. Note the irregular orientation of the clay mineral. The dominant framework clasts are clear straight extinguishing quartz. The Saltwick Formation, Hawsker. x 80 crossed nicols.

Fig. 6.11 S.E.M. photomicrograph of kaolinite booklets (centre and bottom, arrowed). The large flakey mineral to the top left is a detrital mica and note how the plates of this mineral have expanded, partly under the growth of diagenetic material such as kaolinite. The Gristhorpe Member, I.G.S. Brown Moor (107.00) x 1300.

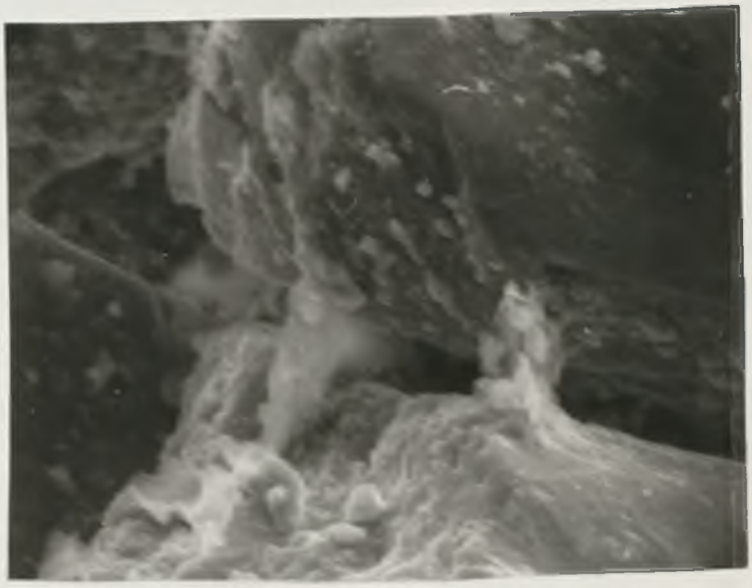
Fig. 6.12 S.E.M. photomicrograph of clay mineral 'bridging' (centre) between adjacent quartz grains. In some samples this is the only cement present. Note that the 'bridges' are apparently amorphous. The surfaces of the quartz grains show minor pitting and etching. The Sycarham Member, I.G.S. Brown Moor (127.00). x 1000.



0·1 mm

x 80

x 1300



x 1000

Pure montmorillonite expands to 16-18Å. These mixed layer clays were not seen in the marine samples analysed (Fig. 6.9D).

Mixed layer clays are abundant detrital constituents of sediments (Schultz, 1979) and form in part from the degradation of illitic clays (Brown et al. 1977). The broad diffraction peaks seen in Fig. 6.9 suggests that much of this material is detrital, but one sample (Fig. 6.9A) gives a sharp peak at 12.5Å which suggests that it is in part diagenetic. Detrital illite/smectites regenerate with the addition of K^+ from the degradation of potash feldspar and illites (Perry,1974). This involves an increase in the illite to smectite layer ratios.

Much of the illite and mixed layer clay is probably therefore detrital in origin, and is not found in the cleaner well washed marine sandstones. The detrital clay will be very fine-grained and poorly crystalline and was difficult to recognise under the S.E.M. Diagenetic clay minerals of either illite or mixed layer composition were found using the S.E.M. where they occur as distinctive 'bridges' between adjacent framework grains (Fig. 6.12). These bridges were amorphous and no crystal outlines were observed. They resemble those demonstrated by Wilson and Pittman (1977) who state that illite, illite/smectite and smectite can all form such cements. As neither authigenic illite nor illite/smectite give obvious crystal outlines recognition is difficult, but as the former is more abundant it may be that these bridges are of this mineral. In some cases the bridges are the only form of binding cement found in the samples, and as a result these sandstones are extremely friable.

4. Chlorite Minor amounts of chlorite were found in the samples after heating had collapsed the superimposed 7Å kaolinite peaks. The

resulting chlorite peaks are small. There was no evidence of chlorite in the S.E.M. analysis, probably indicating that is fine-grained, poorly crystalline and of detrital origin.

6.3b. Other Diagenetic Material

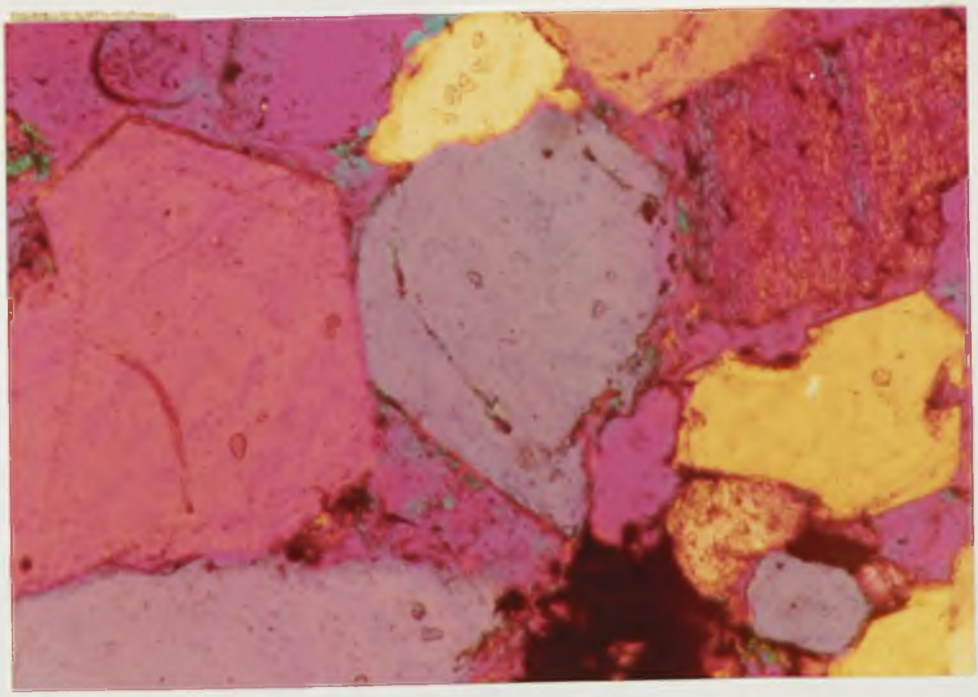
5. Quartz. Evidence of quartz overgrowth is found in most samples but in a varying degree of abundance. Overgrowths appear to be commonest in channel sandstones where the framework is coarser (see section 6.1). They are syntaxial and are usually marked by dust lines (Fig. 6.13). The source of the overgrowth material is partly from grain contact dissolution of adjacent quartz grains, giving sutured contacts (Fig. 6.14), following compaction. Minor amounts of Si^{4+} probably derived from feldspar breakdown with a further addition from evolving clay mineral suites in the associated compacting muds. Large areas of thin section show only pressure solution of quartz grains, without local deposition of the liberated Si^{4+} ions. A simple model of local redeposition of quartz in areas of low stresses adjacent to pressure contacts cannot be applied. The S.E.M. analysis showed marked pitting and etching of quartz, including the overgrowths, during diagenesis.

Beach and King (1978) make several points on the nature of pressure solution. A simple relationship between dissolution and depth of burial does not exist, because stresses at grain contacts are dissipated early during compaction. The stress is induced by burial and compaction and is initially hydrostatic. Concentration of this stress at grain contacts is rapidly reduced by pressure solution, leading to a decline in dissolution, commonly after 6-10% shortening. De Boer (1977) showed that sand grains dissolve inside grain contacts, with ensuing

Fig. 6.13 Photomicrograph of syntaxial quartz overgrowths in a medium-grained channel sandstone sample. Note the euhedral shape of the grains with the pronounced dustlines in the central clast. The patchy grain in the bottom left of the figure is a heavily altered feldspar. The Saltwick Formation, Petard Point. x I40, crossed nicols with a sensitive tint.

Fig. 6.14 S.E.M. photomicrograph of sutured quartz grain contacts especially marked at the top of the figure, indicating the effects of pressure solution. The Sycarham Member, I.G.S. Brown Moor (128.95). x 400.

Fig. 6.15 Photomicrograph showing marked pressure solution in a well sorted crevasse splay (Facies 5ii) sandstone. The Gristhorpe Member at Cloughton Wyke. x 80, crossed nicols.



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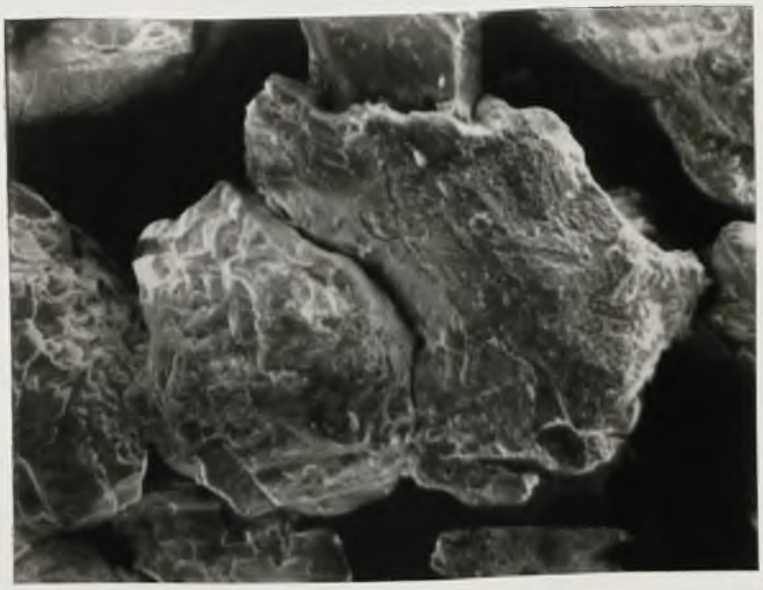
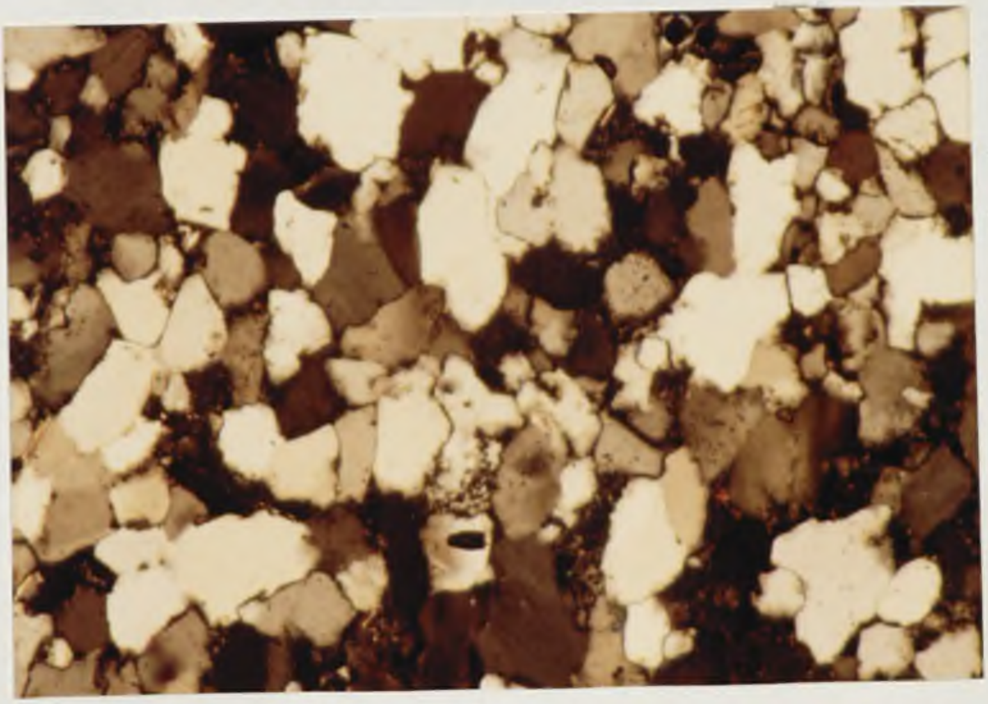
x 140



x 400



0·1mm

x 80

silica diffusion into pore space through adsorbed water. Diffusion is accelerated by clay coatings,as swelling smectite clay minerals contain many water layers compared to one quartz grain adsorbed layer. Too much clay inhibits dissolution however, and this phenomena is more common in cleaner sandstones. Taylor (1978) made the point that pressure solution is commoner in well sorted and coarser-grained sandstones. Initial permeability appears to play an important role in silica redistribution and it is apparent that the crevasse splay sandstones in the Ravenscar Group show marked pressure solution (Fig. 6.15), probably due to their high degree of sorting. Bjorlykke (1980) suggests that large volumes of water are required to cement sandstones by quartz overgrowths. Insufficient Si^{4+} is provided by the dewatering of adjacent shales, and high groundwater circulation is the main supplier of silica cements (Bjorlykke, op. cit.).

Bjorlykke & Elverhoi (1978) mention a further complicating factor affecting quartz dissolution. In sediments with mixed interlayers of sandstones and finer grained clastics such as in the Ravenscar Group fluid pressure resulting from compaction can increase where lateral permeability is poor. Much of the subsequent hydrostatic stress is therefore taken up by the pore fluids rather than on grain to grain contacts. The varying degrees of pressure solution seen in the Ravenscar Group form no coherent patterns, and appear to be due to a complicated interplay of the factors discussed above. The problems of pressure solution and silica redistribution are obviously very complex and still not fully understood.

Most quartz overgrowths reported appear to form in early diagenesis and are one of the first diagenetic effects seen in North Sea Jurassic sandstones (Blanche and Whitaker, 1978). Their formation is favoured by conditions of $pH < 9$ and appear to be relatively unstable during later diagenesis. Sommer (1978) describes etching by later diagenetic clay minerals and Blanche & Whitaker (op. cit.) record similar features resulting from late stage carbonate deposition. The quartz overgrowths in the Ravenscar Group were of early diagenetic origin and there was no evidence for late stage deposition either as overgrowths (Bjorlykke et al. 1979) or as cryptocrystalline silica (Sommer, 1978).

6. Feldspar. Small amounts of feldspar overgrowth were recorded by the S.E.M. analysis (Fig. 6.16). These overgrowths occur on degraded detrital feldspar and were completely fresh. Kaolinite booklets overlie and appear to post-date them. Bjorlykke et al. (1979) and Wilson and Pittman (1977) show a similar relationship between these two diagenetic minerals. The former authors showed that their overgrowths were of an extremely pure potash feldspar, indicating that the pore waters from which they were deposited were rich in K^+. It would appear that the diagenetic feldspar was formed by the liberation of K^+ from decaying micas and detrital feldspar. This relationship between kaolinite and diagenetic feldspar casts doubts on the simple detrital feldspar destruction and concomitant kaolinitisation described by some authors (Blanche & Whitaker, 1978).

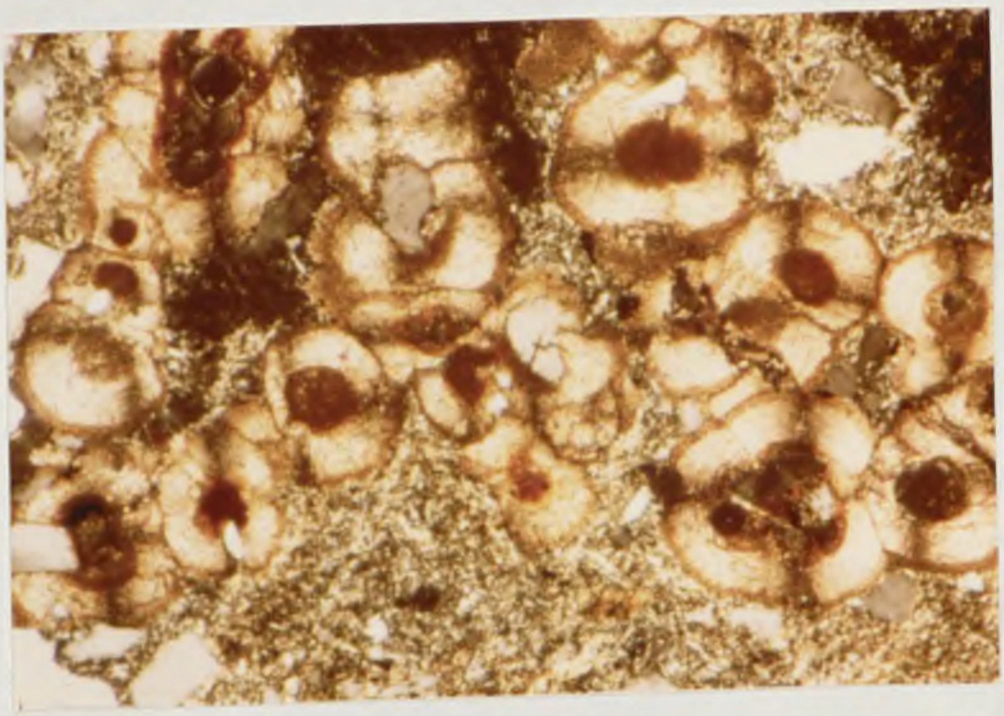
7. Siderite. Iron appears to have been mobile in all stages of diagenesis. Modern analogues for early ironstone formation are recorded by Ho & Coleman (1969) from Mississippi delta sediments. Sphaerosiderite is found in a number of the Jurassic samples, all of them non-marine. It consists of radial fibrous siderite centred on unidentified nuclei, and when it occurs it is usually abundant (Fig. 6.17). Sphaerosiderite grows by displacement and appears to be

Fig. 6.16 S.E.M. photomicrograph of feldspar overgrowths on a detrital feldspar grain. Note the euhedral crystal outline. The Gristhorpe Member, I.G.S. Brown Moor (109.90). x 500.

Fig. 6.17 Photomicrograph of sphaerosiderite aggregates set in a fine-grained clay mineral matrix. The cross extinction is a result of radial fibrous growth of the Fe-carbonate. The Saltwick Formation, I.G.S. Brown Moor (143.50). x 80, crossed nicols.

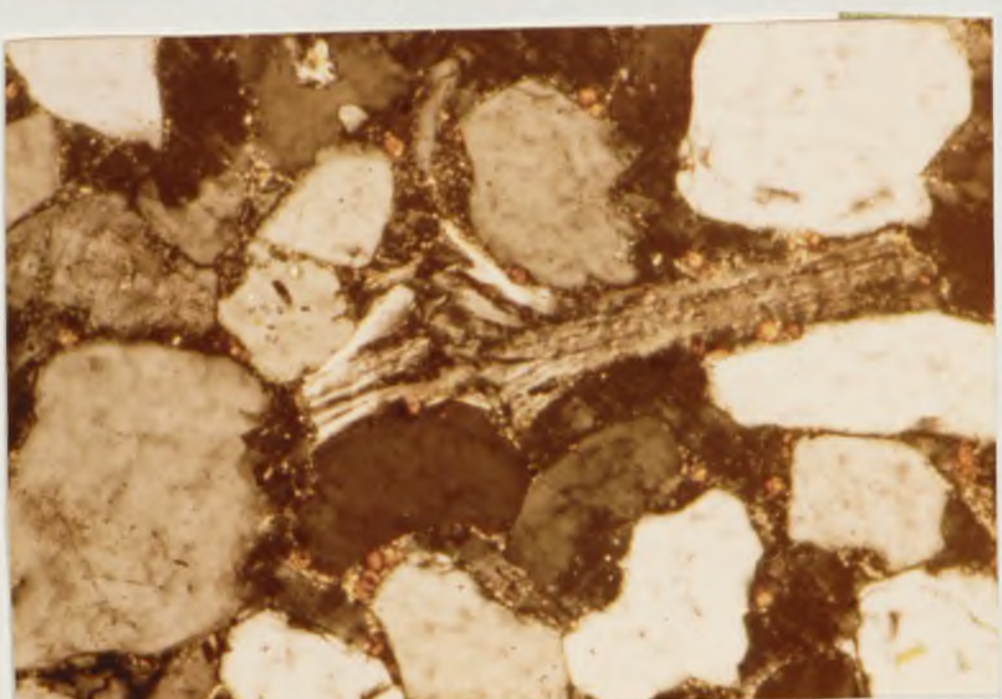
Fig. 6.18 Photomicrograph of mechanically fractured mica resulting from compaction and inter plate growth of kaolinite (not visible). Note the inclusions in the clear quartz grain on the left of the mica. The orange fine-grained patches are siderite rhombs and rhomb aggregates. The Gristhorpe Member, I.G.S. Brown Moor (107.00). x 140, crossed nicols.

x 500



0·1mm

x 80



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x 140

associated with early stages of diagenesis. Later stage siderite rhomb aggregates are also found, mainly in the non-marine samples. Siderite is associated with organic debris, which sources CO_2 in decarboxylation reactions, and is often found in conjunction with bioturbated horizons. Much of the iron involved in siderite formation was probably sourced from ionic expulsion involved in associated compacting shales. Siderite is particularly common as a replacement of mudclasts and muddrapes and is rarer in the marine sandstones where the dominant carbonate is calcite.

8. Calcite. Calcite rhombs occur as a pore infill restricted to marine sediments and their origin will be discussed in section 6.5. Clay sized calcite was recognised from the X.R.D. traces of the marine samples (Fig. 6.9) where it occurred as early rim cements.

9. Pyrite. Small pyrite framboids were seen in some samples and this mineral is also found in shales associated with decayed organic material. It appears to have formed at an early stage in diagenesis.

6.3c. Summary of clastic diagenetic material

As the sediments were gradually buried compaction and freshwater circulation produced grain contact dissolution of quartz. This compaction is shown by mechanically fractured micas (Fig. 6.18) and quartz grains. The amount of pressure solution seen in any one sample is variable and appears to be controlled by a complex interplay of factors not yet completely understood. In the borehole samples pressure solution appears to have ceased fairly early, supporting Beach and Kings (1978) ideas of early stress dissipation, possibly in association with high pore fluid pressures. In some samples, particularly sheet sandstones such as crevasse splay units, more pronounced dissolution is seen, and these sediments may have served as major conduits for freshwater circulation. The silica liberated by dissolution was redistributed to form syntaxial overgrowths. K-feldspar overgrowths also occurred before kaolinisation of the sediments, and presumably resulted from the action of K^{+}-rich pore waters.

During compaction detrital clay minerals started to recrystallise at the expense of degrading feldspar and mica as well as other detrital clay grains. Clay bridges started to form, cementing the sandstones. These are restricted to the non-marine sediments where there was originally detrital clay to source the material. This clay regeneration and diagenetic crystallisation appears therefore to have been a relatively localised reaction.

Following quartz redistribution and partial clay regeneration there was a major period of kaolinitisation, with well crystallised booklets infilling pore spaces. This was an open system with the deposition of kaolinite in all samples with remaining pore space, including the marine ones. This involved a large flux of freshwater to degrade the clastic materials that provide the ions for kaolinite formation (Bjorlykke et al. 1979).

After the main phase of kaolinitisation, continued illite and illite/smectite regeneration occurred. Siderite had been forming throughout diagenesis and formed as pore filling aggregates in the non-marine sediments. In the marine sandstones the CO_2 derived from organic fragments was fixed by Ca^{2+} to continue rhomb calcite formation. The siderite and calcite and the illite, illite/smectite reactions were probably mainly local, closed and reasonably isochemical.

Porosities remained high in most of the non-marine sediments where siderite and kaolinite are the main pore filling deposits. The amount of diagenetic kaolinite was restricted by the relatively mature sediments that constitute the framework (Nagtegaal, 1978). The amount of material sourcing from the associated shales does not appear to have had a marked influence on the sandstone diagenesis (as in Bjorlykke, 1980), and most of it probably served to regenerate the detrital clays. There is no evidence for late diagenetic overgrowths and the deeper burial closed system diagenesis of Bjorlykke et al. (1979).

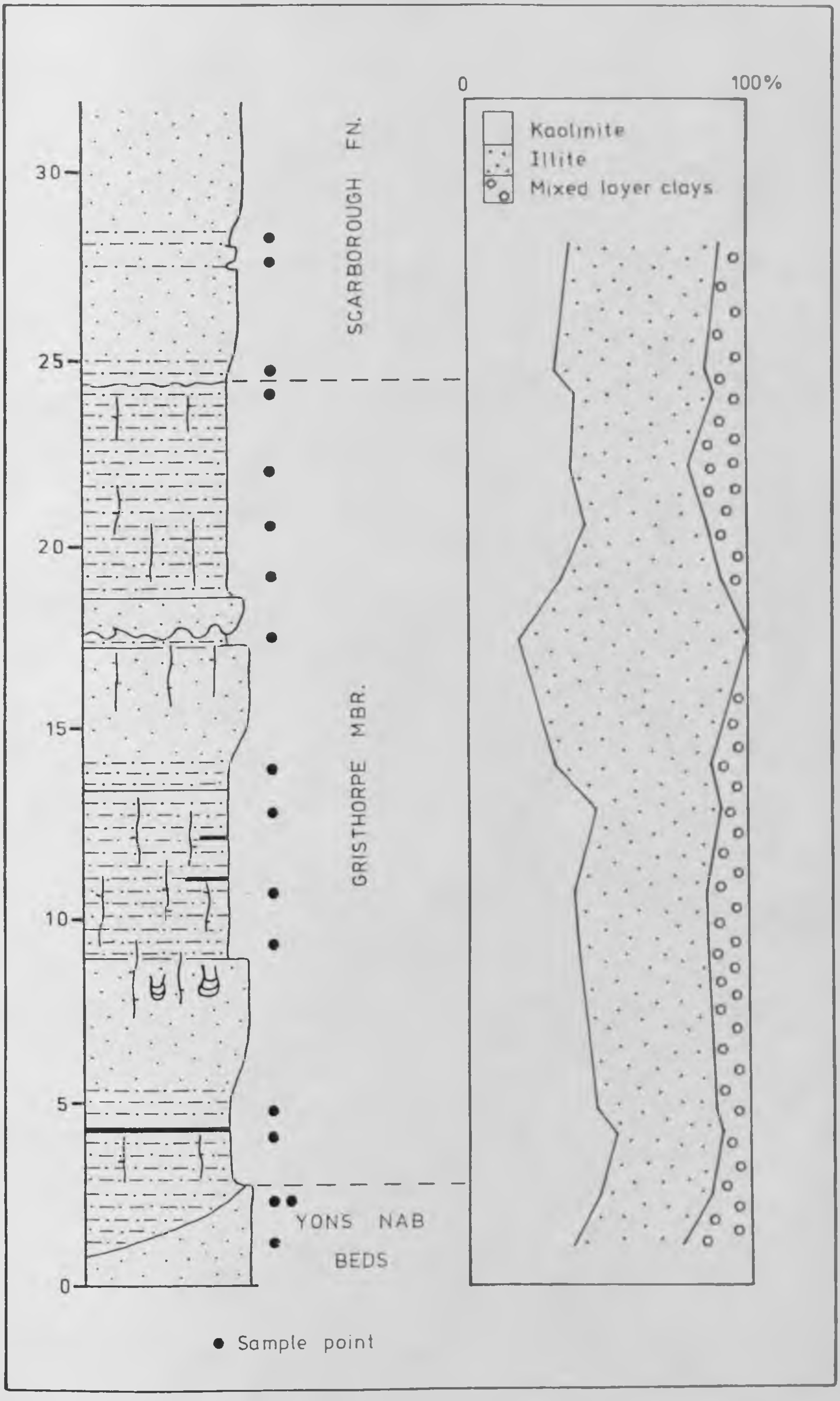
6.4. Clay Mineralogy of the shales

An X.R.D. analysis was carried out on 17 shale samples taken from a vertical profile at Cloughton Wyke. The methods used in this analyses were identical to those described in Section 6.3, and included heating and glyclation treatments. Three main mineral species were identified, kaolinite, mixed layer clays and illites. The mixed layer clays appear to be illite/smectite (mostly montmorillonite) and the kaolinite peaks mask a small amount of chlorite. The relative proportions of kaolinite, illite and mixed layer clays present in each sample was estimated from their peak heights on the X.R.D. traces. In tests with prepared mixtures kaolinite showed twice the height of illite when they were both present in equal quantities and the illite/mixed layer peaks were roughly equal. Although this is a crude way to estimate actual percentages of the minerals present the relative proportions of them can be computed. Sample localities and the results are shown in Fig. 6.19.

Illite was the most abundant mineral found in most of the samples, and the broad peaks suggest that a large proportion was randomly interstratified and detrital in origin. Mixed layer clays occur in

Fig. 6.19 Results of the clay mineral analyses of 17 shale and mudstone samples from a section at Cloughton Wyke, which includes two marine horizons (the Yons Nab Beds and the base of the Scarborough Formation) and the non-marine Gristhorpe Member. Note the increase in kaolinite in the organic rich shales, especially near the coal horizons.

FIG. 6.19


0
100%
Kaolinite
Illite
Mixed layer clays
30
25
20
15
10
5
0
SCARBOROUGH FN.
GRISTHORPE MBR.
YONS NAB
BEDS
Sample point

variable relatively minor proportions and there is no real evidence for the degradation of illite to mixed layer clays found in similar deltaic sequences (Brown et al. 1977). There is also no evidence of the environmental variation in clay mineral suites that the above authors found, with illite dominating marine and progradational phases and mixed layer clays abundant in destructive and aggrading deposits. The clay mineralogy of the two marine sequences in Fig. 6.19 is similar to that of the dominantly non-marine beds.

Kaolinite is the second most abundant clay mineral present. It is noticably present in high levels in the coal bearing parts of the sequence in Fig. 6.19. This kaolinite - high organic association is fairly well documented and has recently been reported from modern sediments (Staub and Cohen, 1978). In this Snuggedy Swamp example kaolinite forms immediately underneath peat deposits in pH conditions of < 5, under leaching by humic acids derived from the organic debris. The overall clay mineralogy of this section shows marked similarities with that of the Scalby Fn.(Nami, 1976) and there appears to be only minor local fluctuations away from a broad overall pattern that could probably be applied to the whole of the Ravenscar Group.

Part II.

6.5. Petrography and Diagenesis of Carbonate Sediments

The limestones of the Lebberston Member were studied using thin section, electron microprobe and cathodoluminescence analyses. The aim was to give a detailed petrographic account and a knowledge of the diagenetic history of these carbonates, which in conjunction with the studies from the siliciclastic sediments would enable an overall diagenetic model to be applied to the study area.

6.5a. Carbonate Framework Constituents

1. Ooids. Ooids consist of concentric carbonate laminae with radial and concentric interlaminar structures surrounding a nucleus. They are the commonest constituents of the limestones (Table 6.20) and reach maximum diameter of 1.9 - 2.0mm in subspherical examples. Ooids with elongate shell debris nuclei may have long axes larger than this. The better sorted limestones, which have a framework ooid content of greater than 90%, show diameters of 0.4 - 0.5mm (Fig. 6.21). The largest ooids were found in the Whitwell Oolite in the south-east of the area and are considerably larger than the ones forming today at Browns Cay in the Bahamas (1mm maximum, Newell et al. 1960). This size restraint may be a function of limited time of carbonate accretion (Bathurst, 1975), in the Bahaman case c. 2,000 yrs.

Well sorted oolitic limestones in the area show a high proportion of spherical ooids which must have been a result of the high energy of the environments. Ooid nuclei are variable in composition and include terrigenous grains, bioclastic debris and peloids. In a few examples no distinct nucleus was discernible. Carbonate coatings varied from one single layer to over 20 recognisable concentric laminae and this is demonstrated as a vertical trend of ooid formation from Yons Nab (Table 6.20). A high organic content gives the ooids a dark mottled appearance and they do not accept stain. All show concentric laminae and a minority demonstrate radial carbonate growth, Where they have not been replaced by later spar the laminae consist mostly of micritic carbonate.

Ooids are forming at the present time in several marine areas, including the Bahamas and the Persian Gulf (Kinsman, 1964). Several

TABLE 6.20

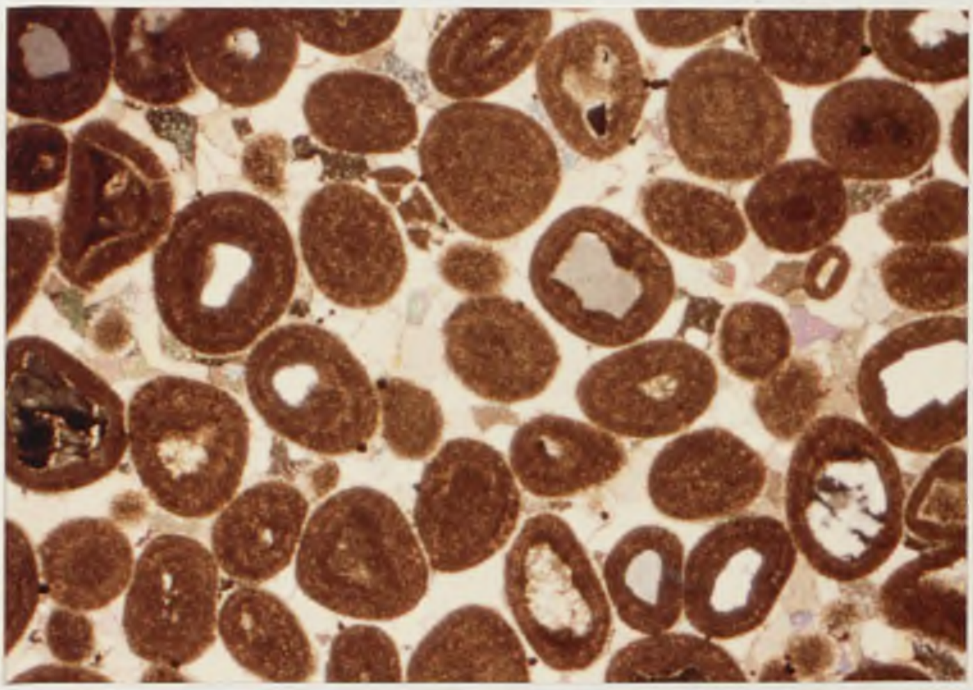
Petrographic modal analyses of the carbonate horizons.

	M81	M82	M83	M87	1	2	3	4
Ooids	72.5	79.5	8	5.25	48	45.5	88.75	82
Peloids	12	14.5	2.5	1	8	9.5	15.5	15.25
Bioclasts	13	5	2.25	1.5	20	22.25	.75	1.75
Grapestone/ Intraclast	2.5	1	-	-	-	-	-	1
Terrigenous	-	2.5	87.25	92.75	24	22.75	-	-
Spar	24.5	38.5	30.75	29.5	33	-	-	25
Rim cement	15.5	-	-	-	-	-	27.5	-
Porosity	-	-	-	-	-	12.5	-	-

Samples M81 - M87 were taken from the Millepore Bed at Yons Nab, M81 at the very top, M82 80 cm below, M83 150 cm below and M87 700 cm from the top (just above the base).

Samples 1 - 4 were taken from the Lebberston Member cored from I.G.S. Brown Moor borehole. Samples 1 and 2 come from the Upper Limestone (113.95 and 114.50 m downhole respectively) and samples 3 and 4 from the Whitwell Oolite (118.90 and 119.35 m downhole respectively). Note that the Upper Limestone contains much more terrigenous material.

Each analysis was based on 400 random counts on a mechanical stage. The values above the line add up to 100%, the values below are expressed as percentages of the whole section.



1mm

x 35

Fig. 6.21 Photomicrograph of well sorted oolitic limestone from the Lebberston Member at I.G.S. Brown Moor (118.95). Note the varied nuclei including quartz, shell fragments and peloids (centre). The feldspar nucleus on the centre left shows etching and replacement by calcite. Note also the radial and concentric ooid structures (arrowed). x 35, crossed nicols.

requirements for their formation are discussed by Bathurst (1975), including supersaturation of $CaCO_3$ solution, available detrital nuclei and grain agitation. Land et al. (1979) demonstrates Holocene ooids from Baffin Bay, Texas with similar variations in radial, concentric and micritic coatings as described above. The chemical variations described by them were not found in the Lebberston Member due to replacement. Davies et al. (1978) provide the most informative explanations for this variety of ooid growth to date. Quiet water ooids exhibit a radial orientation of carbonate crystals and form in the presence of organic material. Organic membranes form concentric shells around ooids and act as growth surfaces for further carbonate precipitation. Ooids with concentric carbonate growth were synthesised under conditions of agitation and supersaturation, but again organic membranes are required for repeated accretion. The presence of both radial and concentric types in the Lebberston Member (in some cases within the same ooid) suggests variable periods of quiet water and agitated overgrowths in a complex and changeable environment.

2. Peloids. Any subspherical grain of organic rich micritic carbonate without internal structure was placed in this group. They are smaller and less common than ooids, partly because they became centres for later carbonate growth after their formation. Bathurst (1975) discusses their origin and it would appear that the elongate ones found in the Lebberston Member were of faecal pellet origin, analogous to modern examples. Although initially soft they harden under deposition of interpore carbonate and are then capable of withstanding the type of high energy environment envisaged for the Lebberston Member. Micritisation

of skeletal particles or of fine-grained ooids would also explain their formation. It was difficult to assign many of the Lebberston Member peloids to any specific class.

3. Grapestone and early cemented intraclasts. Small amounts of grapestone and intraclasts were recorded from the coarser oolitic limestones in the area. They appear to have been exotic to the area of deposition and many show concentric overgrowths of carbonate making them in essence ooids. Grapestones form by the aggregation of carbonate sand grains to produce compound clasts in modern environments (Taylor and Illing, 1969). Early cemented fragments of siliciclastic sandstone were also recorded giving further evidence of the synsedimentary cementation discussed in Chapter 3.

4. Bioclasts. A large variety of marine fauna have been collected from the Lebberston Member (Fox-Strangways, 1892 gives a list). Much of this material is broken and abraded, or later coated with concentric overgrowths to form ooids.

The bryozoan *Hapliocea straminae* is abundant together with crinoid ossicles and other echinoderm plates. Brachiopod and bivalve shell debris is abundant, usually showing the effects of early micritisation and later compaction. The bioclasts are important as centres of early cement growth, discussed below.

5. Terrigenous material. Quartz and feldspar, as well as acting as nuclei for ooid formation are also present in most samples without carbonate coating. The quartz particularly shows evidence of later etching by calcite cements. All the terrigenous material found in the limestones is coarse-grained and very little silt and no clay was recorded from any of the samples.

The limestones are clean and well sorted grainstones (Dunham, 1962) and would be termed bioclastic oosparites or oosparites according to Folk's classification (1959).

6.5b. Carbonate Diagenesis

1. Micritisation and Algal boring. Micritisation plays an important part in early diagenesis. It involves the replacement of original carbonate grains by micritic carbonate (Bathurst, 1966) and is particularly common in thin bivalve shell debris. Micritisation is thought to occur in association with algal colonisation and may involve bacteriological decay reactions (Bathurst, 1975). The original grains are bored and colonised by alga which eventually die and allow the later emplacement of micritic cement. Micritisation of grain rims form envelopes crosscutting primary fabrics, which often remain after later replacement of the host clast (Fig. 6.22). Ooids with algal bores are quite common in the Lebberston Member and they become distinctive if infilled by a subsequent high luminescent carbonate (Fig. 6.23). Large scale micritisation is thought to have formed some of the peloids discussed earlier.

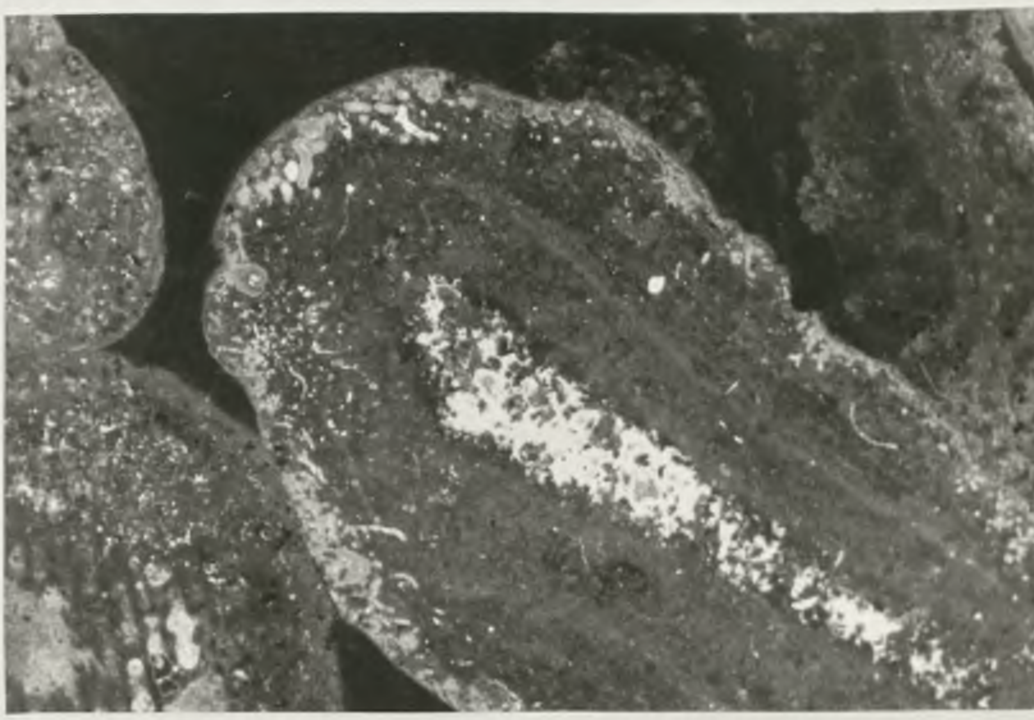
2. Early rim cements. There is ample evidence of syn-sedimentary cementation occurring during the deposition of the Lebberston Member. Sections through the beachrock at Cloughton Wyke show patches of isopachous acicular carbonate and dark areas of micrycrystalline cement (Fig. 6.24) analogous with modern examples. Modern beachrocks form from the precipitation of aragonite and high-Mg calcite following the CO_2 degassing of carbonate saturated groundwaters (Hanor, 1978). Many of the conglomeratic clasts seen in the Lebberston Member and discussed in Chapter 3 also show evidence of rim cementation, binding the constituents together to resist transport and erosion (Fig. 6.25).

Fig. 6.22 Photomicrograph of a micrite envelope surrounding an abraded and replaced bioclast. The original internal structure of the clast can be picked out by lines of fine-grained early cement which pre-date the final spar (S). Note the rim cement overlying the micrite seen on the bottom right hand side of the clast (arrow). The Millepore Bed at Yons Nab. x 35, plane polarised light.

Fig. 6.23 Cathodeluminescence photomicrograph of an ooid showing pronounced algal boring infilled with a highly radiating early carbonate pore filling cement. Note the varied size if the bores (top left compared with right hand side of the ooid). The bioclast nucleus has been partly replaced by the same luminescing carbonate and this was probably contemporaneous with the bore infill. The spar cement (in-between ooids) is completely non-luminescent. The Lebberston Member, I.G.S. Brown Moor (119.35). x 125.

1mm

x 35



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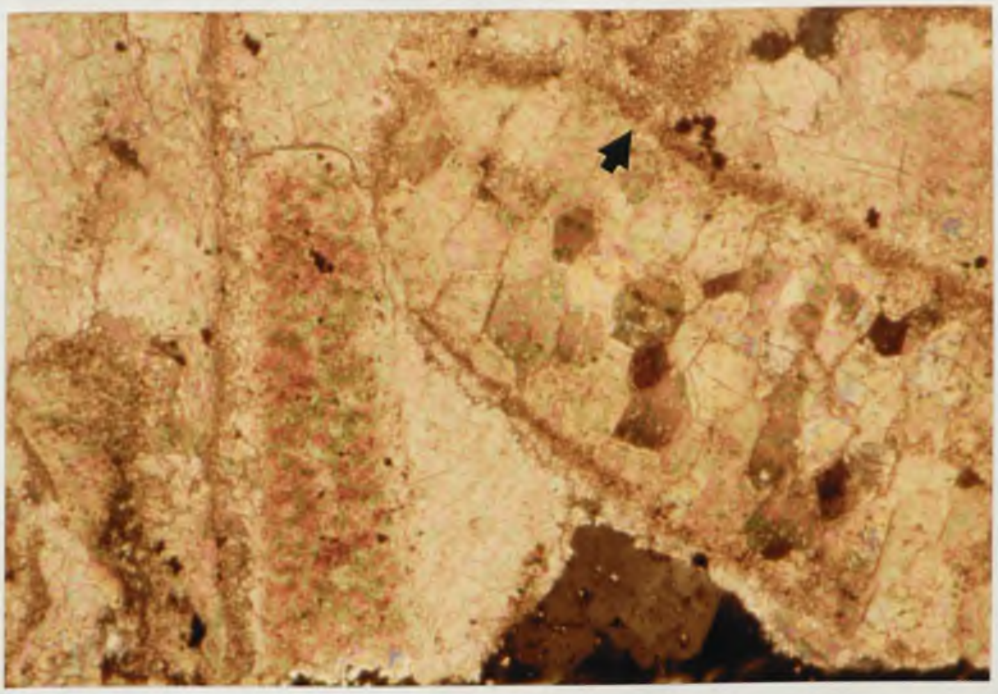
x125

Fig. 6.24 Photomicrgraph of part of the beachrock at Cloughton Wyke showing early rim cements and patchy micritic carbonate cements (arrow). Note also the quartz grain at the bottom which has been etched and partly replaced by the carbonate cements. x 140, crossed nicols.

Fig. 6.25 Photomicrograph of early rim cements (arrowed) surrounding two replaced ooids in a poorly sorted quartzose clast from the Millepore Bed (taken from a conglomerate horizon) at Yons Nab. The dark patches surrounding the two quartz grains (white) at the base of the figure are early micritic cement. The two ooids have been replaced by coarse sparry calcite.



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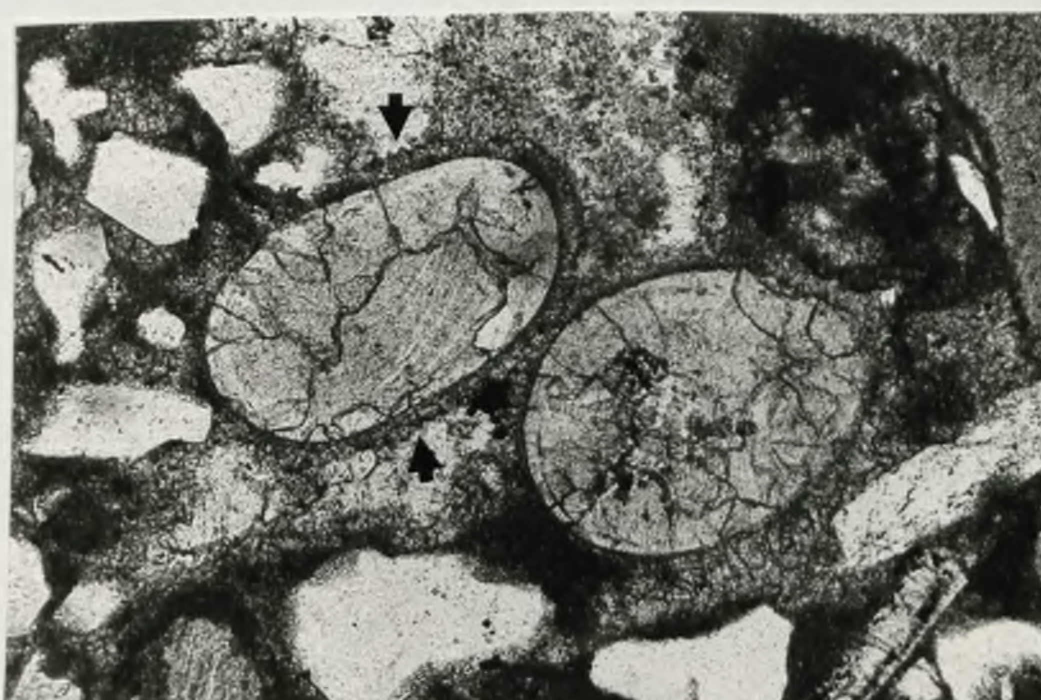
x 140



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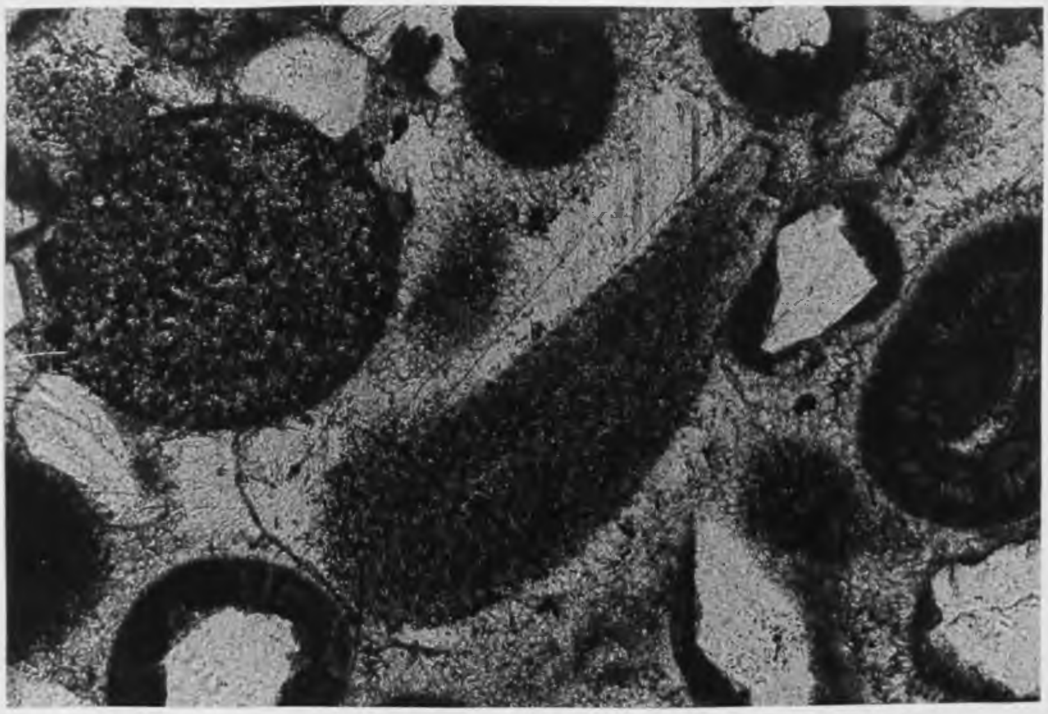
x 125

Some of these clasts show evidence of early micrite cements as well. Rim cements are also found in situ at the top of the Millepore Bed at Yons Nab (Fig. 6.26) and in some I.G.S. Brown Moor samples. These cements consist of short, closely packed carbonate, forming one thin layer coating all grains. The number of individual crystals adjacent to the host grain is higher than at the edge of the rims, analogous to other ancient examples (Marshall and Ashton, 1980). This early cement phase is best developed as overgrowths to bioclasts, especially echinoderm fragments (see Fig. 6.26). This latter observation is very similar to that described by Purser (1969) from Middle Jurassic limestones in the Paris Basin, in association with bored subtidal hardgrounds. There is no evidence from the samples studied of stalactitic druses or meniscus cements, which would be indications of intertidal emergence (Purser, op. cit.).

It would appear that there was considerable early cementation during the deposition of the Lebberston Member. From a consideration of the overall environments of deposition (Chapter 3) it would appear that all but the beach rock formed from submarine lithification. Dravis (1979) demonstrates the occurrence of recent oolitic hardgrounds from the Bahamas, in a similar high energy environment to the one envisaged for the Lebberston Member. He recognised two types of lithified oolitic sediment, in situ crusts and erosional clasts. Aragonite and subordinate high Mg-calcite are the dominant cements, forming rims up to 100 μ thick. Chasmolithic and endolithic algal filaments play an important role in binding and stabilising the sediment, and also produce concomitant micritisation, noted above. The top of the Millepore Bed at Yons Nab appears to be an example of crust formation

Fig. 6.26 Photomicrographs of early rim cements near the top of the Millepore Bed at Yons Nab. The upper photograph is in plane polarised light, the lower one under cathodeluminescence. The central bioclast shows much coarser-grained early cement than the adjacent clasts. The overgrowths show marked uniformly distributed internal zonation reflected in variable luminescence, thought to be due to subtle differences in chemistry. Discussion in text (section 6.5c). Black areas - quartz grains, dark grey - spar in the lower figure.

Brandenberg cathodeluminiser @. 30 Kv.



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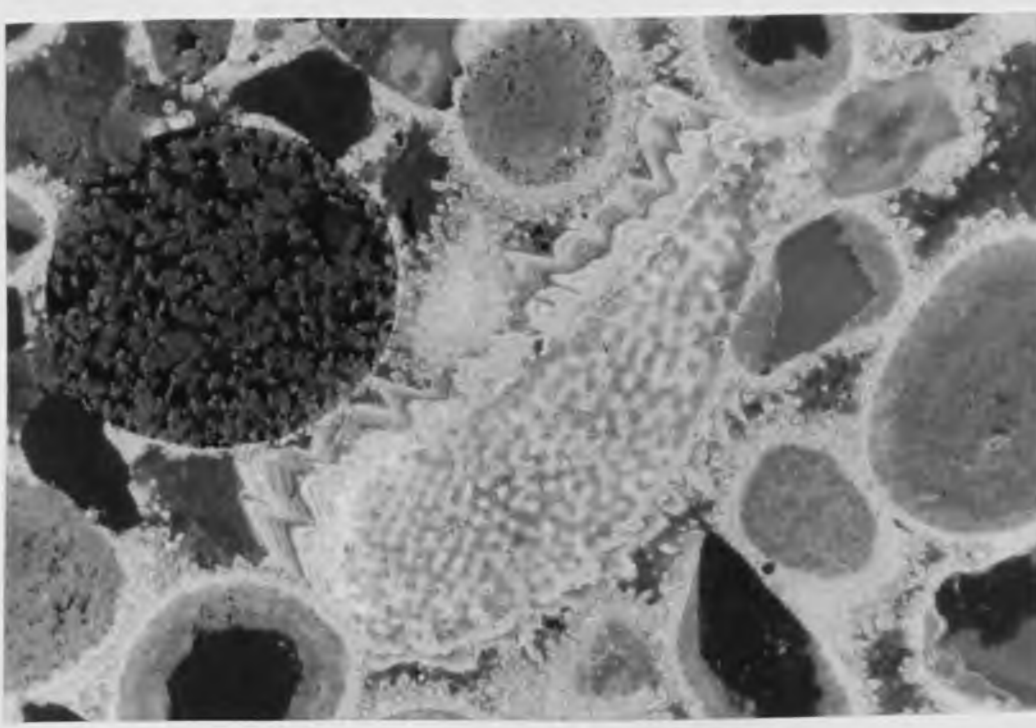


whilst the conglomeratic clasts seen throughout the Lebberston Member will be eroded and reworked examples. The crusts form rapidly in Dravis's example and are found throughout the active oolitic sand environment, with the cementing carbonate precipitating from seawater.

3. Post sedimentary diagenesis. The dominant late diagenetic process in the cementation of the Lebberston Member is the deposition of coarse-grained sparry calcite. It occurs as two forms, as a pore filling cement showing enfacial triple junctions (Bathurst, 1969) and also as a replacement of earlier framework constituents. The latter gives neomorphic textures showing relic structures of original grains (Fig. 6.27). It is possible that the largest spar grains seen (2-3mm) are neomorphic after an earlier spar generation from inclusion traces but its poor luminescence made this difficult to prove. The spar formation gives framework expansion with clasts appearing to 'float' within this cement. Compactional fractures are also enlarged by spar growth (Fig. 6.28).

Not all the Lebberston Member shows the generation of sparry calcite. At Yons Nab large parts of the Millepore Bed show no cement and are soft and friable. These areas have sharp boundaries which crosscut primary bedding planes. Samples from the I.G.S borehole show compacted sandy bioclastic oolites without any spar generation adjacent to similar lithologies with late stage cements (Table 6.20, samples 113.95 and 114.50). If the former were subjected to modern weathering they would produce similar sands to those at Yons Nab. The samples without spar cements are notably more compact than those with (113.95 has 33% spar, 114.50 has 12.5% porosity). This is partly

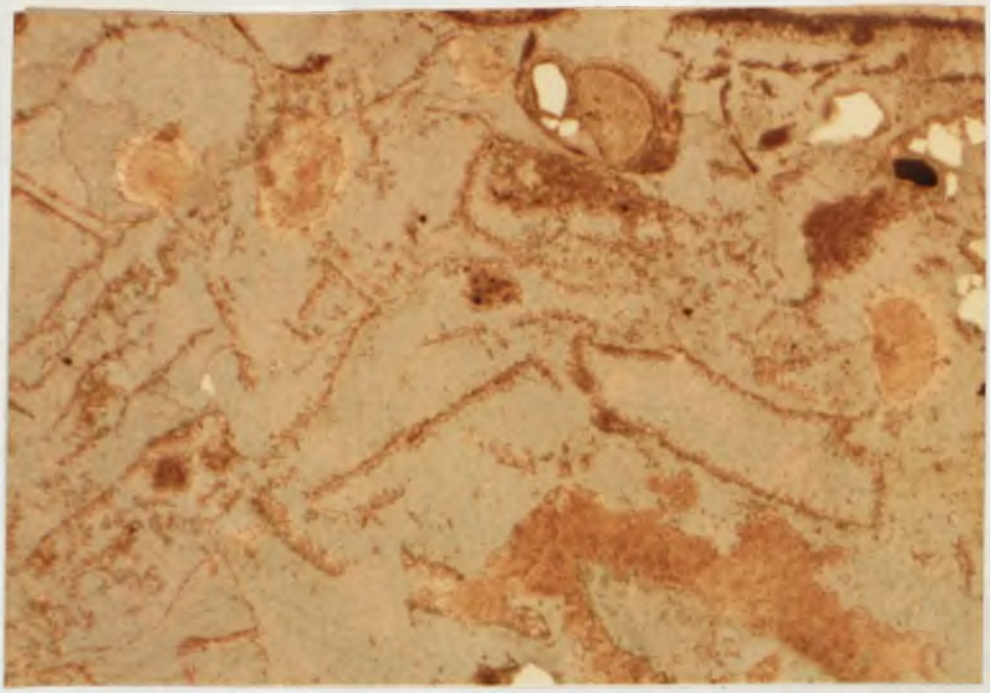
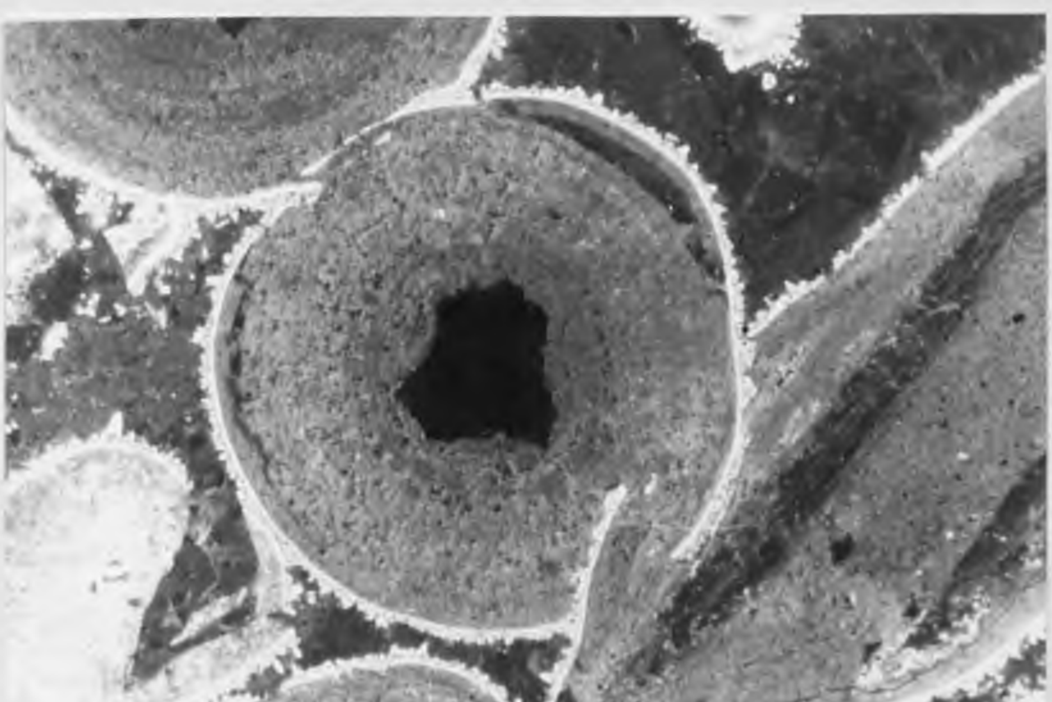


Fig. 6.27 Photomicrograph showing large scale replacement of original clasts by a coarse sparry calcite (pale blue). The primary rim cements (pink) suggest the original outlines of the clasts and have not been replaced. Stained section from the Millepore Bed at Yons Nab. x 125.

Fig. 6.28 Photomicrographs of compacted ooids from the Millepore Bed at Yons Nab. The upper photograph is in plane polarised light, the lower one under cathodeluminescence. Note the grain interpenetration and fracturing of the rim cement in the middle ooid. The middle ooid shows radial internal structures, the upper left one shows concentric growth. The rim cements show high luminescence and the spar (top right) very low luminescence. Note the enlargement of the compactional fracturing by the spar cement growth (arrow, top photograph). x 125.

0·1mm



x125

a result of framework expansion and partly due to later continued compaction. It would appear that not all of the Lebberston Member was cemented by sparry calcite and that large areas were left relatively unlithified in an irregular manner. There was no evidence of dolomite or dolomitisation in any of the samples.

6.5c. Chemistry of the Diagenetic Material

Cathodeluminescence and microprobe studies were used in an attempt to gain further information on the diagenetic history. Unfortunately the sparry calcite did not luminesce and no internal structure or zonations were seen (Fig. 6.29). Non-luminescence is normally attributed to high Fe^{2+} and Mn^{2+} in the calcite lattice (Sommer, 1972, Meyers, 1978) but the Mn^{2+} content in the Lebberston Member spar was below the detection limits of the microprobe used. The rim cements did luminesce, and to a varying amount. Larger overgrowths on echinoderm clasts show that this variation is due to internal zonation (Fig. 6.26). Within any one area this zonation is constant suggesting that all the rim cements in a sample were deposited synchronously.

The microprobe analyses showed that the rim cements had variable Fe^{2+} content (1.2 - 3.4 wt % $FeCO_3$) with the majority lying in the range 1.2 - 2.0 wt % $FeCO_3$. The sparry calcite gave values from 1.9 - 3.1 wt % $FeCO_3$ with most points between 2.2 - 2.6 wt % $FeCO_3$. These microprobe results tie in with the luminescence observed, with the higher $FeCO_3$ contents in the spar quenching radiation. The variable luminescence seen in the rim cements was due to the fluctuations in $FeCO_3$ content. Fig. 6.26 indicates an initial period of low Fe^{2+} and high luminescence, followed by higher Fe^{2+} giving the dark band. Gradual decrease in the Fe^{2+} content increased the luminescence of each

0·1mm

x 125

Fig. 6.29 Photomicrograph of stylolite surface (arrowed) in the Millepore Bed at Yons Nab. Considerable shortening has occurred over this surface resulting in redistribution of carbonate. x 125, plane polarised light.

successive layer as growth occurred. Marshall and Ashton (1980) found bands of higher Fe^{2+} calcite in similar rim cements from staining techniques. This varied chemistry may relate to the original aragonite/high-Mg calcite deposited as a syn-sedimentary cement, but the inclusion of Fe^{2+} in a calcite lattice requires reducing conditions not consistent with their environment of deposition. It is unlikely that selective replacement of excess Mg^{2+} acicular cements by ferroan calcite could explain the gradual zonations seen in this example (Fig. 6.26) as suggested by Marshall and Ashton, but no other explanation seems acceptable. It would appear that the limiting factor on calcite luminescence in the Lebberston Member is a value of about 2 wt % $FeCO_3$.

Mg^{2+} values vary between rim and spar cements as well. The rim cements give values of 0.9 - 1.6 wt % $MgCO_3$ whilst the spar gives values of 1.5 - 2 wt % $MgCO_3$. If the rim replacement was isochemical the original early cements would have been aragonite rather than high-Mg calcite. It is unusual for spar cements to have high Mg^{2+} contents than rims, but these values of Mg^{2+} are still fairly low.

6.5d. Source of the Secondary Cement. In-between the deposition of the primary and secondary cements there was a period of compaction, producing interpenetration of framework grains and the mechanical fracturing of rim cements and ooids (Fig. 6.28). This compaction would produce pressure solution and account for part of the spar cement material. A large part of this secondary material appears to have come from the stylolitisation of parts of the limestones (Fig. 6.29).

This would redistribute a large amount of carbonate. Marked compaction has also been seen from adjacent non-spar cemented sediments and this would also produce the necessary ionic material. Friedman (1975) suggests that large parts of diagenetic carbonate material is produced by the destruction of equivalent amounts in a similar manner to that described above. The increased Fe^{2+} found in the spar cements (in comparison with the rims) probably originates from sulphate reduction during burial diagenesis. It may be that compaction of the adjacent shales in the sequence produced Ca^{2+}, CO_3^{2-}, Fe^{2+} and Mg^{2+} which were then incorporated into the spar cements.

6.5e. Summary of the Carbonate Diagenetic History. Early diagenetic effects were syn-sedimentary and include the formation of submarine hardgrounds and beach rock. Bioclasts show the greatest overgrowths. Early micritisation produced fine-grained carbonate replacement as well as cementing fabric.

As the Lebberston Member was buried by later sediments compaction started to produce Ca^{2+} and CO_3^{2-} ions by pressure solution. Selective dissolution of certain original materials occurred leaving micrite envelopes which deformed on compaction (eggshell diagenesis, Wilkinson and Landing 1978). The carbonate produced by these methods went to form second generation cements richer in Fe^{2+} and Mg^{2+}. Further compaction produced stylolitisation and a further redistribution of carbonates. These diagenetic changes occurred in a phreatic realm which allowed the uninterrupted growth of large equant sparry calcite into pore space (Friedman, 1975). This involves large amounts of water which helped to redistribute the carbonate in solution.

The second generation cement shows evidence of grain growth and was also in part replacive. There was only a limited supply of carbonate and large irregular areas of relatively unlithified sediment remained. This suffered further compaction with increased burial load and contributed more material for spar growth. A late stage vein formation is seen in many samples (Fig. 6.30). It post dates the cementation of the carbonates and marks a slightly extensional tectonic regime.

Part III.

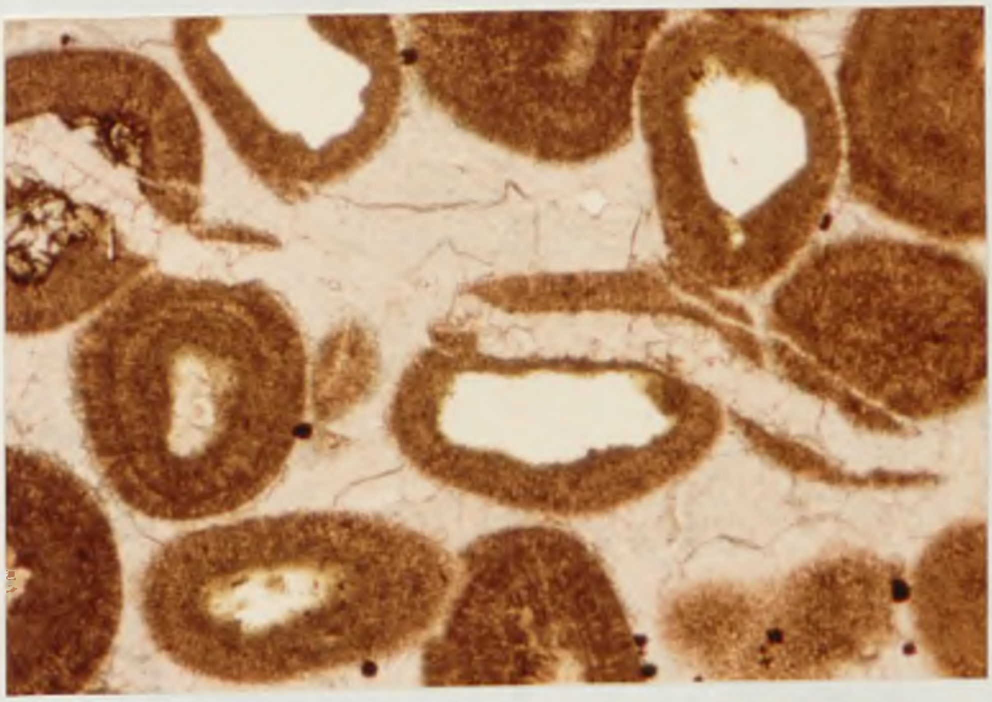
6.6. Diagenetic History of the Lower and Middle Ravenscar Group.

The Saltwick Formation to Scarborough Formation sequence consists of mixed marine and non-marine sediments with one horizon containing oolitic limestones. The framework constituents of the siliciclastic rocks are mature with only relatively small amounts of mica and feldspar present as unstable minerals. Porosities remain quite high in some of these sandstones and can exceed 30%.

An early period of compaction and pressure solution resulting from gradual burial produced silica which was deposited as syntaxial overgrowths. The amount of quartz pressure solution found in the Lebberston Member siliciclastic rocks with a calcite spar cement is limited, suggesting that the deposition of this carbonate was concomitant. Calcite cements are restricted to the marine horizons and are only developed as a spar where there was sufficient initial carbonate material in the associated sediments. It would appear that the Ca^{2+} liberated by limestone pressure solution was quickly redeposited locally. In most of the marine horizons calcium carbonate deposition is restricted, and probably sourced from shell

Fig. 6.30 Photomicrograph of late stage vein post dating the period of spar cementation (pale lilac). The Lebberston Member, I.G.S. Brown Moor (118.90). x 80, plane polarised light.

Fig. 6.31 Large carbonate concretions from the base of the Scarborough Formation (Facies 1a) at Cloughton Wyke.



× 80

debris. In the lower parts of the Scarborough Formation this material forms large carbonate concretions (Fig. 6.31) but the amount of calcite deposited is minor.

Clay mineral regeneration probably occurred throughout the diagenetic history and the formation of new illite and illite/ smectite is restricted to horizons where initial detrital clay levels were high. Feldspar overgrowths appear to have formed at a fairly early stage and they remained stable during later diagenesis, presumably due to their chemistry.

A later stage of kaolinitisation is pervasive where there was still pore space available for its free growth. It post dates all the diagenetic effects mentioned above. Degradation of feldspars is more apparent in the coarser grained channel sandstones which were highly permeable. Where this occurs there appears to have been enough material to infill pore spaces with well developed diagenetic kaolinite crystals.

The calcite and quartz cements require large quantities of freshwater to redistribute the material involved. The source of this freshwater was probably as a natural flow through these deltaic sediments which can act as aquifers soon after deposition (Bjorlykke et al. 1979). This flow will have slowed as the area was sealed by Upper Jurassic fine-grained clastics and pore water chemistry would then play the dominant role in diagenesis. The regeneration of detrital clays and the formation of new illite and illite/smectite is a local effect resulting from such a closed system.

Kaolinisation appears to postdate the early diagenetic effects described above. In the Middle Jurassic sediments of the North Sea kaolinitisation is thought to have occurred during the Cimmerian uplift. Fellow workers (Kantorowicz & Waugh, 1980 pers. comm.) suggest that the Yorkshire kaolinitisation may have occurred during the inversion of the region at the end of the Cretaceous (Kent, 1979).

Kent's model is interesting, but his depth of burial figures are open to question. He suggests that the Ravenscar Group sediments were only buried to 1000-1300m depths at a maximum, before uplift and inversion. The lignitus/sub-bituminous nature of the coals present in the Group suggests that this figure is an underestimate. Wandless and Slater (1939) recorded a fixed carbon figure of 49% from one of these coals, which would roughly correspond to burial depths of 2km (Teichmuller and Teichmuller, 1967). There is no evidence that this thickness of overburden could have been achieved during the Tertiary.

This maximum burial depth of 2km must have played a part in restricting diagenetic effects to the fairly simple processes described above. There is no evidence of ankerite formation, which occurs at around 125°C (2,500m) in the Wilcox Sandstones of Texas (Boles, 1978). There is similarly no evidence of illitisation of kaolinite (Hancock and Taylor, 1978) or of chlorite formation at the expense of kaolinite (Boles, op. cit.), which occurs above c.150°C. This is an important factor in the preservation of permeability, as Nagtegaal (1978) suggested that drastic permeability loss only occurs under the destruction of kaolinite.

Overall the diagenetic history of the Ravenscar Group appears to be fairly simple, with only local variations of increased intensity, probably a result of sandstones acting as permeable conduits to freshwater. The maximum depths of burial appear to be c.2km, and correspondingly maximum temperatures reached would be around 100°C, assuming an average geothermal gradient.

CHAPTER 7

REGIONAL BAJOCIAN GEOLOGY, PROVENANCE OF THE RAVENSCAR GROUP AND GENERAL THESIS CONCLUSIONS

CHAPTER 7

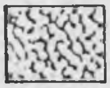
REGIONAL BAJOCIAN GEOLOGY, PROVENANCE OF THE RAVENSCAR GROUP AND GENERAL THESIS CONCLUSIONS

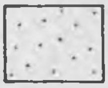
7.1. Regional Structural Evolution

The Mesozoic structural evolution of northwestern Europe is now well documented following major exploration work for hydrocarbon reservoirs, especially in the North Sea area (Zeigler, 1975 and in press, Kent 1975a, b, and Eynon, in press). A series of intermittent Cimmerian fault movements produced a complex structural background to the regions sedimentary patterns. The faulting was accompanied by localised volcanic activity and the mobilisation of mainly Zechstein salt deposits (Zeigler, 1975). These structural events were associated with the Mesozoic disintegration of Pangea and resulted in the production of a complicated horst and graben system. Crustal arching as a result of mantle plume or hotspot activity (Whiteman et al. 1975) occurred, concentrated in the Piper region (Fig. 7.1) at the junction of three rift systems, the Moray (Witch Ground) Graben, the Viking Graben and the Central Graben (Sellwood and Hallam, 1974). Bathonian and Bajocian volcanic activity at this trilete junction produced undersaturated alkaline olivine basalts and clastic volcanics (Howitt et al. 1975). Igneous activity in the North Sea region as a whole resembles the early phase of Miocene tectonics seen in the Eastern rift valley of Africa (Dixon et al., in press). All the trilete rift junctions in the North Sea (Fig. 7.1) are of rrr type without crustal spreading (Whiteman et al., op. cit.).

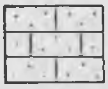
Fig. 7.1 Generalised structural and palaeogeographic setting of northwest Europe during the Bajocian (based on Hallam and Sellwood, 1976).

KEY

 Land or areas of non-deposition

 Dominantly clastic deposition

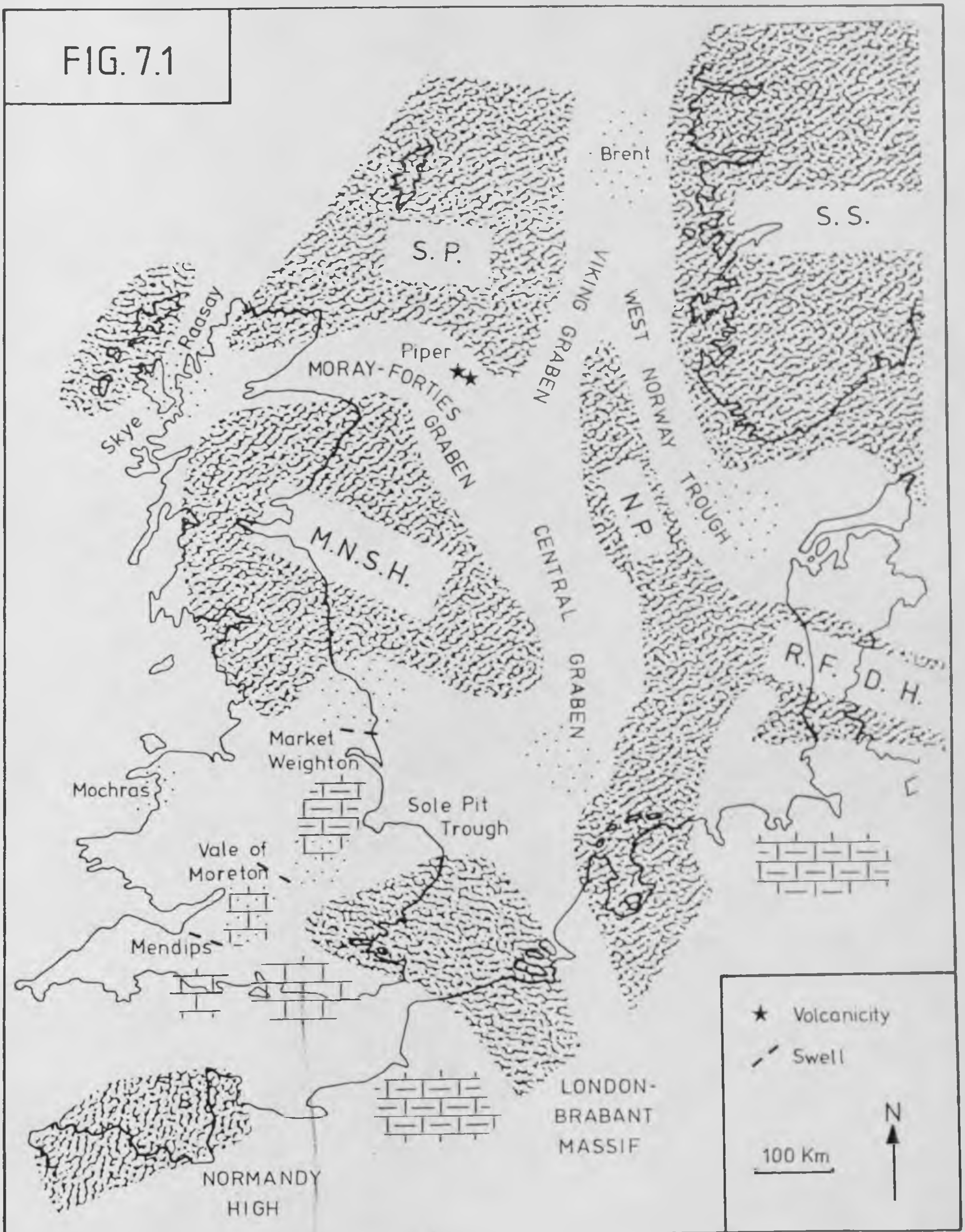
 Dominantly carbonate deposition

 Arenaceous limestone deposition

 Argillaceous limestone, marl etc. deposition

S.P.	Shetland Platform
S.S.	Scandinavian Shield
N.P.	Norwegian Platform
M.N.S.H.	Mid-North Sea High
R.F.D.H.	Ringkøbing-Fyn - Danish High

FIG. 7.1



Brent
S. S.
S. P.
VIKING GRABEN
WEST NORWAY TROUGH
Raasay
Skye
Piper
MORAY-FORTIES GRABEN
N. P.
M.N.S.H.
CENTRAL GRABEN
R. F. D. H.
Market Weighton
Mochras
Sole Pit Trough
Vale of Moreton
Mendips
LONDON-BRABANT MASSIF
NORMANDY HIGH
Volcanicity
Swell
100 Km
N

As well as the development of a major graben system morphological highs such as the Mid-North Sea and Ringkøbing-Fyn areas began to profoundly influence sedimentation, completely altering the palaeogeographies of north western Europe (Hallam and Sellwood, 1976). From being a depocentre for Liassic marine shales (Hallam, 1975) the North Sea uplift brought on marked periods of regression (Kent, 1975a) directly opposed to a world-wide contemporary rise in sea level during the Aalenian/Bajocian. During the Middle Jurassic there were several stages of downfaulting in the Viking and Central Grabens (Zeigler, 1975), and in the Brent area Callovian deposits overlie faulted blocks of Bajocian and Bathonian sediments (Bowen, 1975). This complex block and basin pattern continues into Germany and is also found severely influencing sedimentation in northwest Scotland (Binns et al., 1975). The basins became sites for major accumulations of clastic sediment during the Middle Jurassic,much of which was derived from the adjacent highs. Although areas such as the Mid-North Sea High and the Scandinavian craton had been positive from Triassic times onwards they only began to source large amounts of sediment in the Middle Jurassic. The Ringkøbing-Fyn High and the London-Brabant massif also sourced and influenced sedimentation.

The centre of uplift was in the northern North Sea and it is in this region that tectonic effects produced large amounts of clastic material. Further south in mainland Great Britain the graben effects give way to basin and swell types of sediment controls (Hallam and Sellwood, 1976). Brittany/Normandy, the Mendips and the Vale of Moreton (Oxfordshire shallows, Sylvester-Bradley, 1968) (Fig. 7.1) were stable areas similar to Market Weighton. They sourced little, if any, detrital material. These stable areas and the intervening basins show variable stage-to-stage oscillations especially in the Lower and Middle Jurassic (Sellwood and Jenkyns, 1975). Intermittent subsidence provoked by downfaulting in the Hercynian basement produced marked thickness variations in the Middle Jurassic sediments. Towards the end of the Jurassic movement diminished and northwest Europe became generally more stable.

7.2. Contemporary Bajocian sediments in north western Europe

During the Bajocian a wide variety of sediments were deposited in the North Sea region, mostly in localised areas influenced by the tectonic factors discussed above. Sediments of similar age to the Bajocian Ravenscar Group are tabulated in Fig. 7.2. Bajocian volcanic lavas were extruded and clastic material was deposited in the Piper area (Fig. 7.1), and during the Bathonian volcanics were interbedded with non-marine deltaic sediments (Williams et al. 1975). This volcanically active area was the main centre of uplift in the North Sea. The major Brent and surrounding oilfields have reservoirs in Bajocian deltaic sediments which form part of the Brent Sand Formation (Bowen, 1975), (Fig. 7.2). The basal micaceous sediments in this formation are similar to the opalinum Dogger Formation deposits at Blea Wyke (Hancock and Fisher, in press) and may represent contemporaneous shallow marine environments. In the Brent field the mica sands are overlain by a Bajocian delta lobe, which bears similarity to the non-marine parts of the Ravenscar Group. The Bajocian sequence is terminated by shallow marine sediments in Brent, and elsewhere in the

Fig. 7.2 Correlation of contemporary Bajocian sediments in the British Isles and Brent. Based on Arkell (1933 and 1956), Evans (1952), Morton (1965), Bowen (1975), Parsons (1976), Leeder and Nami (1979) and Ashton (1980).

STAGE	YORKSHIRE	LINCOLNSHIRE	COTSWOLDS	DORSET	N.W.SCOTLAND	BRENT
BATHONIAN	Scalby Fn ? 60m	Upper Estuarine Series 9m	Lower Fullers Earth 42m Chipping Norton Lst. 3-9m	Lower Fullers Earth Clay 40m Crackment Lst.	Gt. Estuarine Series 121m	
BAJOCIAN	? Scarborough Fn 32m Lebberston Mbr 0-19m Eller Beck Fn 3-8m	? Lincolnshire Limestone Fn max.40m	Clypeus Grit Upper Trigonia Grit Witchellia Grit 30m Lower Trigonia Grit	The Red Bed 1·5m	Bearreraig Sandstone 200-485m	? Upper Brent Mbr Middle Brent Mbr max.257m
AALENIAN	Dogger Fn 0-7m	Lower Estuarine Series 6m Northampton Sand Fn 7-15m	Tilestone Harford Sands Freestones Pea Grit L. Limestones	Bridport Sands		Lower Brent Mbr (Mica Sands) ?

Viking Graben there are two further periods of Bathonian deltaic activity (Eynon, in press).

Fault controlled tectonic activity allowed rapid subsidence and the accumulation of 200-435m of shallow marine sediments in two basins on Skye and Raasay (Fig. 7.1) (Morton, 1965, 1976). These deposits represent a continuous sequence from opalinum to gargantiana age (see Fig. 1.6) and are collectively named the Bearreraig Sandstone Formation. The Bajocian nearshore environments on Skye and Raasay finally shallowed at the beginning of the Bathonian to allow lagoonal deposition of the Great Estuarine Series (Hudson, 1962). The local nature of fault controlled sedimentation is demonstrated by the concavum transgression in the Bearreraig Sandstone which is directly opposite to the general pattern of uplift seen contemporaneously.

In the Norwegian part of the North Sea rift system (Norwegian Trough, Fig. 7.1) some 80m of undated Middle Jurassic deltaic sediments are overlain by a transgressive marine sandstone (Myhre, 1977). Spectacular local deposition of Aalenian to Lower Bajocian clastics are reported by Heybroek (1975) from the Dutch part of the Central North Sea Graben (Fig. 7.1). Here 1000m of sandstones, shales and coals are overlain by 300m of Upper Bajocian marine shales. Although Heybroek described the non-marine sediments as being lacustrine they are probably comparable with the Ravenscar Group clastics. In the Sole Pit Trough (Fig. 7.1) there is no evidence of Middle Jurassic deltaic deposits (Kent, 1980). Minor Bajocian (?) sediments are reported from the Cardigan Bay area by Penn and Evans (1976) but most of the Middle Jurassic sedimentation in this region is of Bathonian age. Although the information from the North Sea area is incomplete there is ample evidence of local basins accumulating sediments similar to those of the Ravenscar Group throughout the Bajocian and into the Bathonian. From the localised thickness variations and the complex topography of the North Sea region during the Mesozoic it is probable that individual basins were fed by small scale alluvial sedimentary systems.

The Middle Jurassic non-marine and shallow marine ('deltaic') sediments described above are markedly different from the deposits found to the south of Yorkshire. South of Market Weighton the Upper Aalenian to Bajocian sequence (Inferior Oolite Series) is represented by a variety of shallow marine and lagoonal clastics and carbonates. In the Lincolnshire Basin the Northampton Sandstone Formation marks minor marine clastic deposition of opalinum age close to the London-Brabant Massif (Sylvester-Bradley, 1968) (Figs. 7.1, 7.2). The Grantham Formation (Lower Estuarine Series) consists of 6m of marsh clays with marine shale (Kent, 1975c) and is probably contemporaneous with the Saltwick Formation (Fig. 7.2). The main Bajocian depositional environments in the Lincolnshire Basin produced lagoonal, tidal flat and shallow marine carbonates found in the Lincolnshire Limestone. This carbonate sequence has a maximum thickness of 40m and thins northwards towards Market Weighton and southwards towards London. Ashton (1980) suggests that the Lincolnshire Limestone shows the landward migration of an offshore barrier complex (the Upper Lincolnshire Limestone) over lagoonal and tidal flat deposits of the Lower and Middle Lincolnshire Limestones. The Bajocian carbonate sequence in Lincolnshire is overlain by the Bathonian Upper Estuarine Series and there is a marked time gap between the two horizons (Evans, 1952), (Fig. 7.2).

In the Cotswolds there is carbonate platform development of Inferior Oolite age which reaches a maximum thickness of c.100m (Arkell, 1933). Most of this sediment is Upper Aalenian in age (70m) and consists of oolitic and bioclastic limestones (Freestones, Pea Grit, and Lower Limestones) overlain by marls and the Harford Sands (Baker, 1975). The Lower Bajocian deposits are dominantly oolitic and fossiliferous limestones, including the Ragstones (Fig. 7.2). The Cotswolds and Lincolnshire Basins are separated by the Vale of Moreton axis (the Oxfordshire shallows of Sylvester-Bradley, 1968) a westerly extension of the London-Brabant Massif (Fig. 7.1). Between the two basins Upper Bajocian (parkinsonae) Clypeus Grit directly overlies Liassic sediments (Arkell, 1933). The Ragstones are laterally equivalent to the bulk of the Ravenscar Group studied, and consist of calcareous sandstones, pisolites, oolites and coral rich bioclastic limestones. Most of the bioclastic material was derived from the destruction of nearby reefs in a shallow marine environment (Arkell, op. cit.).

The Dorset area was a swell during Lower Inferior Oolite times and only preserves a condensed sequence, demonstrating internal erosion, of limestone known as the Red Bed (Fig. 7.2). In-between Dorset and the Cotswolds Basin the Mendips acted as a similar high to Market Weighton and the Vale of Moreton. In Hampshire and Sussex, south of the London-Brabant Massif, the Aalenian/Bajocian thickens to 100m and includes oolitic limestones and sandy calcareous sediments (Hallam and Sellwood, 1976). This horizon is represented in northern Germany and the eastern Paris Basin by shallow marine marly limestones and clastics (Arkell, 1956). There is rather a marked trend, therefore from clastic deposition in the northern North Sea/Yorkshire area to carbonate sedimentation in southern England and northern continental Europe during the Bajocian period. This trend directly reflects the major periods of uplift during the Middle Jurassic, concentrated in the northern North Sea and discussed in Section 7.1.

7.3. Provenance and Regional Palaeogeography

Palaeocurrents taken from the non-marine horizons (see Chapter 5, Fig. 5.2) indicate a sediment derivation from the north east of the general depositional site in Yorkshire. The sandstones throughout the Ravenscar Group from the Saltwick to the Scalby Formations show a general uniformity of grain size and degree of sorting. Texturally these sandstones are submature to mature. This is true of all the samples from the Ravenscar Group analysed in this study and those investigated by Nami (1976).

The sandstones are either subarkosic or quartzarenites. It is probable therefore that one source area can be envisaged for the whole of the Ravenscar Group, and this Middle Jurassic sequence falls into the protoquartzite province of the Mesozoic of the North Sea, as proposed by Selley (1978). The distribution of the undulating extinction and polycrystallinity of the quartz grains seems to indicate a polycyclic source for the detrital silica (see Chapter 6.2). The compositional and textural evidence indicates a sedimentary source area, as suggested by Hemingway (1974) for the Moor Grit (basal Scalby Formation). From the paucity of rock fragments in the samples it is possible to exclude schistose metamorphic or volcanic hinterlands as potential source areas.

Carboniferous megaspores have been reported from the Ravenscar Group sediments (Harris, 1958, 1961). Harris thought that an unspecified proportion of these spores were present due to recent sample contamination but Windle (1979), in a general review of Carboniferous palaeobotanical debris within the Jurassic, suggests that they included genuinely reworked examples. Smithson (1942) reported the presence of apatite in the Ravenscar Group and suggested a Triassic sedimentary source for this unstable detrital mineral. However no quartz grains with syntaxial overgrowths preserving haematite rims were recorded from any of the thin sections analysed, which may refute major clastic derivation from Devonian or Triassic sources.

From the above discussion a reworking of Carboniferous sediments would appear to be the most likely source for the Jurassic clastics in the Ravenscar Group. The only problems with this conclusion arise when one considers the abundance of feldspar (max 11%) in some samples and the amount of mica in the opalinum Dogger formation at Blea Wyke. In the Pennine Carboniferous province only the Namurian sandstones contain sufficient feldspar to be likely sources of the Ravenscar Group clastic material. Stevenson and Gaunt (1971) report a mean feldspar-content of 14% for the Namurian sandstones of Derbyshire. From a consideration of the overall petrography of the Millstone Grit Gilligan (1920) concluded that a likely Namurian source area would be granitoid gneisses associated with Caledonian rocks to the north east of Yorkshire. Much of the feldspar in the Ravenscar Group is remarkably fresh, perhaps too fresh to have undergone two cycles of weathering, deposition and diagenesis. The mica in the opalinum Dogger Formation of Blea Wyke constitutes up to 10% of some samples, and it is also unlikely to have been derived from the simple reworking of a sedimentary hinterland. The feldspar and mica may indicate a source area that included older gneissic material at outcrop as well as more abundant, dominantly Carboniferous, sediments.

In the past numerous authors have speculated on the possible hinterlands of the Ravenscar Group. Kendall and Wroot (1924) suggested a land to the north of Scotland, whilst Arkell (1933) indicated a Fenno-Scandinavian source. Smithson (1942) favoured a north westerly source but both Black (1934) and Bate (1965) preferred a derivation from the north east. The recent disclosures on the tectonic evolution of the North Sea region have brought to prominence the Mid-North Sea High as a possible hinterland (Sellwood and Hallam, 1974). Such a source area was favoured by Nami (1976) for the Scalby Formation detritus. Unfortunately Kent (1975a) finds little evidence for the existence of thick Carboniferous sediments in the southern Mid-North Sea High area, but this may be because it was reworked into Jurassic sediments. Considering the tectonic evolution and the regional Mesozoic geology in the North Sea region a northern Mid-North Sea High area with exposed Carboniferous sediments and subordinate Caledonian outcrops would be a likely hinterland for the Ravenscar Group as a whole.

The general palaeogeographic setting of the Ravenscar Group is summarised in Fig. 7.3. A local coastal plain system depositing clastic sediment occurred on the southern edge of the Mid-North Sea High, infilling a small basin developed by subsidence in the underlying basement and sediments. Marginal to the delta system shallow water lagoonal carbonates were deposited in Lincolnshire and one period of transgression brought these sediments into the Yorkshire Basin. To the southwest clear water carbonates with reef debris were deposited adjacent to a lowland area, the London-Brabant Massif. There

FIG. 7.3

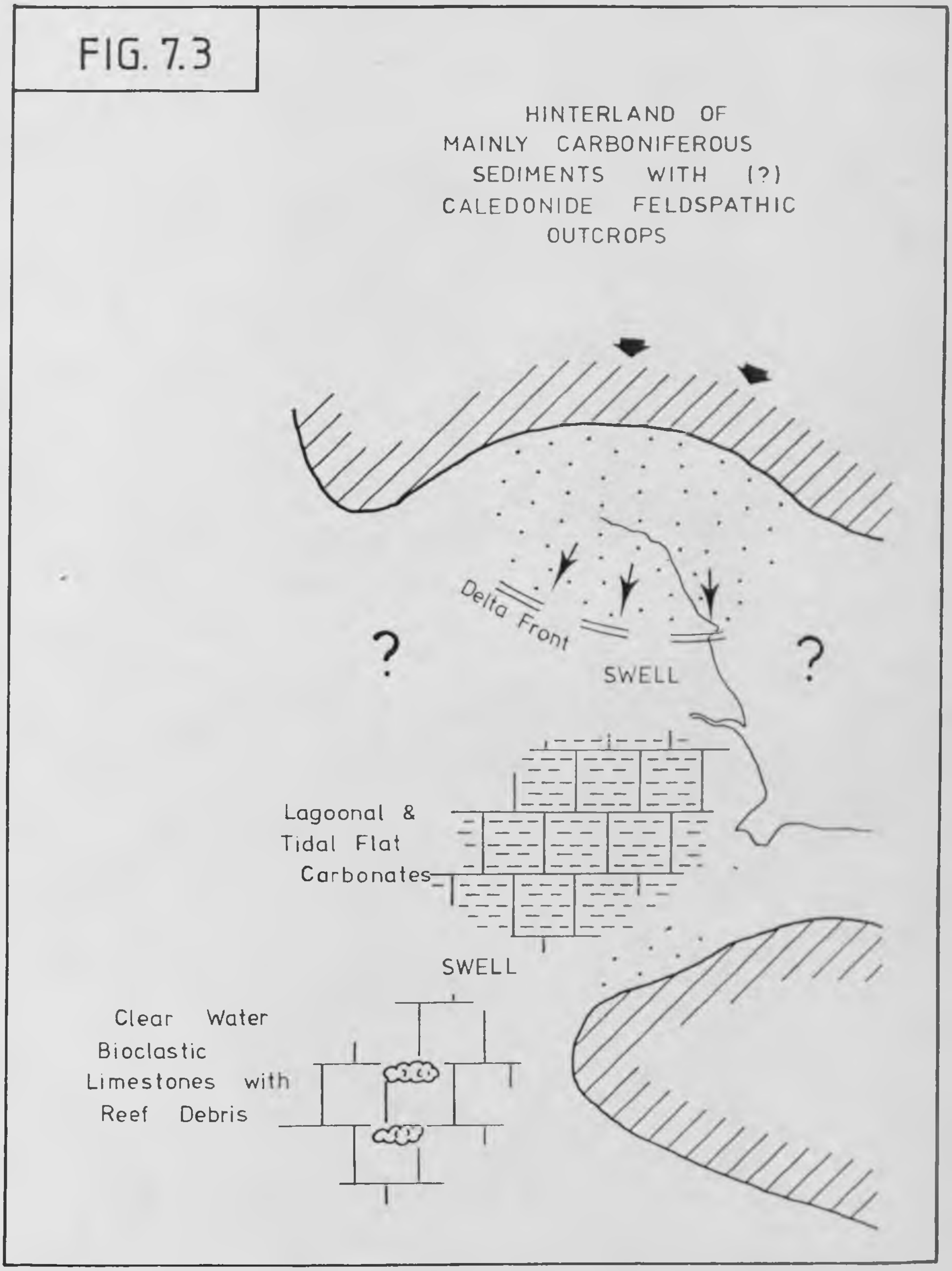


Fig. 7.3 Generalised palaeogeographic map of England during the Bajocian period.

is little evidence for the existence of a Pennine landmass to the west of Yorkshire, but the old Askrigg Block may have been stable with minor subsidence or sedimentation occurring in this vicinity.

7.4. General Thesis Conclusions

This thesis is the result of a general sedimentological study of part of the Ravenscar Group in the Yorkshire Jurassic basin. The sequence under consideration spans the upper part of the Dogger Formation to the basal member of the Scarborough Formation and is predominantly Bajocian in age. The sediments consist of interbedded marine and non-marine clastic deposits, with one wedge shaped carbonate bearing horizon occurring in the Lebberston Member.

Within the section studied three marine coarsening-upward sequences are identified, resulting from periods of sudden transgression followed by gradual shoreline progradation under wave and tidal influences. All three sequences differ in detail and formed under varied depositional conditions. The Lebberston Member carbonate bearing horizons (the Millepore Bed, the Whitwell Oolite and the Upper Limestone) formed from a gradual transgression which reworked underlying sediments. As sea level stabilised ooids formed at the top of the Millepore Bed in an offshore tidal sand belt adjacent to a low wave energy coastline. Early cementation in both beach and submarine environments is recognised and the horizon has many similarities with the Recent Bahaman sedimentary cycle. Evidence from the marine strata as a whole suggest overall micro- to mesotidal conditions with varied low to high energy waves reworking the coastal sediments.

The majority of the sediments represent fluvial dominated coastal plain environments showing a wide variety of overbank and channel deposits. The Saltwick Formation and coastal exposures of the Gristhorpe

Member show marked vertical variation in facies type indicative of coastal plain abandonment by rivers carrying coarse sediment. Overall facies distributions within the Ravenscar Group suggest that the original sedimentary system in operation during the period extended well beyond the present day outcrop and this is reflected in the depositional palaeogeographies.

The only coastal plain margins occur in the Lebberston Member - Gristhorpe Member transition, reprsented by the Yons Nab Beds. In this horizon rapid progradation of a wave-tide-fluvial influenced delta front is recognised, similar to the modern Niger or Burdekin river outlets. This delta model can only be applied tentatively to the other non-marine horizons due to the poor overall exposure of these sediments.

The diagenesis of the sequence is broadly comparable with like deposits of the same age in the North Sea oilfield basins, with ubiquitous kaolinitisation and a restriction of calcite cementation to the marine horizons. Illite and mixed layer illite/smectite have also been recognised as cements and there is evidence of varied quartz redistribution under pressure solution. The mudrocks consist mainly of Illite, but kaolinite is abundant in organic rich sediments. There is little variation in the clay mineral suites of the marine and non-marine shales and mudstones.

Palaeocurrent and petrographic considerations indicate a hinterland to the north of the outcrop area in Yorkshire, with detritus sourcing from weathered (mostly Carboniferous) sediments. Petrographic and palaeocurrent uniformity throughout the Ravenscar Group suggest that the non-marine horizons represent repeated periods of progradation of the same sedimentary system. The mixed sequences of interbedded marine and non-marine horizons probably resulted from tectonic instability in the North Sea region as a whole, associated with Mesosoic plate movements. Biostratigraphic evidence indicates that the Dogger Formation to Scarborough Formation sequence spans approximately five million years of coastal plain and shallow marine sedimentation. More detailed discussions can be found at the end of each chapter.

APPENDICES

APPENDIX 1

SUMMARY OF PALAEOCURRENT ANALYSIS

DOGGER FORMATION

Locality	Grid Ref.	No. Obs.	Vector Mean	% Length
Guisborough Wood	631147	20	183 (60, 240)	11.4 (58.6)
Rosedale Head	692006	32	159 (69, 249)	3.10^{-9} (84.0)
Cleugh Gill	663033	26	70 (21, 201)	7.4 (51.4)
Cribdale Gate	593111	14	351 (100, 280)	5.4 (70.1)
High House, Upper	693975	8	172 (81, 261)	$3.1.10^{-9}$ (83.5)
Lower	"	22	20 (140, 320)	3.2 (51.9)
Keysbeck	662948	15	185 (43, 223)	6.9 (72)
Underhill	684943	6	132 (46, 226)	$1.4.10^{-9}$ (83.5)
Ankness	629941	16	226 (131, 311)	$2.9.10^{-9}$ (87)
Scotland Farm	530938	22	102 (28, 208)	2.10^{-9} (91)
Snilesworth	513958	22	143 (47, 227)	$7.9.10^{-9}$ (88.5)
Arnsgill	525957	18	146 (67, 247)	$2.9.10^{-9}$ (85.2)
Blea Wyke	989014	10	61 (23, 203)	42.9 (57.3)
Rosedale East	702995	21	$2.49.\ 10^{-1}$	70.3
Yew Grain	717018	19	356.9	77.8
Finkel House	747057	12	69.5	23.5
Combined		221	125 (56, 236)	$9.9.10^{-1}$(36.5)

All readings except Blea Wyke-Finkel House are small scale wave-generated cross-stratification.

SALTWICK FORMATION

East Cliff Whitby	905114	10	164	84.7
Boulby	750197	25	216	79.6
Loftus	740199	16	234	74.4
N. Sandsend	855138	10	247	80.9
Sandsend	858138	18	204	91.7
Runswick	811164	10	263	81.3
N. Overdale	854145	6	190	95.1
Blea Wyke	992014	16	148	87.6
Beast Cliff	012995	64	241	89.9
Hawsker	945082	10	118	95.3
Trennet Bank	550984	19	218	88.1
Petard Point	005988	20	211	79.5
Hayburn Wyke	010970	17	129	72.9
"	"	31	189	93.5
Combined		272	209	68.4

All readings taken from large and medium scale trough cross-stratification.

ELLER BECK FORMATION

Locality	Grid Ref.	No. Obs.	Vector Mean	% Length
Lingrow Howe	805172	16	118 (37, 217)	0 (93.4)
Whitby	902115	40	298 (76, 256)	2 (60)
Blea Wyke	993012	30	269 (106, 286)	11.8 (60.6)
Cornelian Bay	064857	70	169 (88, 268)	0 (87.5)
Iron Scar	016967	70	152 (74, 254)	3.4 (80.6)

All readings taken from wave-generated small scale cross-stratification.

CLOUGHTON FORMATION

GRISTHORPE MEMBER

Stonegate Gill	776085	9	194	91.9
Hawsker	932092	15	229	87.6
Cloughton Wyke	022950	31	175	94.0
Yons Nab	084846	21	252	83.8
"	"	33	261	98.3
Black Brow	860060	29	173	80.8
"	"	13	151	75.0
Northdale Beck	723995	12	109	93.6

SYCARHAM MEMBER

Whitby, East Cliff	905114	9	200	87.7
Iron Scar	016967	14	254	94.2
Roger Trod, South	020958	13	201	94.2
Roger Trod	019960	8	127	93.0
Ravenscar	983020	23	182	73.9
Common Cliff	993011	8	331	96.8
Combined Cloughton Formation		253	194	53.2

All readings taken from large and medium scale cross-stratification.

BLEA WYKE MEMBER of the SCARBOROUGH FORMATION

Ravenscar, Upper	992008	24	175 (93, 273)	0 (86.0)
Ravenscar, Lower	992009	57	277 (148, 328)	1.3 (50.4)
Bloody Beck	946980	14	166 (84, 264)	0 (93.2)
Cloughton Wyke	020950	17	211 (100, 280)	6.8 (74)
"	021950	27	17 (89, 269)	6.8 (75)
Yons Nab	084846	48	224 (84, 264)	23.9 (59.1)
Combined		187	230 (98, 278)	61 (44.8)

All readings taken from small scale wave-generated cross-stratification, except those at Yons Nab which were medium scale trough and planar cross-sets.

LEBBERSTON MEMBER

Locality	Grid Ref.	No. Obs.	Vector Mean	% Length
South-west				
Upper Limestone				
Crambeck	738674	24	55	42.7
Whitwell Oolite				
Westow Low Grange	767648	26	327 (178, 358)	8.9 (47.5)
Mount Pleasant	734670	16	280	-
Crambeck	738674	18	22 (85, 265)	27.1(49.0)
Westow	754651	26	38	43.9
Coast				
Yons Nab	084846	25	165 (59, 239)	5.7 (40.9)
"	"	12	187 (87, 267)	5.2 (93.9)
Winter Gill	757014	36	52 (46, 226)	5.5 (67.0)
Osgodby Point	069850	16	72	94.8
Northdale Beck	716000	15	286 (54, 234)	6.7 (82.7)
Yons Nab	084846	31	4 (11, 191)	27 (71)

All readings taken from medium scale cross-stratification except Winter Gill, Northdale Beck and the rose with 12 readings at Yons Nab which were taken from small scale wave-generated cross-stratification.

Figures in brackets under 'Vector Mean' and '% Length' are re-calculated assuming that the distributions are bipolar.

APPENDIX II

The locations sampled for the grain size analysis presented in Tables 6.2a, b.

Sample No.	Location	Stratigraphic horizon	Facies
1	Yons Nab	Millepore Bed	2b
2	Yons Nab	Millepore Bed	2b
3	Common Cliff	Millepore Bed	2a
4	Petard Point	Millepore Bed	2a
18	I.G.S. Brown Moor	Lebberston Member	2b
29	I.G.S. Brown Moor	Lebberston Member	2b
30	I.G.S. Brown Moor	Lebberston Member	2b
31	Crambeck	Lebberston Member	2b
32	Crambeck	Lebberston Member	2b
5	Petard Point	Yons Nab Beds	3b
6	Cloughton Wyke	Yons Nab Beds	3b
15	I.G.S. Brown Moor	Cloughton Formation	5ii
16	I.G.S. Brown Moor	Cloughton Formation	5ii
19	I.G.S. Brown Moor	Cloughton Formation	5ii
20	Beast Cliff	Saltwick Formation	4
22	Common Cliff	Saltwick Formation	4
23	Hawsker	Saltwick Formation	4
24	Whitby, West Cliff	Saltwick Formation	4
25	Peak Alum Quarries	Saltwick Formation	4
26	Petard Point	Saltwick Formation	4
28	Hayburn Wyke	Saltwick Formation	4
7	Cloughton Wyke	Gristhorpe Member	4
8	Cloughton Wyke	Gristhorpe Member	4
9	Yons Nab	Gristhorpe Member	4
10	Yons Nab	Gristhorpe Member	4
12	Yons Nab	Sycarham Member	4
14	Osgodby Point	Gristhorpe Member	4
17	Osgodby Point	Gristhorpe Member	4
34	Kilton Beck	Hawsker Member	4
35	Kilton Beck	Hawsker Member	4
36	Kilton Beck	Hawsker Member	4
37	Kilton Beck	Hawsker Member	4
11	Whitby, East Cliff	Hawsker Member	4
13	Yons Nab	Sycarham Member	4
21	Iron Scar	Sycarham Member	4
27	Hawsker	Hawsker Member	4

All the above samples were sieved.

Sample No.	Location	Stratigraphic horizon	Facies
58	Common Cliff	Millepore Bed	2b
57	Cloughton Wyke	Yons Nab Beds	3b
50	Cloughton Wyke	Lower Scarborough Fn.	1
51	Cloughton Wyke	Lower Scarborough Fn.	1
52	Darnholme	Sycarham Member	5ii
53	Common Cliff	Gristhorpe Member	5ii
54	Cloughton Wyke	Gristhorpe Member	5ii
56	Cloughton Wyke	Gristhorpe Member	5ii
100	Hawsker	Saltwick Formation	4
55	Widdy Head	Hawsker Member	4
59	Yons Nab	Gristhorpe Member	4
60	Whitby, East Cliff	Hawsker Member	4

All the above samples were analysed using a calibrated microscope stage.

APPENDIX III

SIEVE SAMPLE PREPARATION AND TECHNIQUES FOR GRAIN SIZE ANALYSIS

Thirty-seven loosely consolidated sandstone samples were friable enough to be disaggregated and sieved for the grain size analysis discussed in Section 6.1. Thin section techniques were used for the well cemented samples. The friable sandstones were disaggregated using the methods described below.

The sample was broken into 2-3 cm. pieces using a hammer. These pieces were placed in a weak hydrogen peroxide solution which, upon boiling, disaggregated most of the very weakly consolidated samples. The samples were then gently washed over filter paper and allowed to dry on a heated tray. In several cases this treatment produced almost complete disaggregation.

The partly prepared samples were then transfered to a large pestle and mortar for complete disaggregation. The sandstones were protected from direct impact by thick rubber sheets. A period of gentle pounding with the pestle produced complete disaggregation. The sample was repeatedly checked to ensure that individual quartz grains were not being split during this period of sample preparation. The checking was achieved using a binocular microscope which was also used to ensure that no grain aggregates remained after this period of disaggregation. If any aggregates were found the whole sample was returned to the pestle and mortar for further treatment until none remained.

All the completely disaggregated samples were then placed through a set of standard sieves (B.S. 10-300) in an automatic shaker. A standard period of 15 minutes in the shaker was used. Between 50 and 80 grams of sandstone were analysed. Table 6.2a is a presentation of the results .

APPENDIX IV

PREPARATION OF CLAY MINERALS FOR X.R.D. IDENTIFICATION

All the sandstone and mudstone samples subjected to the X.R.D. analysis were treated in the same way to avoid variable bias in preparation. The following procedure was used in an attempt to segregate the $< 2\mu$ matrix and diagenetic clay-sized material.

1.- The samples were carefully washed in distilled water in an ultrasonic bath. This was especially important to clean off the drilling mud from the I.G.S. Brown Moor samples.

2.- Fifty to 100 grams of each sample was disaggregated in distilled water. Some of the mudstones required treatment in a jaw crusher before complete disaggregation was possible.

3.- The sample was then wet sieved through a 300 mesh and the residue dried and weighed.

4.- All the material that remained in suspension after sieving was of silt grade or finer. A few drops of ammonium hyroxide were added to the suspension to act as a dispersing and deflocculating agent.

5.- The suspension was thoroughly stirred and transferred to a slim measuring cylinder. By allowing a period of 5 minutes for each 10 cm. of suspension the coarse silt was able to settle out (according to Stoke's law of gravity sedimentation).

6.-The fine silt and clay that remained in suspension was then transferred to a centrifuge tube . After a period of three minutes at 750 rpm the silt was brought out of suspension. The remaining clay sized material was then syphoned off.

7.- The clay suspension was then pipetted onto prepared glass slides and allowed to dry at room temperature. This gradual drying produced suitably orientated mounts of clay minerals representative of the original sample.

8.- The orientated mounts were analysed in the Dept. of Ceramics at Leeds University. A Phillips diffractometer was used under fixed operating conditions to allow simple sample comparisons. Cu $k\alpha$ radiation (Ni filtered) at 24 mA., 30 k.v. was employed with a range of 10^3 x 4 and a time constant of 1.

9.- After a preliminary survey all the samples were subjected to ethanediol (glycolation) and heat treatments (300° C, 550° C), using fresh mounts taken from stage 7. Every analysis used the operating conditions outlined in stage 8. The treatments followed the suggestions of Carroll (1970).

APPENDIX V

FIELD LOCALITY DETAILS

murchisonae Dogger Formation (see Fig. 2.19)

Coastal sections :-
Blea Wyke (989014) to Whitby (905114) show only opalinum age sediments below the Saltwick Formation
North of Whitby murchisonae age deposits were recorded at
North of Sandsend (858138) in an old alum quarry
Deepgrove (856138) pebbly sediments of unknown age
Kettleness (832158) mostly removed by a Saltwick Formation channel
Runswick Bay (823155) full but dangerous section half way down the cliff (previously unrecorded)
Port Mulgrave (797177) overgrown but reasonable section
Boulby (750197) exposure of black shales below the Saltwick Formation (previously unrecorded)
Loftus (740199) Black's (1934) section well exposed

Inland sections:-
Guisborough Wood (631147) at the top of an old alum quarry - thick black shales
Ayton Moor (592123) stream section, with good cut bank of black shales grading into wavy sandstones
Cribdale Gate (593111) complete section in stream, good fossil locality in basal ironstones
Eskdale :- mostly older Dogger Formation sediments except
Glaisdale Head (741016) Ajalon sandy oolites over older Dogger
Hollins Wood (822015) Ajalon oolites.
Great Fryupdale :- now mostly slipped or overgrown except
Finkel House (747057) difficult exposure to work on - overgrown
Woodhead Scar (dale head) (721022) well exposed
Yew Grain (717018) complete accessible exposure
Slidney Piece (710033) incomplete exposure, heavily weathered
Westerdale and Danby Dale :- now slipped or cut out by Saltwick Formation but one good exposure at Cleugh Gill (663033) remains
Baysdale :- one good exposure at Black Beck (613056)
Rosedale :- in the northern part exposures are good but south of Rosedale Abbey are now non-existant.
Rosedale Head (692006) full exposure of coarsening upward sequence
High House (693975) excellent exposure
Northdale Beck (725995) exposure partly removed by channelling
Rosedale east (705984 -693003) uppermost sandy exposures only
Farndale :- very few exposures remain
Blakey Mines (680978) upper parts only
Keysbeck (662948) complete exposure in small gill
Dale Heads mostly unexposed, some sections show only Saltwick Formation channel sands
Bransdale :- only the exposure at Ankness (629941) remains, in the northern parts of the dale the Dogger Formation has been removed by channelling
Western escarpment and Bilsdale :-
Greenhow Moor to Carlton Bank (603020 - 499028) completely or partially removed by later channels
Osmotherly (463963) complete section in an old alum quarry
Scugdale (527988) part exposure including murchisonae age limestones

Fangdale Beck (563946) part exposure cut out by channel sandstone
Snilesworth and Ryedale :-
Snilesworth (514960) complete exposure, some scrappy exposures on the eastern side of the beck
Scotland Farm (530938) complete exposure including basal black hydrocarbon impregnated oolite

The good exposures are logged in Fig. 2.20

Saltwick Formation (see Fig. 4.23)

Coastal sections:-
Ravenscar to Iron Scar (983020 - 016967) :-
Ravenscar to Blea Wyke (993012) inaccessible or sandstone exposures only
Blea Wyke to Beast Cliff (012995) includes several accessible exposures at the top of the formation with numerous channel sandstones at the cliff base. North of Rocky Point (998005) overbank exposure is poor but just to the south (Fig. 4.23F) the section is loggable.
Beast Cliff to Iron Scar :-
Hayburn Wyke (010970) to Iron Scar shows good exposures of the top of the Saltwick Formation (Fig. 4.23G). 300m north of Hayburn Wyke there is excellent exposures of Facies 5 sediments including <u>Equisitites</u> horizons. From here to Beast Cliff the exposures are mostly inaccessible
Whitby (905114) to Robin Hoods Bay (sq. 9506) :-
The base of the Saltwick Formation is well exposed from Whitby to Saltwick Bay (917107) and includes the section in Fig. 4.23C. The Hawsker sections (c. 934090) include one complete log (Fig. 4.23E), but are in the main inaccessible. Max. 32m of Saltwick Formation exposed.
Sandsend to Loftus (858138 - 740199) :-
Overdale (854145) to Sandsend show a number of old alum quarries with channel sandstone at the back wall (including Deepgrove 854142). At Overdale the base of the formation is exposed (Fig. 4.23B). The top of the formation is exposed at Lingrow (Fig. 4.23A, 808170). Boulby (750197) and Loftus are old alum quarries with very extensive exposures of Facies 4iii sandstones near the base of the Saltwick Formation.

Inland sections :-
Exposure of Facies 5 overbank sediment is very poor inland, and only isolated outcrops of channel sandstone occur

The Eller Beck Formation (see Figs. 2.12, 2.13)

Coastal sections :-
Cornelian Bay (064856) complete exposure on the seaward side of a major fault. Previously unrecorded and of importance in Facies 1b palaeogeographies. Fig. 2.13
Iron Scar (016967). Complete type locality
Blea Wyke (993012). Complete exposure
Whitby East Cliff (902115). Complete readily accessible exposure
Lingrow (805172).
Kilton Beck (706177).

Inland sections :-
Great Fryupdale (713024) - see Fig.2.18. Carlton Bank (499028) Fig. 2.13, incomplete exposure.

The Sycarham Member (Fig. 4.25)

This horizon is very poorly exposed and where it dips into the sea at Rodger Trod (019962) the section is obscured by a large cliff failure. Sections occur north of Cloughton Wyke (021955) (the top of the Member) and at Hawsker (945082) (the base of the member). Sandstone dominated exposures occur at Ravenscar (983020), Common Cliff(993011), Yons Nab (085844) and Whitby (905114). Inland sections are restricted to stratigraphically undefined exposures at Darnholme (835022).

The Lebberston Member (Fig. 3.1)

The Millepore Bed :-
Northdale Beck (716000) - small sandstoneexposure
Winter Gill (757014) - as above
Ravenscar (980019), Common Cliff (993011), Petard Point (005988) and Cloughton Wyke (020950) are coastal exposures of Facies 2a. Osgodby Point (065855) and Yons Nab (085844) are coastal exposures of Facies 2b. The latter is extensive (see Fig. 3.7).

Southwestern exposures :-
Crambeck (SE738674) - old quarry exposure, the best example of this horizon remaining (see Fig. 3.11).
Westow Low Grange (SE767648) - old quarry exposure of the Whitwell Oolite, c. 4m remaining.
Westow (SE754651) - the best remaining exposure of the Whitwell Oolite.
Mount Pleasant (SE734670) - the top of the Whitwell Oolite

The Yons Nab Beds :-
Petard Point (005988) and Cloughton Wyke (020950) - Facies 3b
S. Petard Point (006987) and Rodger Trod (019962) - Facies 3c
Osgodby Point (065855) and Cloughton Wyke - Facies 3d
Yons Nab (085844) - Facies 3a
Apart from the above exposures non of the cliff sections are accessible and there are no inland outcrops of this horizon except ? :-
Oulston (SE549738), Fig. 3.24.

The Gristhorpe Member (Fig. 4.26)

The only complete accessible exposures on the coast are at Yons Nab (085844) and Cloughton Wyke (020950), Fig. 4.26. At Blea Wyke - Ravenscar (993012) the central part of the member is exposed. The sections at Hawsker (c.945082) are largely inaccessible, but one clifftop quarry (932092) is available. Inland there is one complete section at Goathland - Darnholme (along the railway) (833022), Fig.4.26C. An incomplete combined quarry and beck section remains at Commondale (660110), Fig. 4.26D.
Channel sandstone exposures occur at Stonegate Gill (776085), Black Brow (860060), Northdale Beck (723995) and Kilton Beck (702173). Inland exposures are sparse, because the Cleveland Dome elevates the Cloughton Formation to outcrop at the top of the Moors.

The Blea Wyke Member of the Scarborough Formation (Facies la)

The best exposures of this horizon are on the coast :-
Yons Nab (085844), at the base of the cliff and in reefs, Fig. 2.2
Cloughton Wyke (020950), on the southern side of the bay, the best exposure of the facies, Fig. 2.2 and 2.12.
Blea Wyke (989014) and Common Cliff (992010) show continuous exposure of the unit, Fig. 2.2.
Hawsker (937080), in a stream section, Fig. 2.2
Moorgate Laithes (near Whitby) (907100) a much thinned sequence, Fig. 2.2.
Inland exposures are poor but include an almost complete section at Bloody Beck (947981). Other exposures include Darnholme (835022), Collier Gill (797998) (Fig. 2.2) and Wheeldale (793987).

The grid references are unambiguous within the outcrop area shown in Fig. 1.1 and include the National Grid Reference Grid letters NZ, SE and TA.

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