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THE STRATIGRAPHY AND SEDIMENTOLOGY OF THE SKIPTON MOOR GRITS (NAMURIAN E_{1C}) AND THEIR LATERAL EQUIVALENTS.

John G. Baines

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ABSTRACT

The Skipton Moor Grits (E_{1C} Namurian) are the first major clastic influx into the northern part of the Central Pennine Basin and form the lowest group of the Millstone Grit. The Central Pennine Basin is bounded to the north by the Askrigg Block. During the Hercynian orogeny the Millstone Grit in the northern part of the basin was compressed against the Askrigg Block, forming the northeast - southwest trending Ribblesdale Fold belt.

A prograding deltaic sequence is recognised and divided into three facies associations: the Turbidite Association, the Slope Association and the Delta Top Association. These three associations correspond to the Pendle Grits, Pendle Shales and Grassington Grits, herein defined respectively. A review of their possible lateral equivalents is made and the tripartite division is recognised throughout the basinal development of the E_{1C} succession.

Where present, the base of the Low E_{2a} Marine Band defines the top of the E_{1C} succession. Within the basin, recognition of this marine band is problematic. The Low E_{2a} Marine Band is present on the Askrigg Block but is thought to be absent in the basin owing to erosion at the base of the Bradley Flags. It is suggested that the contrasting nature of the fine grained Bradley Flags and the coarse grained Skipton Moor Grits is due to separate phases of deposition.

The Turbidite Association, up to 290m thick, is characterised by frequent intercalations of dark mudstone, thin turbidites and thick composite sandstones cut by lenticular bodies of coarse grained "ropy-weathering" sandstone. The whole association is interpreted as a turbidite fan complex and the lenticular sandstones are regarded as feeder channels which supplied the fans.

The Slope Association, up to 340m thick, is dominated by a coarsening-up sequence of dark grey siltstones and fine sandstones. These too are cut by feeder channels filled with coarse "massive-weathering" sandstones.

The Delta Top Association is areally the most extensive of the three associations and is found on the Askrigg Block as well as in the basin. In the basin, it attains a maximum thickness of 200m and is dominated by channel bound, coarse grained fluviatile facies. Medium scale cross-beds, occupying low-sinuosity channels, are found on both the block and basin, whereas large scale cross-beds, with an average thickness of 15m have a more restricted development in channels of the basin only. The widespread development of the Bradley Coal marks the abandonment phase of the delta.

Twenty five ichnogenera are described from the Skipton Moor Grits and these are used in the palaeoenvironmental and bathymetric reconstruction. Lophoctenium, Rhizocorallium and Curvolithus indicate that the Turbidite and lower Slope Associations belong to the relatively deep water Zoophycus facies of Seilacher, whilst Monocraterion and Pelecypodichnus indicate that the top of the Slope Association is in the shallow water Skolithus facies.

The E_{1C} clastic influx is thus interpreted as a turbidite-fronted, river dominated, high-constructive delta developed in a restricted basin. Palaeocurrent determinations show that both the currents and slope were directed to the south. The delta attains its thickest development of 750m in the Skipton area and thins northwards to the North Craven Faults, the basin margin.

ACKNOWLEDGEMENTS

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LIST OF CONTENTS

CHAPTER 4. FACIES ASSOCIATIONS

TEXT FIGURES PAGE

PAGE

PAGE

PAGE

TABLES

CHAPTER 1

1.1 INTRODUCTION

This study is part of an investigation of the Upper Carboniferous rocks of the northern part of the Central Pennine Basin, England. It concerns the lowermost clastic division of the Namurian, the so-called E_{1C} Skipton Moor Grits and their lateral equivalents.

The purpose of the investigation was to elucidate the depositional environment of the E_{1C} formations by means of a detailed analysis of regional stratigraphy, sedimentology and Ichnology.

It was the author's deliberate intention to survey and map as wide an area as possible. It was hoped that by doing so, a broad regional pattern of sequential events would emerge. Previous research on this part of the sequence normally concentrated on small localized areas, usually with a stratigraphic bias only. These researches have been reviewed and incorporated into a broad scheme of events. However, two limitations are imposed. First, in covering such a wide area, several localities could be visited on a reconnaissance basis only. Secondly, lack of exposure and/or lack of geological control meant difficulty in recognising some of the finer detailed stratigraphy. These two reasons therefore caution a total acceptance of the results discussed. It is hoped, however, that the thesis will stimulate a closer examination of these areas with a consequent refinement of the regional analysis.

1.2 PREVIOUS RESEARCH

The earliest work of any importance in the area is the "classic" account, "Illustrations of the Geology of Yorkshire: Part II, The Mountain Limestone" by John Phillips (1836). In it, he outlined the broad rock succession around Skipton and recognised the division between the Carboniferous Limestone and the Millstone Grit. In the late nineteenth century, the Geological Survey systematically mapped the area. Notable work was done by Dakyns, Dalton, Fox-Strangeways, Gunn, Lucas and Tiddeman. (Dakyns et al 1879 and 1892).

The Geological Survey assumed a continuity of prominent beds of gritstone from Yorkshire to Derbyshire, but this led to a major error in regional correlation. They correlated the lower "basement" grit (Skipton Moor Grit) of the Skipton area with the Kinderscout Grit of North Derbyshire. Dakyn's (1889) one-inch Geological Survey map, sheet 92 N.E. (Old Series) shows that these lower grits are designated by the letter K (= Kinderscout Grit). Other Old Series Geological Survey maps have an alternative terminology, still based on the erroneous correlation whereby the grits are termed "First" to "Fourth". The Skipton Moor Grits were termed the "Fourth Grit".

In an outstanding piece of work, Bisat (1924) established a zonal classification based on goniatites and with it he showed that the Skipton Moor Grits were considerably older than the Kinderscout Grit. Numerous refinements and modifications have been made to this work, most notably by Bisat (1928), Hudson and Cotton (1943), Hudson (1945) and Stephens et al (1942). The latter work classed Bisat's sub-divided genus-zones (Bisat 1928) as "stages" and equated them with lithological units. For example, stage E_1 (Lower Eumorphoceras) included the Skipton Moor Grits and the Upper Bowland Shales. This scheme, with minor modifications, was adopted by the Geological Survey for the regional memoirs: "Geology of the District North and East of Leeds" (Edwards et al 1950) and "Geology of the Country between Bradford and Skipton" (Stephens et al 1953).

From the early twentieth century, independent researchers, mapping the lower grits, made considerable advances once the stratigraphical framework was established. Publications, with maps and sections were made by the following: Tonks (1925), Nidderdale area; Bray (1927), Lothersdale area; Anderson (1928), Skyreholme Anticline; Hudson and Mitchell (1937), Skipton Anticline; Hudson (1939), Simonseat Anticline; Hudson (1941), Mirkfell area; Jones (1943), Beamsley Anticline; Dunham and Stubblefield (1945), Greenhow area; Moseley (1954), Lancaster Fells; and Earp (1955), Bowland Tunnel.

Chubb and Hudson's work (1925) on the Askrigg Block clarified the relationship of the Millstone Grit to the Yoredale Succession. They demonstrated that the basal Millstone Grit rested unconformably upon successively lower horizons of Yoredale beds in a southerly direction. Mapping to the north west of Askrigg by Rowell and Scanlon (1957) also confirmed this, as did the work of Dunham and Stubblefield (1945) at the southern edge of the Block.

More recently, work continued to be concentrated on the Askrigg Block. For example: Wilson and Thompson (1959, 1965), Wilson (1960) and Thompson (1957). Just to the south of the Askrigg Block, Williamson (1960) remapped part of the Bordley area.

The 1961 Geological Survey Memoir "Geology of the Country around Clitheroe and Nelson" (Earp et al 1961) was a major contribution to knowledge of the succession west of Skipton.

Sedimentological research on the Millstone Grit initially proceeded at a slow pace, and only in the last two decades have major steps been made. Sorby (1859) and Gilligan (1920) were undoubted pioneers. Both were interested in the origin and source of the sedimentary material that constituted the Millstone Grit in the Central Pennine Basin. They concluded from various lines of evidence that the clastic sediments were derived from a "crystalline terrain" lying to the north east. Over 30 years elapsed before Trotter (1951), using Bisat's stratigraphical framework, described the Namurian in terms of sedimentary facies. He suggested that the sediments represented two types of river deposits; one continental and the other estuarine.

Various other authors have contributed to the sedimentological knowledge of the basin. For example, Stephens et al (1953), C. T. Walker (1955), Wright (1964, 1967) and Shackleton (1962), but the major breakthrough in sedimentological thinking in the Central Pennine Basin was with the publication of Allen's (1960) paper on the Mam Tor Sandstones in which he recognised their turbidite origin. This work was put into its full context by Reading (1964 and 1971) when he suggested that the E_{1C} and R_1 sediments were two major pulses of sedimentation with similar styles of accumulation.

The detailed sedimentological make-up of the R_1 sediments is now well known as a result of the work of J. R. L. Allen (1960), R. G. Walker (1965 and 1966), Collinson (1969 and 1970) and McCabe (1975a). However, the regional sedimentology of the Skipton Moor Grits has not previously been documented and the present work attempts to fill this gap in knowledge.

In the end folder (Vol. 2), there are ten enclosures which accompany the text and photographs. Enclosure I details the vertical measured sections through the Skipton Moor Grits.

CHAPTER 2 STRUCTURAL AND STRATIGRAPHIC FRAMEWORK

2.1 STRUCTURAL FRAMEWORK

The Craven Fault Complex is one of the most important structural elements in the north of England. It separates an area to the north (the Askrigg Block), in which the superficial rocks are dominantly horizontal, from an area to the south (the Central Pennine Basin), where the strata are folded into tight anticlines and synclines (the Ribblesdale fold belt). (Figure 1). The Craven Fault Complex also marks an abrupt change in litho- and bio-facies between the Askrigg Block and the Central Pennine Basin.

Disturbances alone the line of the faults took place over a long period of time. Ramsbottom suggests that movements on the North Craven Fault probably pre-date Lower Carboniferous P_{1C} times. He notes that in the Greenhow area, there is a condensation of the Lower Yoredale Limestone into the Coldstones Limestone (Ramsbottom 1974).

In the Malham and Cracoe areas, boulder beds within a short distance of the Mid and North Craven Faults are interpreted as submarine talus deposits, resulting from contemporaneous movements of the faults. These movements are dated as extending from P_{1C} to early E_1 times.

Post Permian movement is indicated by the fact that near Ingleton, a small patch of Permian has been preserved adjacent to the outer South Craven Fault (Thompson 1957).

The Ribblesdale folds (Phillips 1836) are aligned north east - south west. These folds are 'concentric structures' with half wave lengths between 1.6 and 6.4 Km (Moseley 1972) and amplitudes between 300 and 800 metres (Kent 1974). Since the folds involve strata of diverse lithologies, there are often intense disharmonic relationships (Moseley 1972).

The Ribblesdale fold belt is unusual in that it has an apparently anomalous north east - south west trend which contrasts with east-west folds that would normally be expected from a north-south Hercynian compression. Turner (1949) has suggested that this may be due to a relationship with earlier Caledonian trends, whilst Westoll (1967) concluded that they could in fact be

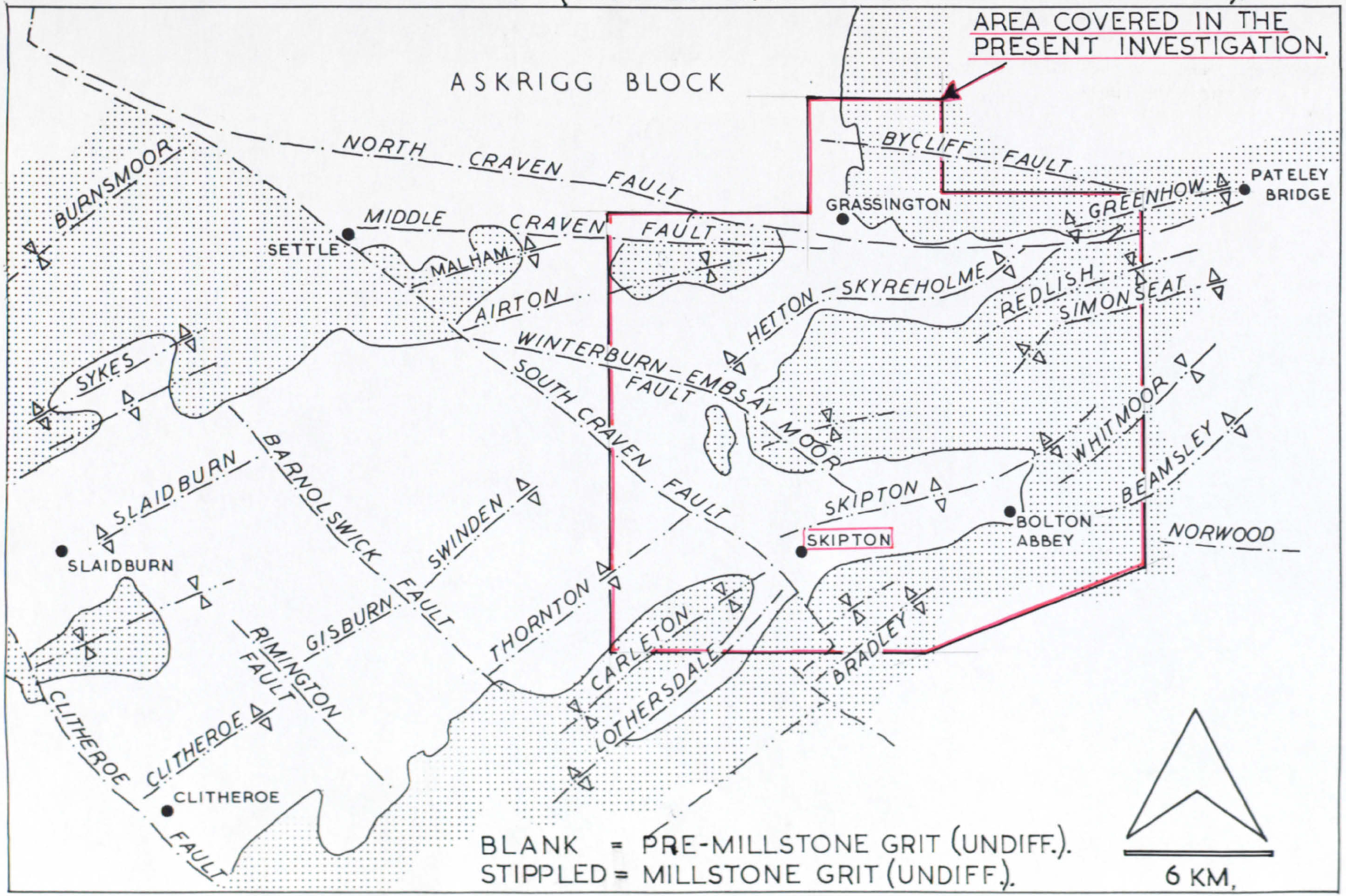


FIGURE 1. SKETCH MAP SHOWING THE MAJOR FAULTS AND FOLDS IN THE SKIPTON AND CLITHEROE AREA. (ADAPTED FROM HUDSON AND MITCHELL 1937).

a variety of 'drag' folds related to dextral movement on the Craven Faults. Moseley (1972) has noted that a north west orientation of the Craven Faults in relation to a regional E - W stress would give sinistral, not dextral, movements. Furthermore, he suggests that Turner's original Caledonide trend concept bears some credence and he demonstrates Variscan joint orientations in relationship to fractures in the underlying Caledonian basement (Moseley & Ahmed 1967). Moseley maintains that any type of north east Caledonide structure at depth, be it fold or cleavage, could give a trend of weakness capable of being propagated upward through the Carboniferous rocks during a period of stress.

2.2 STRATIGRAPHICAL FRAMEWORK

2.2.1 INTRODUCTION

Widespread correlation of the "Millstone Grit" Formations has been made comparatively simple, thanks to the goniatite zonal scheme pioneered by Bisat (1924). Reading (1964 Fig.1) and Ramsbottom (1966 Plate 4), present representative diagrammatic cross sections of the Namurian of the Central Pennine Basin as a whole. At a more local scale however, difficulties and disagreements regarding detailed correlation still exist.

Bisat (1924 and 1928) proposed a series of "genus" zones which were then extensively sub-divided into "species-zones". The genus zones were identified by the initial letter of the eponymous goniatite genus (with the exception of Posidonia, a pelecypod). Thus, in the Visean, the zones include Beryichoceras (B_1 and B_2) and Posidonia (P_1 and P_2), whilst in the Namurian, the zones in ascending order are: Eumorphoceras (E_1 and E_2), Homoceras (H_1 and H_2), Reticuloceras (R_1 and R_2) and lower Gastrioceras (G_1). The Upper Gastrioceras (G_2) zone is Westphalian.

Stephens et al (1942 p. 345) regarded the Namurian species zones as "stages" and these they equated with various allied lithological units (Table 1).

TABLE 1.

Stephens <u>et al</u> 1942			Hudson and Cotton 1943
STAGE	GONIATITE STAGE	GROUP NAME	
G_1	L. Gastrioceras	Rough Rock Group	Yeadonian
R_2	U. Reticuloceras	Middle Grit Group	Marsdenian
R_1	L. Reticuloceras	Kinderscout Grit Group	Kinderscoutian
H	Homoceras	Middleton Grit Group	Sabdenian
E_2	U. Eumorphoceras	Silsden Moor Grit Group	Arnsbergian
E_1	L. Eumorphoceras	Skipton Moor Grit Group	Pendlian

A revision of stage names was proposed by Hudson and Cotton (1943) and Hudson (1945), and as a consequence, the E_1 became known as the Pendlian. Bisat (1928) however, had already termed this stage the Grassingtonian, but Hudson and Cotton mistakenly thought that the E_1 beds were missing at Grassington and therefore thought the term Grassingtonian inappropriate. Since the term Pendlian has now achieved widespread use, Ramsbottom (1971a) thinks that there is little point in reverting to Bisat's original term.

2.2.2 <u>STRATIGRAPHICAL FRAMEWORK</u> (Problems and Solutions)

Until 1962, the palaeontological framework for the Askrigg, Skipton and Pendle areas had seemed reasonably straightforward, very much as envisaged by Ramsbottom (1966 Plate 4). The top of the Skipton Moor Grit Formation was taken at the bases of the supposedly synchronous Cockhill, Edge and Warley Wise Marine Bands. However in 1962, Yates proposed a revision of lateral correlations in the light of evidence suggesting that the Cockhill fauna is significantly older than the Edge-Warley Wise fauna (Yates 1962).

Yates made a comprehensive study of the Namurian marine bands in the Slieve Anierin area of Co. Leitrim and was able to distinguish two distinct faunas within beds referred to as E_{2a}. The lower level was dominated by <u>Cravenoceras</u> <u>cowlingense</u>, whilst the upper level contained <u>E. bisulcatum</u> <u>ferrimontanum</u> and <u>E. bisulcatum</u> <u>erinense</u> faunas.

Yates' findings are simplified and illustrated in Table 2.

TABLE 2.

HIGH E_{2a}	*E. bisulcatum ferrimontanum*)- *E. bisulcatum erinense*) *Chaenocardiola footii*	DOMINANT
LOW E_{2a}	*C. cowlingense* *E. bisulcatum grassingtonense*	DOMINANT RARE

She also examined the faunas in the North of England and concluded that there was a low E_{2a} fauna on the Askrigg Block. For example, the Mirkfell Ironstone (Hudson 1941) contained *C. cowlingense* and *E. bisulcatum grassingtonense* as does the Cockhill Limestone (Dunham & Stubblefield 1945). Within the basin succession, however, the Edge Marine Band contains *E. bisulcatum* *erinense* and *Chaenocardiola footii*, and Yates therefore suggested that the Edge and Warley Wise Marine Bands should be correlated with the High E_{2a} Marine Band of Slieve Anierin (Table 3).

TABLE 3.

EIRE	NORTH OF ENGLAND			
	BLOCK		BASIN	
Slieve Anierin Yates 1962	Mirkfell area Hudson 1941	Greenhow Mining Area Dunham & Stubblefield 1945	Bradford & Skipton Areas Stephens et al 1953	Lancaster Fells Moseley 1954
High E_{2a}	--	--	Edge Marine Band	Brennand Marine Band
Low E_{2a}	Mirkfell Marine Band	Cockhill Marine Band	--	Tarnbrook Wyre Marine Band

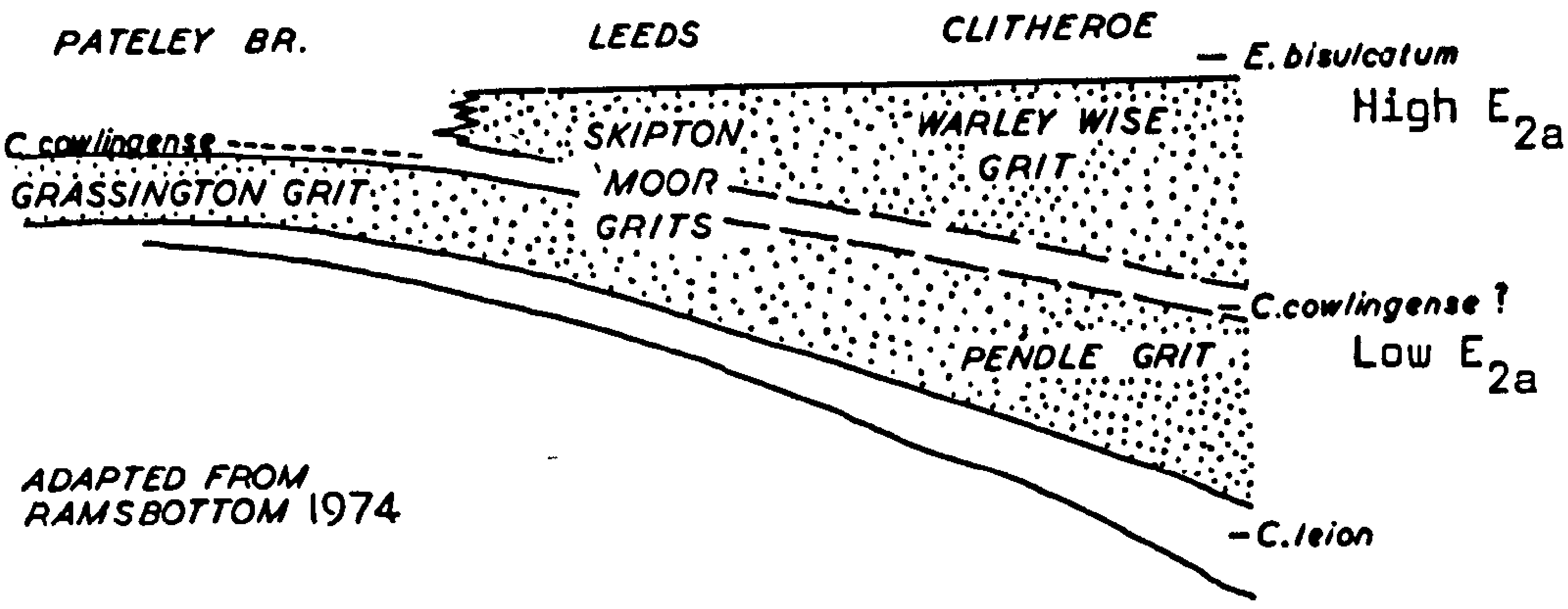
(Partially adapted from Yates 1962.)

From Table 3, it is obvious that the Cockhill Marine Band and the Edge Marine Band cannot be correlated. Where, then, are their respective lateral equivalents? For the basinal Edge Marine Band, a possible block equivalent could be the Herne Beck Limestone (Burgess and Ramsbottom 1970). Finding a basinal equivalent for the Cockhill Marine Band, however, is much more difficult. Ramsbottom (1974) states, "It seems most likely that the *C.*

cowlingense horizon should occur between the Pendle and Warley Wise Grits and somewhere within the Skipton Moor Grits." This idea is illustrated in Figure 2.

Figure 2. Correlation of E_1 Namurian strata in the northern part of the Central Pennine Basin.

(Adapted from Ramsbottom 1974.)



So far, however, the marine band has remained elusive in the area suggested by Ramsbottom, and he admits, "...... only bivalve faunas have been collected at these levels." These, the present author would suggest, are normal delta front inhabitants and, as such, have been reported at numberous levels within the delta front assemblage (Aitkenhead and Jones, in Press, and Wilson, pers.comm.).

Field mapping, by the author, in the Skipton area has failed to reveal the C.cowlingense Marine Band in the basinal area and, significantly, it has not been found or recorded in the Boulsworth Borehole, the Fletcher Bank Borehole or the Bowland Forest Tunnel. It has, however, been reported from the Lancaster Fells, (the Tarnbrook Wyre Marine Band of Moseley 1952, see Yates 1962 for discussion) and immediately above the Almscliff Grit (Hudson 1930, Godwin 1971).

In the area around Skipton and as far south west as Lothersdale, there is no direct evidence of the C. cowlingense fauna below the accepted level of the Edge Marine Band. However, if present, where would be the most likely position? The sedimentological evidence suggests that up to the top of the coarse grits (the Bradley Grits of Stephens et al 1953), the whole of the succession above the Upper Bowland Shales is dominantly a regressive "coarsening-upward" sequence. However, above the Bradley Grits and Bradley Coal, there is a marked lithological change. Sediments between the Bradley Coal and the Edge Marine Band are referred to as the Bradley Flags (Stephens et al 1953). These Bradley Flags are dominantly fine grained and exhibit a range of sedimentary structures not normally seen in the lower coarser facies.

It is suggested that the horizon of the C. cowlingense Marine Band may be at this junction between the Bradley Grits and the Bradley Flags (see Figure 3) rather than at lower levels as suggested by Ramsbottom. It is conceivable that most, if not all of this marine band was eroded during the deposition of the various Bradley Flag facies. According to Ramsbottom (1974), the marine band, where last seen at the edge of the Askrigg Block (i.e. in the Cockhill Adit) is extremely thin and consequently it would need very little erosion to remove it. In areas where the Bradley Flags or their possible lateral equivalents are not developed in the basin, there is preservation of the C. cowlingense fauna, for example, at the top of the Almscliff Grits, at Greenhow (the Cockhill Marine Band) and at Tarnbrook Wyre. Significantly, at this last locality, Moseley (1952 pp 454) notes that the marine band "... has not been found in the Hindburn or Whitendale areas and that it APPEARS TO BE CUT OUT to the east by a thick overlying grit."

There is also the possibility that the marine band may not have been deposited in parts of the basin at all. It may be the case that the transgression phase responsible for the deposition of the marine fauna was so shallow (as already suggested) that it failed to completely inundate the whole delta surface.

In the case of the former suggestion, of particular interest is the discussion by Trewin and Holdsworth (1973 p. 407) in reply to Ramsbottom. They note that if subsidence and supply are comparatively light during the transgression, then only a thin pelitic sediment layer, probably with an impoverished marine fauna would occur. This condensed sequence could rapidly be destroyed by slight reworking during the next regressive phase. "No angular unconformity or discordant erosion surface needed to result, and with marine faunas lacking, disconformity would be largely undetectable" (Trewin and Holdsworth 1973, P. 407).

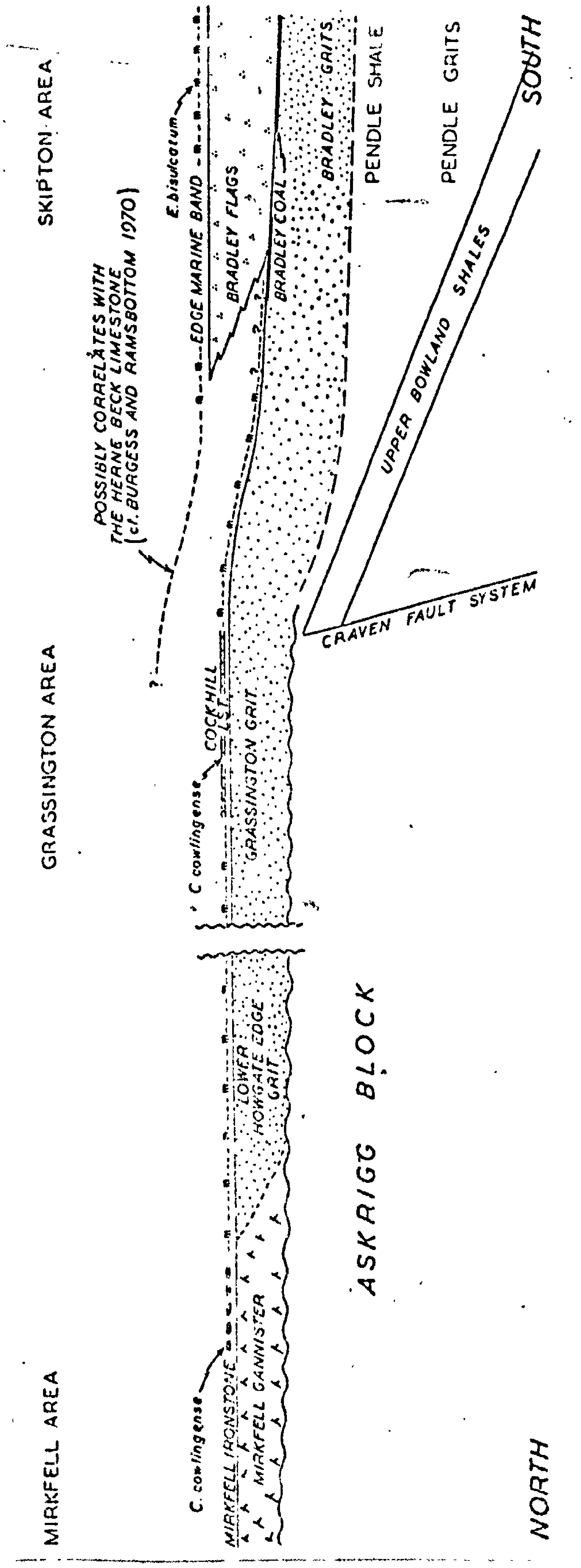


Fig. 3. North-South cross section of the proposed E_{1C} correlation between the Askrigg Block and Central Pennine Basin.

2.3. STRATIGRAPHICAL DETAILS

2.3.1 INTRODUCTION

The succession between the Upper Bowland Shales and the base of the Grassington Grits can be divided into two parts, which are referred to in this thesis as the'PENDLE GRIT FORMATION' and the 'PENDLE SHALE FORMATION'. The field division between the two is rather arbitrary but in general, the lower division has a predominance of coarse composite and lenticular sandstone units whilst the upper part is dominantly argillaceous (Fig.23).

2.3.2 THE PENDLE GRIT FORMATION

The name Pendle Grit was first used by Tiddeman on the one-inch Old Series Geological Survey Sheet No.92 South East, published in 1878. Subsequently, Parkinson (1936) altered the name to Pendle Top Grit so as to distinguish it from the Pendleside Sandstones which occur lower in the succession. Numerous authors, notably Bray (1927), Hudson (1944) and Moseley (1954) used the name Pendle Top Grit, but Earp (1955) reverted to the original usage on the grounds of priority. Since then, all authors have used the name Pendle Grit.

The base of the Pendle Grits is taken at the incoming of the first major arenaceous beds. These have sharp contacts but come in at different topographic levels (Stephens et al 1953 Fig.4) and consequently the position of the mapped base is variable.

To the east of Skipton town, the Pendle Grits form a prominent scarp along the north facing slope of Rombalds Moor. These grits can be traced across the River Wharfe into the Beamsley area. Here, Jones (1943) referred to the lowermost coarse horizons as the Deerstones Grit and equated them with the Pendle Grits. Further east, the Geological Survey (Edwards et al 1950) described the Lindley Moor Grits and correlated these with the lower part of the Skipton Moor Grit (i.e. the Pendle Grit). In the adjacent Harrogate area, Edwards et al (1950) correlated the Harrogate Tunnel Grit and the overlying Oakland Sandstone (Hudson 1930) with the Lindley Moor Grits. The author considers that the Harrogate Tunnel Grit should be correlated with the Pendle Grit.

In the Ribblesdale and Preston areas, the Pendle Grits are referred to as the Lower Wilpshire Grits (Wright et al 1927, Price et al 1963). In the area just to the west of Skipton, the base of the Pendle Grits occurs more or less at a constant stratigraphic level along the southern flank of the Clitheroe Anticline (Earp et al 1961).

In the Lancaster Fells, Moseley (1954) reported as much as 274m of sediments which are referable to the Pendle Grits. The lower 182m are dominantly arenaceous and are considered to represent the Pendle Grits Formation of this account. (Fig. 4).

2.3.3 THE PENDLE SHALE FORMATION

Bray (1927) called the argillaceous beds above the Pendle (Top) Grit, the Surgill Shale, and reported that these argillaceous beds were up to 243m thick. A similar thickness of sediments was reported by Earp (1955) from the Bowland Forest Tunnel. To the south west of the Pendle area, the argillaceous division decreases in thickness until only 61m of shale separate the Lower Wilpshire Grits (=Pendle Grit Formation) from the Main Wilpshire Grit (=Warley Wise Grits =? Grassington Grits).

In the Lancaster Fells, Moseley (1952) reported that the Upper 91m or so of the Pendle Grits are sandy shales and flags; these are considered to represent the Pendle Shale Formation of this account.

Stephens et al (1953) commented on the fact that on the northern slopes of Skipton Moor, there is a "shaly portion" in the middle of the Skipton Moor Grits. On the east side of the River Wharfe, Jones (1943) calls this shaly horizon the Beamsley Shales.

Within the Lindley Moor Grit Group, Edwards et al (1950) distinguished an upper shaly portion which they called the Norbeck Shales and these are now equated with the Pendle Shale Formation. The Oakland Sandstone first reported by Hudson (1930) lies at a similar level and likewise is equated with the Pendle Shale Formation.

Colour Code:- Purple- Upper Bowland Shales; Dark Green- Pendle Grits;
Light Green- Pendle Shales; Orange- Grassington Grits/Warley Wise Grits.

Fig. 4. Northern Central Pennine Basin correlation chart. (E_{1C} Namurian).

2.3.4 THE GRASSINGTON GRIT FORMATION

The Grassington Grits are extremely widespread and laterally persistent, being found both on the Askrigg Block and in the northern part of the Central Pennine Basin. Few authors have previously attempted to differentiate the various lithological facies within the Grassington Grits Fm., with the notable exception of Wilson and Thompson (1959).

The term "Grassington Grit" of "Grits of Grassington Moor" was first introduced by Dakyns (1891). This term was incorporated into the key of the Geological Survey Sheet No.97 S-E Old Series. Dakyns and the other Survey Officers continued to use this and various miners' terms such as "Bearing" or "Basement" grit for much of their mapping on the Askrigg Block. In 1891, Dakyns correlated the Grassington Grit with the Lower Howgate Edge Grit and the Mirkfell Gannister. These correlations were subsequently confirmed by the mapping of Rowell and Scanlon (1957 and 1958). Dakyns (1891) also recognised that the isolated outliers of "grit" on Ryloaf Hill and Ingleborough could be correlated with the Grassington Grits. Agreement that the Kirby Fell Grits and the "Ingleborough Grits" are correlatable with the Grassington Grits comes from Hudson (1930b) and Hicks (1959) respectively. Other isolated outliers which can be included with the Grassington Grits are the "Grits of Black Hill" (Garwood and Goodyear 1924), and "Fountains Fell Grit" (O'Conner 1964).

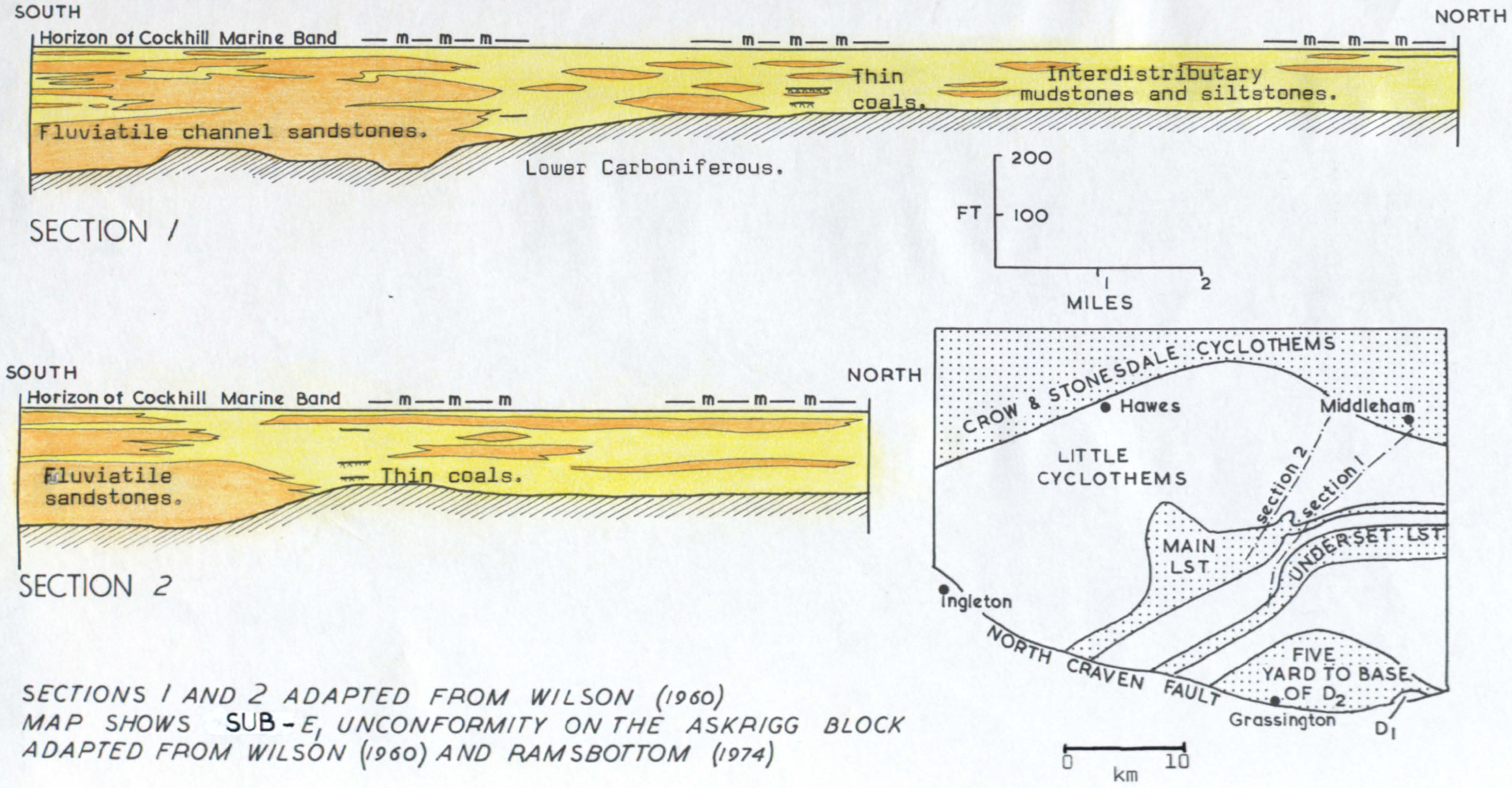
The recent one-inch Geological Survey Sheet No.50, Hawes 1971, refers to all of these outliers as the "Lower Howgate Edge Grit."

Below the Grassington Grits and Lower Howgate Edge Grits, there is a considerable unconformity in the area between Swaledale and Grassington. This unconformity is associated with substantial uplift and planation of the southern margin of the Askrigg Block. The effects of the planation are seen in the distribution of the beds underlying the Grassington Grits, (Fig. 5), (Wilson 1960, Ramsbottom 1974). Northwards, the thickness of missing beds decreases and the unconformity disappears north of Swaledale (Rowell and Scanlon 1957).

Fig. 5. The intra-E_1 unconformity on the Askrigg Block.

A/. Fluviatile channel distribution.

B/. Map of the top of the sub-Grassington Grit surface.



SECTIONS 1 AND 2 ADAPTED FROM WILSON (1960)
MAP SHOWS SUB - *E_1 UNCONFORMITY ON THE ASKRIGG BLOCK*
ADAPTED FROM WILSON (1960) AND RAMSBOTTOM (1974)

Continuity of lateral correlation of the Grassington Grits between the Askrigg Block and the Central Pennine Basin has been made principally through the mapping of Dunham and Stubblefield (1945) and Hudson (1939). Hudson refers to the grit sequence on Simonseat and Pockstones Moor as the Great Pockstones Grit and the Little Pockstones Grit; both correlatable as part of the Grassington Grits. These beds can be traced southwards into the Beamsley area where Jones (1943) termed them the Beamsley Grits. Jones (1943 Fig. 2) assumes that these grits correlate with the Bradley Flags and Grits at the top of the Skipton Moor Grit Group (Stephens et al 1953).

When traced westwards from the Skipton area, the escarpment formed by the Bradley Grits (=Grassington Grits) can be clearly traced into the Lothersdale area. Here, Bray (1927) called them the Warley Wise Grits, a term adopted by the Geological Survey in the Clitheroe Memoir (Earp et al 1961) although Parkinson (1936) did refer to them as the Grassington Grits. Earp (1955) also reported a thick development of Warley Wise Grits encountered in the construction of the Bowland Forest Tunnel.

The Warley Wise Grits have been traced further south west into the Wilpshire and Preston area where they have been called the Main Wilpshire Grit (Wright et al 1927 and Price et al 1963).

Complications arose in the naming of the grits in the Waddington Fells area. For some time, the grits were referred to as the Newton Fells Grits (Parkinson 1926). This in fact is a name that is applied to a Lower Carboniferous formation in the same area. However, the recent 1973 1:25000 Survey map (Clitheroe and Gisburn Sheet SD 74) now refers to these grits as the Warley Wise Grits.

Moseley (1954) introduced the name Brennand Grit in the Lancaster Fells for a sequence which is thought to equate with the Grassington Grits, and later acknowledges the correlation between the Brennand Grits and the Grassington Grits (Moseley 1956). This correlation also encompasses the grits of the Keasden area and Sykes anticline, (Moseley 1956 and 1962).

Finally, the most recent correlation has been that of the Almscliff Grits with sediments close to the top of the Skipton Moor Grits (Ramsbottom 1974). A sedimentological appreciation of the facies descriptions of Edwards et al (1950) and Hudson (1930a) shows that these grits would appear to be identical to the Grassington Grits.

2.3.5 THE BRADLEY FLAGS

In Chapter 2.2.2, it was suggested that the base of the Bradley Flags may represent the level of the Cockhill Marine Band, even though the marine band itself is not exposed to the south and east of Skipton. One of the main reasons for making this correlation is that the Bradley Flags differ markedly in their sedimentology from the underlying Skipton Moor Grits, suggesting that they are the product of a different environmental regime. If the suggested stratigraphic position is correct, one could regard the Bradley Flags as strictly falling outside the scope of the thesis. However, their close association with the Skipton Moor Grits, the contrast which their sedimentology provides and their possible implications for the regional stratigraphy are all thought to justify their inclusion. Details of their sedimentology are presented in Appendix 2.

CHAPTER 3. THE FACIES

3.1 INTRODUCTION

The rock types comprising the Skipton Moor Grit Group are dominantly clastic. They range in grain size from mudstones and very fine siltstones through to coarse and pebbly 'grits.' Various facies are distinguished and described on the basis of characteristics thought to be of native and diagnostic importance. Usage of the term 'facies' follows the definition of Walker (1966), Collinson (1969) and McCabe (1975a), namely:-

> "..... a group of rocks differing from other rocks by virtue of their appearance in the field. This is controlled by such parameters as grain size and composition of the sediment, geometry and scale of sedimentary structures and the influence of biological activity." (Collinson 1969 p. 197).

Thirteen facies have been established but since the scheme is inherently capable of refinements, several of the facies have been further sub-divided. Field mapping quickly showed that many of the facies were intergradational and that in several instances, identification and separation could only be subjective.

The individual facies are described and interpreted below. In Chapter 4, a study is made of the facies relationships which lead ultimately to an environmental reconstruction.

3.2 FACIES 1. MUDSTONES

3.2.1 DESCRIPTION

Black or dark grey mudstones are usually seen in a highly weathered (paper laminated) state, although more blocky, conchoidally fracturing mudstones also occur. Rare cubes of pyrite can occasionally be found, along with rare fish scales and bivalve remains. Jarosite, the weathering product of diseminated pyrite frequently veeners weathered surfaces. Bioturbation is uncommon.

3.2.2 INTERPRETATION

The fine grained nature of the sediment and the general evenness of bedding, along with the lack of traction current structures, suggests that deposition was largely from suspension in a low energy environment. The dark colour of the mudstone is caused by high concentrations of finely divided iron sulphide and unoxidized organic matter (Heckel 1972). Heckel notes that both of these substances are typical of "anoxic" environments, i.e. where normal processes of oxygenation no longer operate. Heckel considers this type of environment as generally inhospitable to benthonic and necto-benthonic life. This could account for the overall lack of macro- and Ichno-fauna in the mudstones. However, the apparent scarcity of bioturbational structures could possibly be due to "collection failure", especially in a sediment which is so homogenous and highly weathered and where delicate structures would not be readily visible.

3.3 FACIES 2. FAUNAL MUDSTONES

3.3.1 DESCRIPTION

The faunal mudstones are distinguished from the barren mudstones, described above, by their organic content. This dark mudstone contains a macro-fauna of crushed and uncrushed goniatites and pectinoid bivalves.

3.3.2 INTERPRETATION

This facies is important since it indicates that marine influences were prevalent, at least during the deposition of the faunal mudstone. The lack of benthonic forms suggests that bottom conditions were euxinic and that the fauna lived in the upper oxygenated water and only dropped to the floor on death. In fact, Holdsworth (1966) has even suggested that the abundance of pelagic and nektonic fossils in faunal bands might be attributed to slowness of deposition rather than the super-abundance of organisms.

The faunal mudstone is therefore taken to indicate a period of very slow sedimentation in quiet marine conditions.

3.4 FACIES 3. MUDSTONES WITH MICRO-LAMINATED SILTSTONES

3.4.1 DESCRIPTION

Within the dark mudstones, occasional thin light coloured silty laminae occur. These laminae are best seen in polished section where the banding or laminae forms a monotonous repetition. The laminae show normal grading and frequently display flat sharp bases although occasionally some lower bounding surfaces appear to be gradational. The upper boundary is always gradational. The thickness of the laminae varies between 2 and 5 mm. and each lamina appears to be laterally continuous within the limits of the exposure, which may be up to 3 or 4 metres in width.

3.4.2 INTERPRETATION

Piper (1972) described "graded laminated beds" broadly similar to those described above. He reviewed several hypotheses for the emplacement of the laminated siltstones, amongst them pelagic settling, turbidity currents and sediment transport by contour currents and nepheloid layers. He suggests that only turbidity currents could explain frequently occurring graded beds. He argues that a steadily waning bottom current could produce a graded bed similar to a turbidite but that steadily waning bottom currents were unlikely to occur.

3.5 FACIES 4. PARALLEL BEDDED AND STRIPED SILTSTONE

3.5.1 DESCRIPTION

This facies includes sediments with a wide range of bedding and weathering characteristics. For descriptive purposes, the facies has been divided into two types, although there are many intermediate types.

3.5.2 Type A

This is a blue-grey, poorly sorted sandy siltstone. The sediment splits easily along bedding planes when dry and is friable in hand specimen. The sediment is extremely rich in mica and finely comminuted carbonaceous matter gives the sediment its dark colour. Larger plant fragments (up to 10 cm.long) occasionally occur, some of which resemble Calamites.

The beds are discreet alternations of light and dark stripes, which are very conspicuous in unweathered or polished hand specimens. The stripes are horizontal and vary in thickness between 0.5 and 5 cms. Some show an upward grading with lighter coloured material at the base and darker, more carbonaceous material at the top. The beds have very diffuse gradational boundaries.

3.5.3 Type B

Type B is much lighter in colour, better sorted and generally coarser and therefore harder. It is noticeably less carbonaceous and micaceous, although both components are still present. Striping is only occasionally developed and is not particularly conspicuous because of the lack of colour contrast. When weathered, this sediment also splits along horizontal bedding planes but not as readily as in Type A. In fresh and unweathered specimens, the parting planes are light-grey or buff in colour. Weathered, they are usually a dull red/brown.

The degree of parting in the sediment depends on grain size. Where the sediment is comparatively coarse, beds tend to break away in 8 to 10 cm. "flags". Finer grained beds break into thinner "flags" similar to the Type A sediments, except that they are not as dark in colour nor as carbonaceous and micaceous. Type B beds also tend to split with a gently undulose surface.

The base of Type B beds is either sharp or rapidly gradational. The sharp bases show no sign of tool marking or loads and flame structures. The top of the bed can also be sharp or gradational. Occasionally an outcrop will show several successive changes in grain size in which case each change is gradational and each bed is characterised by its weathering profile.

Both Types A and B contain a great variety and abundance of trace fossils. Bioturbation structures tend to be more conspicuous in the Type A sediments. Beds can have horizontal burrows on nearly every parting plane. All the ichnogenera are described in Appendix I.

3.5.4 INTERPRETATION

Within this facies, there is a total absence of structures indicative of traction current activity. This suggests a low energy environment, entirely below wave base. The slight grading and horizontal striping would seem to indicate deposition from suspension. The monotonous repetition of stripes in Type A suggests a persistent but erratic supply. Coleman and Gagliano (1965) consider the pronounced repetition seen in similar deposits from the Mississippi, as a seasonal layering. The somewhat coarser and cleaner sediments of Type B probably reflect proximity to source and better sorting.

The Type A striped silts compare closely with Walker's (1966) facies G, Sandy and Silty Mudstones with Horizontal Burrows, and with Collinson's (1969) facies 2, Striped Siltstones. Type B is comparable with Walker's facies J, Parallel Bedded Silty Sandstones, and Collinson's facies 3, Silty Sandstones. Both of these authors consider that deposition was from suspension and that there was no subsequent reworking other than by various organisms.

3.6 FACIES 5. RIPPLE CROSS-LAMINATED SANDSTONES

3.6.1 DESCRIPTION

Sediments, ranging from clean well sorted, fine grained sandstone, to poorly sorted "dirty" micaceous and carbonaceous sandstone, are found bedded in small cross-laminated sets. These sets are usually found exposed on bedding planes, either as a regular "rib and furrow" structure (Stokes 1953, Hamblin 1961) or as a more irregularly orientated pattern.

The sets are on average 4 cm. thick and up to 10 cm. in width. The foreset laminae dip down-current at angles of up to 30°, and are tangentially based to the lower bounding surface. This lower surface is erosional and may either be scoop shaped or planar. The traces of the foreset laminae, when seen on the bedding plane surface, are concave down-current.

3.6.2 INTERPRETATION

There is a direct association of the internal cross stratification structures with surface ripples, (see J. R. Allen 1967 for review). Allen (1963a) interprets the structure as being due to the migration of small scale ripples under conditions of net sedimentation. Harms and Fahnstock (1965) working in the Rio Grande demonstrate this association conclusively. They observed two types of ripple, one lunate and the other linguoid, but when small excavations were made through either type, the internal structure was always a small scale trough. The cross stratification filled this trough which had been initially formed as an erosional hollow in front of linguoid or sinuous-crested ripples. The scouring of the hollow was a direct resultant of lee side vortices, whilst the infilling was due to the advancement of the lee face of the ripples. The length of the trough is considerably longer than the length of the instantaneous scour (Harms & Fahnstock 1965), due to the downstream movement of the ripple field.

The organisation of the cross-lamination depends on the arrangement of the ripple forms, either as regular or irregular plans. When there is a regular plan, the associated lee scours are expected to have a parallel orientation, but when the ripple plan is more irregular, then there is a more haphazard orientation.

3.7 FACIES 6. THIN TURBIDITE SANDSTONES

3.7.1 DESCRIPTION

This facies consists of parallel sided beds of sandstones, which are 100 cm. or less in thickness. They are fine to medium grained, poorly sorted, dark-grey when fresh (or pink to brown when weathered).

The base of the bed is always sharp and erosive and may be ornamented with tool marks, load marks, scour marks or organic markings. The tool and scour markings are the dominant forms and are good palaeocurrent indicators.

3.7.2 Tool Marks

Tool marks may be divided into two main types. There are the very common prod, bounce and brush marks and there are the less common groove and chevron marks. The first group consist of discontinuous structures.

A. Prod Marks (Dzulynski & Slaczka 1959).

These are semi-conical or triangular depressions which are deeply impressed in a downstream direction. They may be straight or curved and frequently they show striations caused by irregularities on the tool (Photos 3, 4 and 12).

B. Bounce Casts (Wood & Smith 1959. Dzulynski & Walton 1963).

Small symmetrical ridges tapering at both upstream and downstream ends.

C. Brush Marks (Dzulynski & Slaczka 1959).

Impact marks whose longitudinal profile is a gentle curve. (Photo 4).

These discontinuous tool marks are gradational with the second type, the continuous groove and chevron casts (Dzulynski & Sanders 1962).

D. Groove Casts (Shrock 1948).

These are linear, usually straight ridges, occasionally 3 or 4 cm. deep. They vary in size from short striations to smooth or ribbed grooves. Crossing pairs are common and sometimes three intersecting sets are seen. (Photo 5).

E. Chevron Marks (Dunbar & Rodgers 1957).

Photos 7 and 8 show a specimen of a chevron mark. The small V-shaped ridges are arranged linearly with the V's pointing downstream. (Craig & Walton. Plate Va 1962).

3.7.3 Scour Marks

Scour marks are less common than tool marks, but they provide valuable directional indicators. Three main types are found, flutes, longitudinal ridges and cresent scours.

F. Flutes (Hall 1843. Kuenen 1957).

These have an asymmetric vertical profile parallel to the flow and are parabolic in plan. Frequently, the flutes are skewed to either left or right and may interfere with each other (Photo 9).

G. Longitudinal Ridges (Dzulynski & Walton 1965).

This structure consists of narrow, parallel or sub-parallel ridges which are regularly spaced. They vary between 10 and 30 mm in width, and have a relief of between 0.5 mm and 3 mm. They are separated by sharp anastomising furrows. The rounded or bulbous end is at the upcurrent end,(Photo 11). Locally, the parallel ridges may be broken by a rotation of the trend to give a swirled appearance to the pattern. Structures similar to the Fleur-de-Lys pattern of Craig & Walton (1962) have also been found (Photo 13).

H. Cresent Scours

These are discussed in Appendix I (Trace Fossils) (Photo 10).

3.7.4 Internal Organisation

The majority of beds are characterised by the development of three internal divisions (Bouma 1962, Walker 1965). These are:-

C. Ripple laminated division

B. Plane laminated division

A. Massive or graded division

This sequence, when fully developed, normally begins with the 'A' division at the bottom of the bed. However, it is not uncommon to find beds beginning with division 'B'.

A. Massive or graded division.

Grading is not always apparent in the field, in which case the basal portion is described as massive. Shale clasts, occasional pebbles and comminuted carbonaceous debris can all be present and are usually oriented parallel to bedding.

B. Plane laminated division.

The laminae are invariably accentuated by concentrations of plant debris and detrital mica flakes. This usually gives good parting or splitting surfaces. In plan view, these laminations may show well developed primary current lineation.

C. Ripple laminated division.

The upper surface of the sandstone is normally sharply overlain by the interbedded mudstones and shows a highly distinctive rippled morphology.

In cross section, the ripples show an asymmetric profile, with the lee face considerably steeper than the stoss side. The crest of the ripple is always smooth and rounded. Normally, only one ripple set is formed on the top of the sandstone and this has a scoop shaped erosional lower bounding surface. Occasionally, one set may show a small rate of climb. In this, the scoured base truncates the laminae of the downcurrent set.

The foreset laminae are tangentially based and carbonaceous and micaceous material tends to concentrate in the lower part of the foreset laminae.

The plan of the ripples is best examined on a broad exposed surface (Photo 1). Here, a highly characteristic ripple pattern is seen which is best described as Bow-shaped linguoid (Allen 1968 P.64). When perfectly developed, this type of ripple shows two broad and rounded saddles, separated by a median lobe. The crest line of the ripple is strongly curved and at the flanks it opens out upcurrent (Fig.7, b and c). The inter saddle distance (Fig. 6) varies between 40 and 120 mm whilst the semi-chord varies from 30 to zero mm. The maximum height of the ripple measured between the highest point, normally the median lobe reflection point and the lowest scour point, ranges between 2 and 30 mm.

On a broader scale, the 'ripple-train' shows an 'out-of-phase' relationship. The median lobe of the ripple occurs at the distal end of the crestal ridge of the

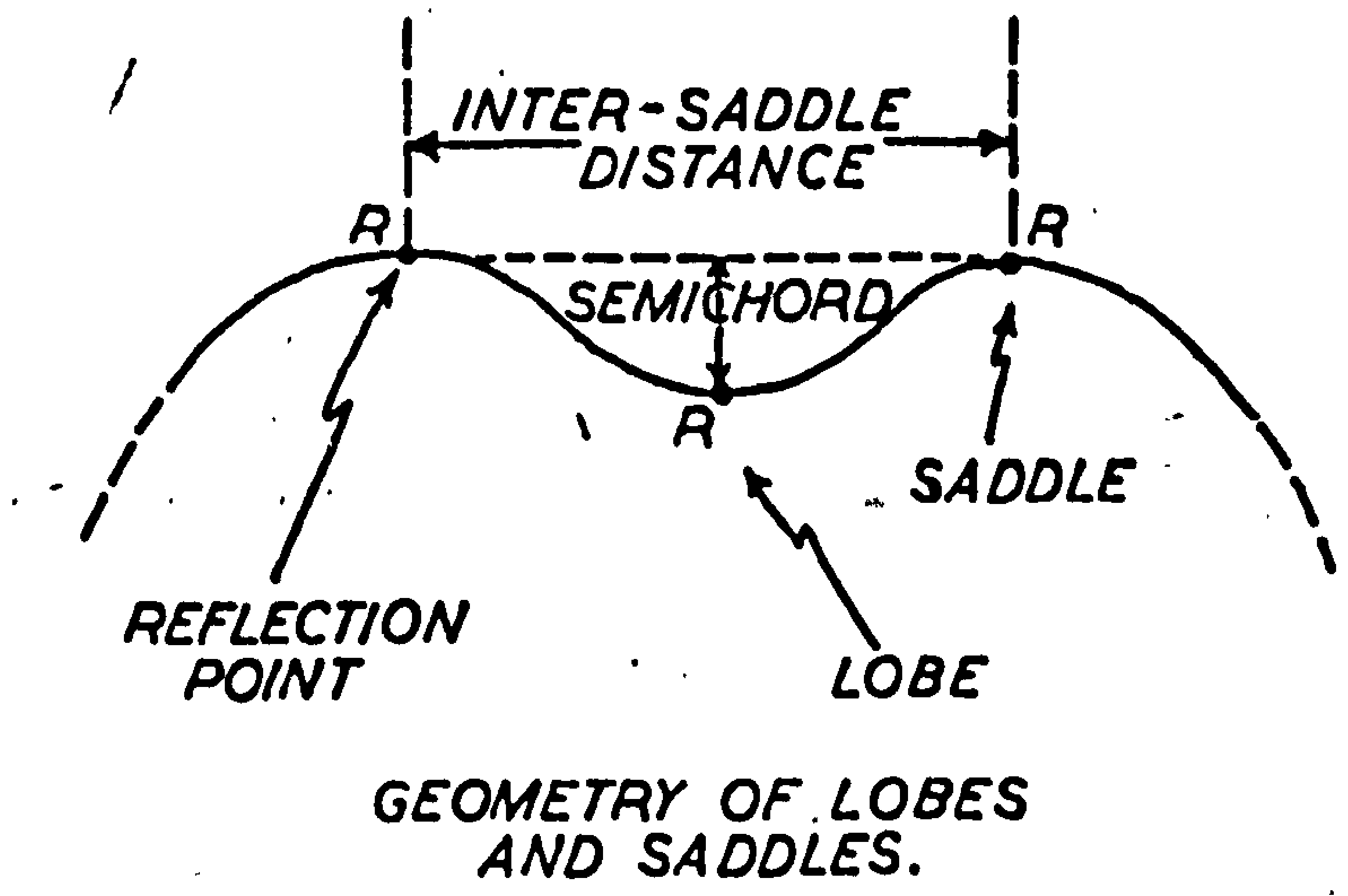


Fig. 6. Diagram illustrating the nomenclature used to describe the bow-shaped linguoid ripples (after Allen 1968).

Diagram A. Catlow Gill (SD96834946) Carleton.

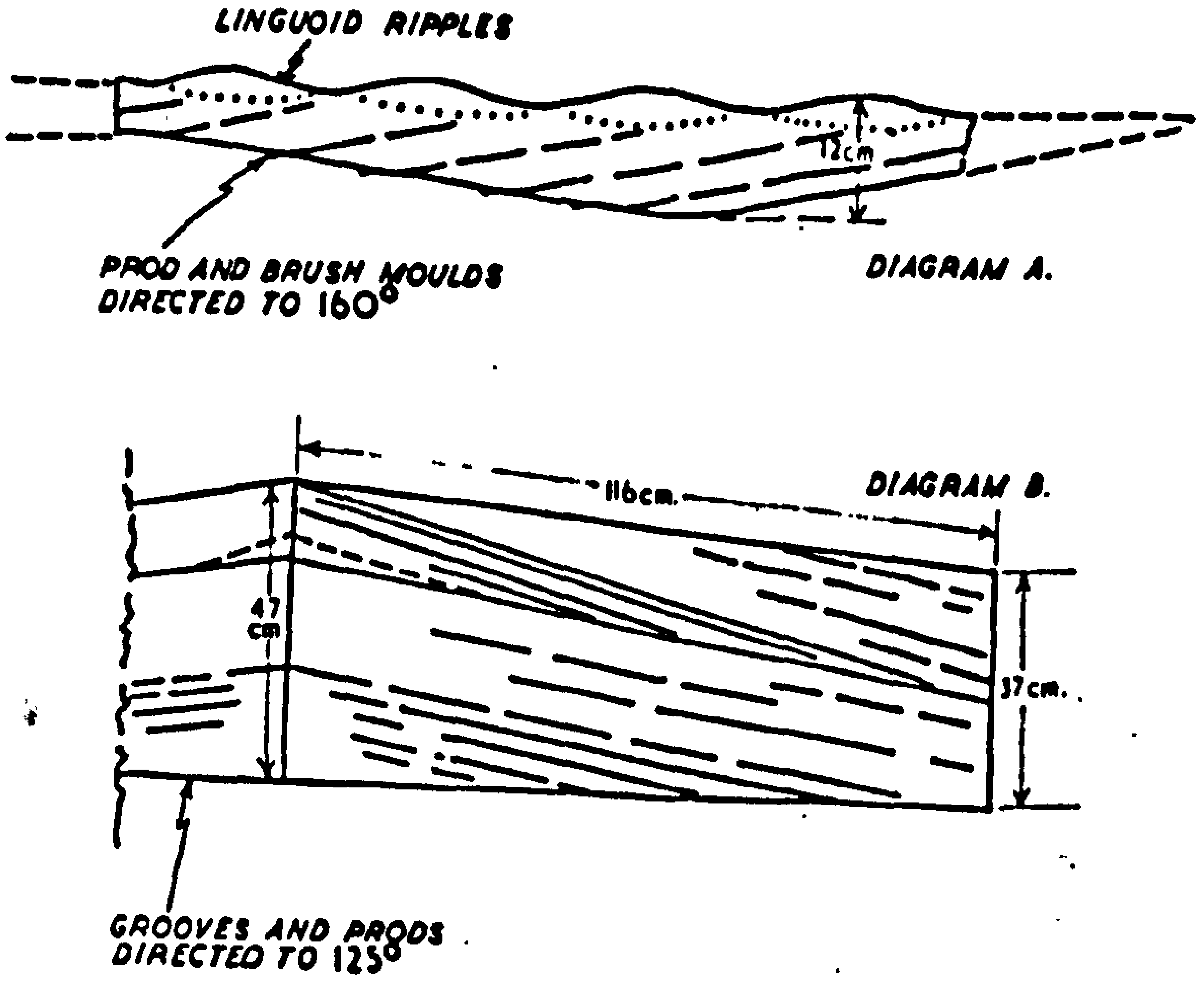


Diagram B. Catlow Gill (SD97704887) near Glen Cottage, Carleton. (See Photo 2).

Fig. 8. Two sketches of Dune structures in facies 6, Thin turbidite sandstones.

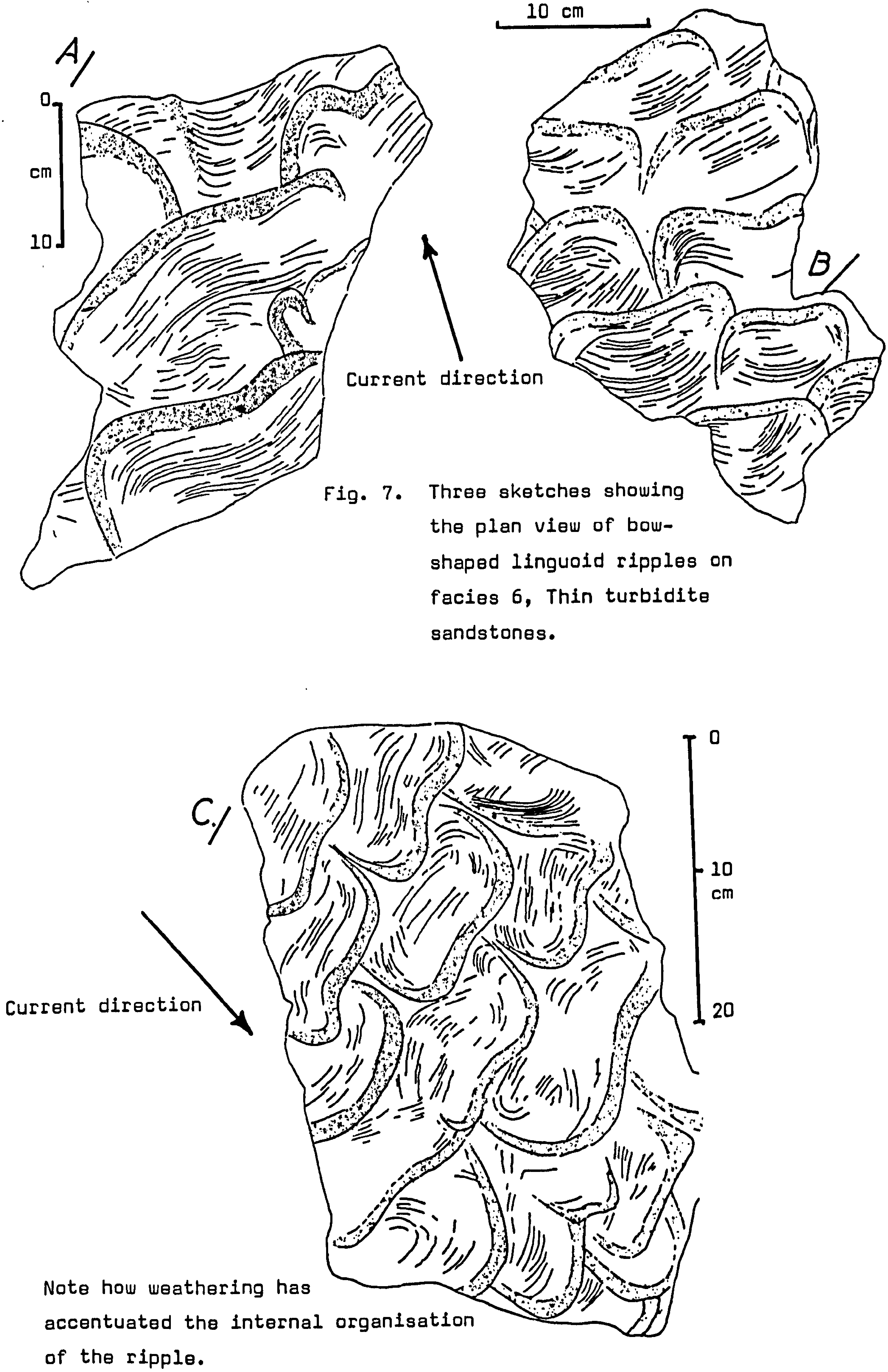


Fig. 7. Three sketches showing the plan view of bow-shaped linguoid ripples on facies 6, Thin turbidite sandstones.

Note how weathering has accentuated the internal organisation of the ripple.

ripple immediately downcurrent (Fig. 7.c). As the median lee face advances over this distal ridge, it becomes slightly elevated above the saddles on either side. In the field, it is not uncommon to find the ripple train developed in an irregular pattern. The ripples then show a 'swept' pattern (Allen 1968 P.66) with the lobes and saddles skewed either to the left or right, relative to the current flow. In some instances, there is an even more irregular development whereby the ripple crests became straight or semi-circular, or even complicated by minor saddles and lobes. Ripples may coalesce or show 'blow-out' structures (Fig. 7a).

3.7.5 DUNE STRUCTURES

Several instances of beds with a set of parallel or sub-parallel 'foreset laminae' dipping at shallow angles have been found. These are equated with structures described as Dune structures by Hubert (1966a). They are on a much larger scale than the bow-shaped linguoid rippling described above, and are clearly unrelated. Examples of Dune structuring can occur in either facies 6 or facies 7 sandstones. However, they are easier to detect in the facies 6 sandstones.

The foreset laminae appear to have an angular relationship with the base of the bed. This phenomenon is developed in beds of various thicknesses (Fig. 8.).

Figure 8a shows a thin sandstone with the laminae dipping at angles of 7° or less. These laminae have an angular relationship with part of the base. The upper ends of the laminae are truncated by the erosive base of asymmetric bow-shaped linguoid ripples. The foreset laminae are perfectly straight and show no deformation whatsoever. In this particular example, the bed thins rapidly to the right such that the base of the bed rises to meet the horizontal rippled top. Consequently, the laminae at this end are parallel to the base of the bed.

In Fig. 8 b and Photo 2, a thicker bed is seen. Again, the laminae are perfectly straight and in the lower portion they dip towards the base of the bed. The upper half, however, appears to be more complicated. In Photo 2, at the level of the hammer pick, an amalgamated surface is clearly seen dipping parallel to the laminae below. Above it, the laminae are inclined at a slightly steeper angle and dip towards the plane of disconformity. The three dimensional outcrop shows that the laminae have a straight strike and this is confirmed from other examples.

In both examples, there is a considerable divergence of directional sense between readings obtained from the sole structures when compared with the true dip directions of these tabular sets. This divergence is usually between 45° and 90° but so far no readings have been obtained where the dip sense of the laminae is opposed to the directional sense of the sole marks.

3.7.6 INTERPRETATION

The external and internal structures observed fit with those to be expected from the deposition from a turbidity current. (The actual genesis of the turbidity current is discussed in Chapters 6.1.5).

An idealized turbidite sequence was systematized by Bouma (1962). He recognised five intervals (re-named divisions by Walker 1965), namely:-

e) Pelitic division
d) Upper division of parallel lamination
c) Division of current ripple lamination
b) Lower division of parallel lamination
a) Graded division

Subsequently, this Bouma Sequence was interpreted in terms of laboratory flow regimes (Harms & Fahnstock 1965, and Walker 1965). (See Fig. 2 in Middleton and Hampton 1973 and Fig. 1 in Walker 1967).

Most of the structures observed in the descriptive section can be explained by a combination of erosion (at the head of the turbidity current) and more or less rapid deposition (from the body and tail of the current).

There are however, two important departures from the idealized model.

(1) Only the a), b) and c) divisions are recognised in the turbidite, with e) being the interturbidite division, in this case Facies 1, dark mudstones. The d) division is not developed.

(2) There is a Dune division developed which may occur as a replacement division for either a) or b). (This second modification is discussed more fully below).

The sole markings originated with the passage of the erosive head of the turbidity current. The effect of irregularities in the path of the turbidite, plus the strong three dimensional turbulence aspect, account for the variations in the orientation of the tool marks (Allan 1971).

The prod, bounce and brush marks are formed by the impacting of small tools on the bottom. They imply a "saltation" of the tool responsible, probably either a mud clast or a plant fragment. Tumbling motions and irregularities in turbulence account for the more twisted and rotated impact marks.

Where objects such as twigs have dragged along the bottom, longer more continuous grooves have resulted. Many of the grooves show fine ribbings which would match with the Calamites-like plant fragments, also found in the sandstones. So far, no actual cutting tool has been found at the termination of the groove marking. There are, however, examples in the literature of basal groove moulds which terminate in angular shale fragments, e.g. the Carpathian flysch and Aberystwyth Grits (Dzulynski & Radomski 1955; Wood and Smith 1959 respectively). Dzulynski & Radomski (1955) have also found the remains of a log at the downcurrent end of a groove.

Flute casts, although less common than the tool markings, also indicate a certain degree of turbulence of the eroding current. According to Allen (1971), they originate from a scouring of the soft mud bottom by captive eddy currents. However, the greater proportion of tool marks as opposed to scour marks might be a direct consequence of the large quantity of carbonaceous debris being carried by the turbidity current.

Dzulynski and Sanders (1962) suggested that with excessive loading, a traction carpet formed which had a damping effect on turbulence and so inhibited the formation of flutes.

The longitudinal ridges are considered to be a result of current scour by longitudinal vortices (Dzulynski and Walton 1965, Craig and Walton 1962). Allen (1971) demonstrated that "the ridge crests may be interpreted as streamwise separation lines, and the longitudinal axes of the furrows are lines of streamwise re-attachment .... this would appear to be associated with paired vortices similar in knuematic structure to the Taylor - Görtler type."

The crested scours form as a result of local turbulence around an obstacle; in this case probably vertical cemented burrows. Flow separation and scouring occurs on the upstream side of the small bed projection. The zone of turbulence and scour extends around the sides but the area immediately downstream is usually protected.

The graded (or massive) basal division is considered to be the result of very rapid deposition from a quick bed (Middleton and Hampton 1973). Less rapid deposition from the body and tail of the current gives the division B Plane Lamination.

As mentioned above, facies 6 (and 7) sandstones occasionally show a development of dune bedding. This dune development is named after similar dune foreset bedding first described by Hubert (1966a and b). He reports foreset laminae with amplitudes of up to 20 cm and dips ranging from 5 to 31 degrees.

The exact genesis of dune bedding is still uncertain, but it is clearly unrelated to antidune bedding as described by Harms and Fahnstock (1965), Walker (1967) or Skipper (1971). Dune bedding has been described and interpreted by Allen (1970), Hendry (1972), Hubert (1966a and b), McBride (1969), Rocheleau and Lajoie (1974) and Thompson and Thomasson (1969).

The dune bedding appears to be confined to comparatively coarse grained turbidites (Reineck and Singh 1975). It may be formed when the turbidity current flow decelerates from the upper to lower flow regime (McBride 1969). In the examples from the facies 6 (and 7) sandstones, there was a marked difference in orientation between the sole mark and the dune foreset laminae azimuths. It was concluded that after the erosive head of the turbidity current had passed, there was a delay in deposition sufficient for the turbidity tail to have swung to a new orientation (a mechanism similar to that described by Parkash and Middleton 1970).

Also formed by the tail of the current are the bow-shaped linguoid ripples. Their origin is probably due to dilution of the turbidity current and the subsequent mixing with water above. This can produce an "entrained layer" of low concentration fluid which is dragged along in the wake of the turbidity current. This entrained current then effectively reworks the upper part of the sediment deposited by the body and tail of the turbidity current (Walker 1967).

The facies 6, Thin turbidite sandstones compare closely with the Facies C sandstones of Walker and Mutti (1973). They claim that these sandstones are typical classical turbidites. They also acknowledge that they can be part of a continuum of beds which range from Facies C to Facies B_2. (Facies B_2 equates with facies 7, Composite sandstones of this thesis).

3.8 FACIES 7. COMPOSITE SANDSTONES

3.8.1 DESCRIPTION

This facies consists of parallel sided sandstones which show many of the external and internal features described above in the facies 6, Thin turbidite sandstones. However, this facies is characterised by the fact that each sandstone bed is in very close proximity with vertically adjacent and identical beds (Fig. 9 and Photo 52). In addition, individual beds may be up to 150cm thick.

The sandstones are fine to coarse grained, poorly sorted and often include considerable amounts of mudstone clasts and carbonaceous debris. The bases of the beds are either sharp or amalgamated (Walker 1966). Bases have been

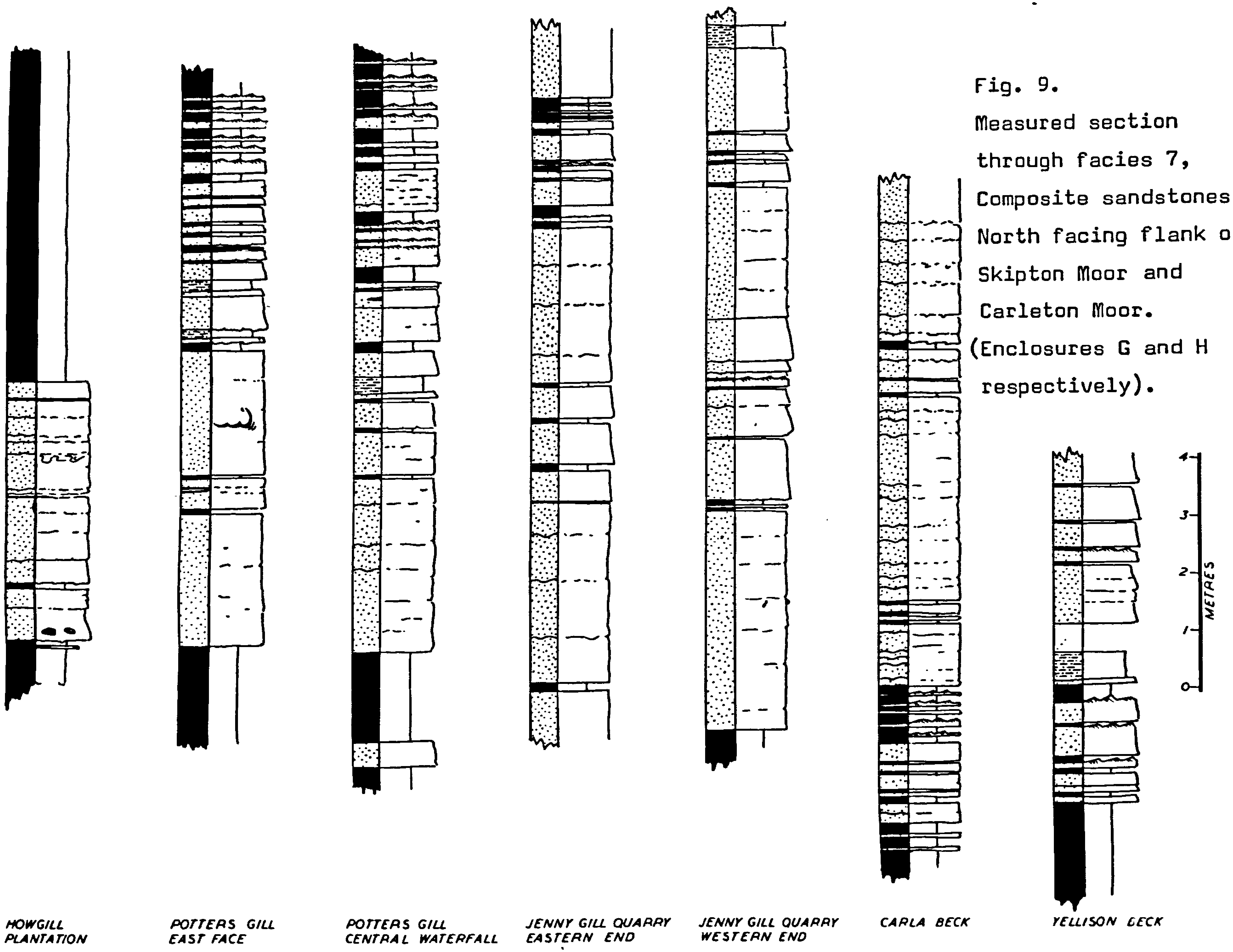


Fig. 9.
Measured section through facies 7, Composite sandstones. North facing flank of Skipton Moor and Carleton Moor. (Enclosures G and H respectively).

differentiated according to Lovell's (1969) sub-divisions.

(1)	Sharp	Type 1
(2)	Sharp & Loaded	" 2
(3)	Straight Amalgamated	" 3
(4)	Curved Amalgamated	" 4

Where the base of the bed is eroded into mudstones, (Fig. 11), it is either smooth and flat (Type 1) or loaded (Type 2). Tool and scour marks are usually uncommon and organic sole markings are extremely rare. In Types 3 and 4, the sandstone rests directly on the sandstone below and the intervening mudstone (facies 1) is absent. This "fusion" of the beds may be marked either by a change in grain size, or by a zone of mudclasts.

While individual beds may show an internal organisation similar to that described in facies 6, more often they have a massive appearance with little obvious structuring.

The lower part of the bed may either be ungraded, or it may show a normal grading and only very rarely a reverse grading. In general, grading is very difficult to detect in the field.

The upper part of the bed, corresponding to the B-division may show a weak parallel lamination. Mud flakes and comminuted carbonaceous debris tends to be concentrated on these bedding planes. The C-division, if present, always has a sharp top and is developed as bow-shaped linguoid ripples (see description above).

Mudstone clasts, occasionally measuring up to 14 by 24 cm, can be distributed throughout the bed, although large clasts tend to be concentrated towards the base. The mudclasts, often quite angular, are flattened and lie parallel to the base, although one example of mudclast imbrication has been seen (Photo 53).

3.8.2 SHEET DEWATERING STRUCTURES

In one locality (Deerstones SE08985295), a series of ramifying vertical and sub-vertical structures have been observed within the composite sandstones. The base of the sandstone is irregular with the basal

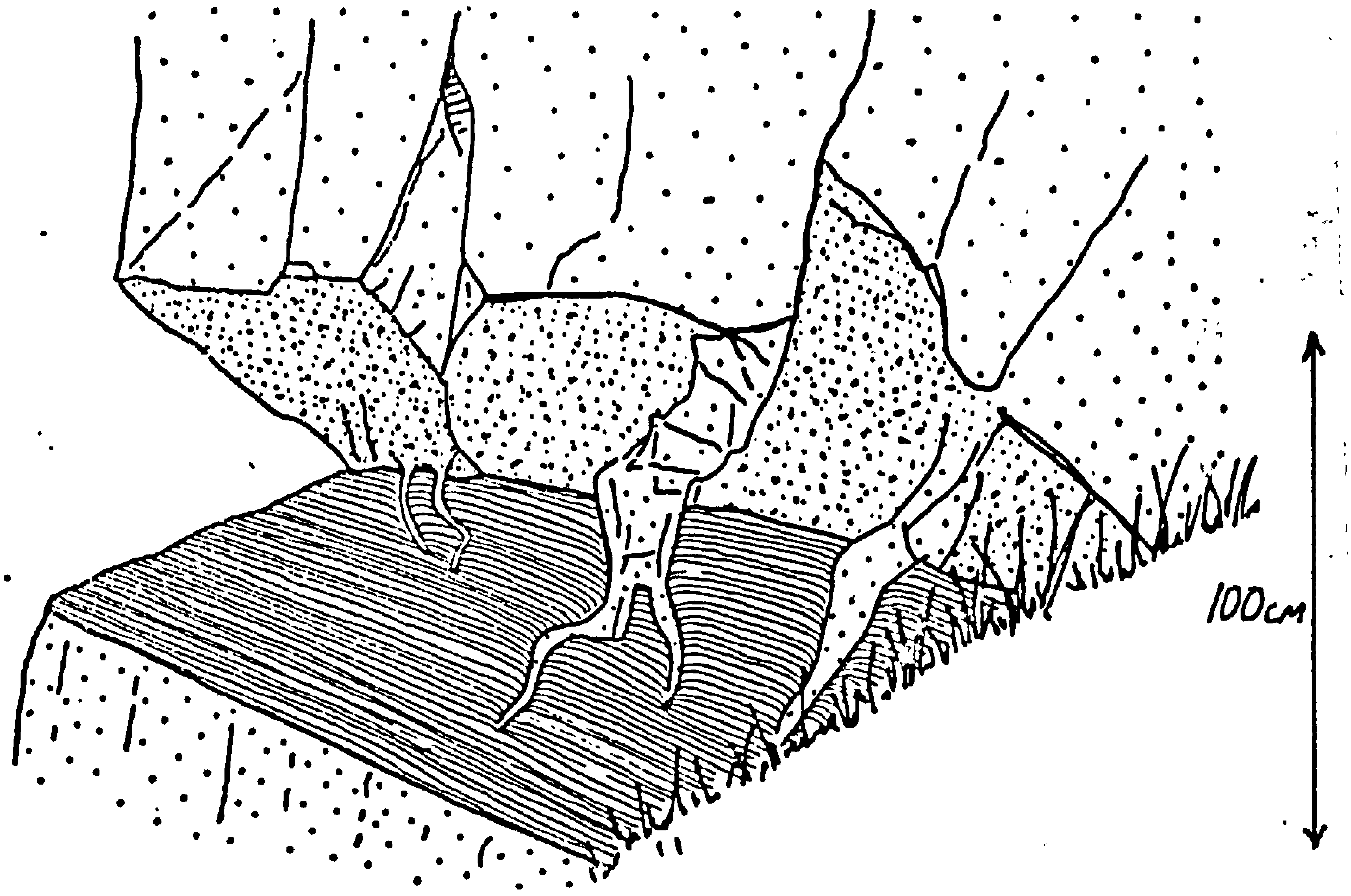


Fig. 10. Clastic dykes at the base of facies 7, Composite sandstones. Jenny Gill Quarry (SE00365095). Skipton Moor.

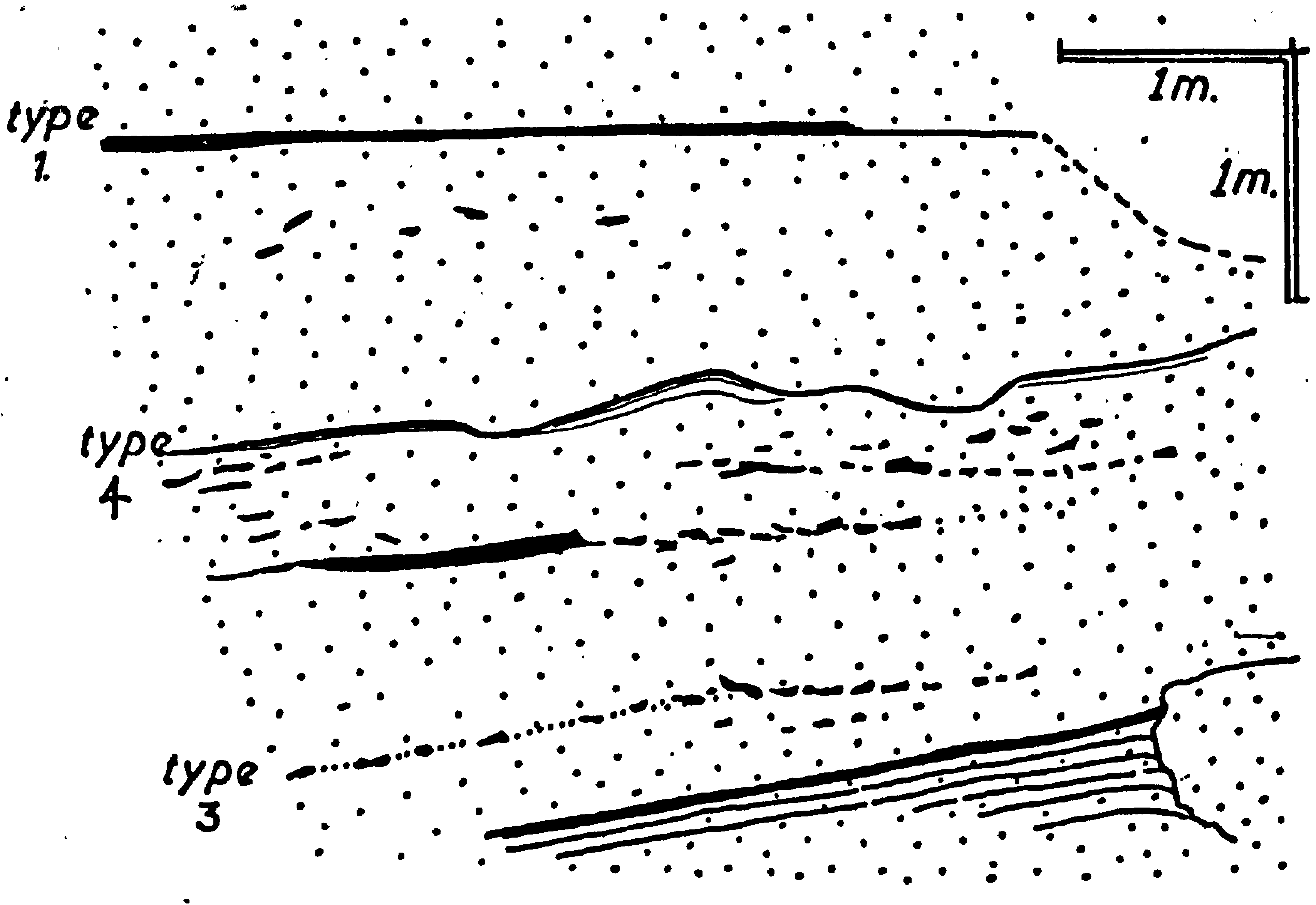


Fig. 11. Base types in facies 7, Composite sandstones. Witshaw Bank Quarry (SE00165484). Embsay Moor.

15 to 20 cm packed with numerous mudclasts. The top of the outcrop is concealed with vegetation, but is presumed to be amalgamated with an overlying sandstone.

The vertical structures weather-out as faint ribs, usually slightly paler in colour than the surrounding rock. (Photos 17, 18, 19, 20 and 21). Close examination of the outcrop shows that the ribs start near the base of the unit. They are minute and closely but regularly spaced. Progressively further up the face, the ribs coalesce to form slightly thicker ribs or columns. Eventually the columns are two or three centimetres in width and are separated by up to 20 centimetres. There is a distinct impression that the columns coalesce at definite horizons and this causes a faint horizontal layering to be imparted to the outcrop. At the top of the complete structure, this is especially obvious (Photo 19).

In 3-dimensions, the ribs may form a lattice-like sheet. In hand specimens (Photo 21), the ribs can be seen to form penetrative sheet-like structures. Since vertical tubes have been seen on faces mutually at right angles to each other, it is presumed that the sheets must intersect, giving a grid lattice.

3.8.3 CLASTIC DYKES

Clastic dykes are uncommon, usually being restricted to small injection structures one or two centimetres in depth and less than 20 cm in length. However, in Jenny Gill Quarry, a large sand injection dyke is seen at the base of a composite sandstone. The connection of the dyke with the source rock is clearly seen (Fig. 10). Three such dykes are present and two of them show bifurcation. The longest of the dykes is approximately 100 cm in length. The mudstone (facies 1) is deformed in a downward manner immediately adjacent to the dyke.

3.8.4 INTERPRETATION

The composite sandstones are vertical groupings of facies 6 sandstones and as such, the same process of deposition applies to each individual sandstone within facies 7.

The composite sandstones compare closely with the massive sandstones in the R_{1C} Shale Grit succession, origionally defined as facies C sandstones (Walker 1966) and then B_2 massive sandstones without dish structures (Walker and Mutti 1973). Walker & Mutti (p.129) interpret them as being the product of turbidity currents although they do acknowledge that the sandstones cannot be appropriately described by the Bouma sequence. Since the Bouma sequence is poorly developed, the turbidity current is considered to be immature and there has been no significant lateral and vertical grain segregation (Walton 1967).

The term 'Vertical Sheet' structure has been taken from Laird (1970) who describes similar structures from the massive or graded division of coarse sandstone turbidites. The vertical tubes, or elutriation columns (Wentworth 1967) probably represent fluid escape pipes or sheets attributed to localized upward movement of water through the bed during and after deposition. As yet, the lattice-like patterning is unexplained.

Similar "sheet-dewatering" structures have been recorded in coarse massive turbidites in the Duffield Borehole (Aitkenhead-pers comm); Upper Cambrian proximal turbidites (Corbett 1971), and the Aberystwyth Grits (Wood and Smith 1958).

The sandstone dykes are thought to have formed some time after deposition of the sandstone. A combination of vibration, perhaps due to earthquakes or a mobilization of water from compacting clays may cause liquefaction and injection phenomena (Middleton & Hampton 1973).

3.9 FACIES 8. PARALLEL BEDDED SANDSTONES

3.9.1 DESCRIPTION

This facies consists of medium to very coarse and pebbly sandstones arranged in parallel sided units. The sandstone can weather into a crumbling rotten bed, or into blocky, parallel sided beds (Photo 22) (Fig.12) EXPOSURE OF THIS FACIES IS VERY POOR ALTHOUGH LOOSE BLOCKS SUGGEST IT IS FAIRLY WIDESPREAD. AN exposure can be found immediately below The Waterfall in Waterfall Beck - Ellerbeck, (SD98545679) Cracoe Fell. The outcrop shows a sandstone bed 5 metres thick. The base of the bed is sharp and probably erosive

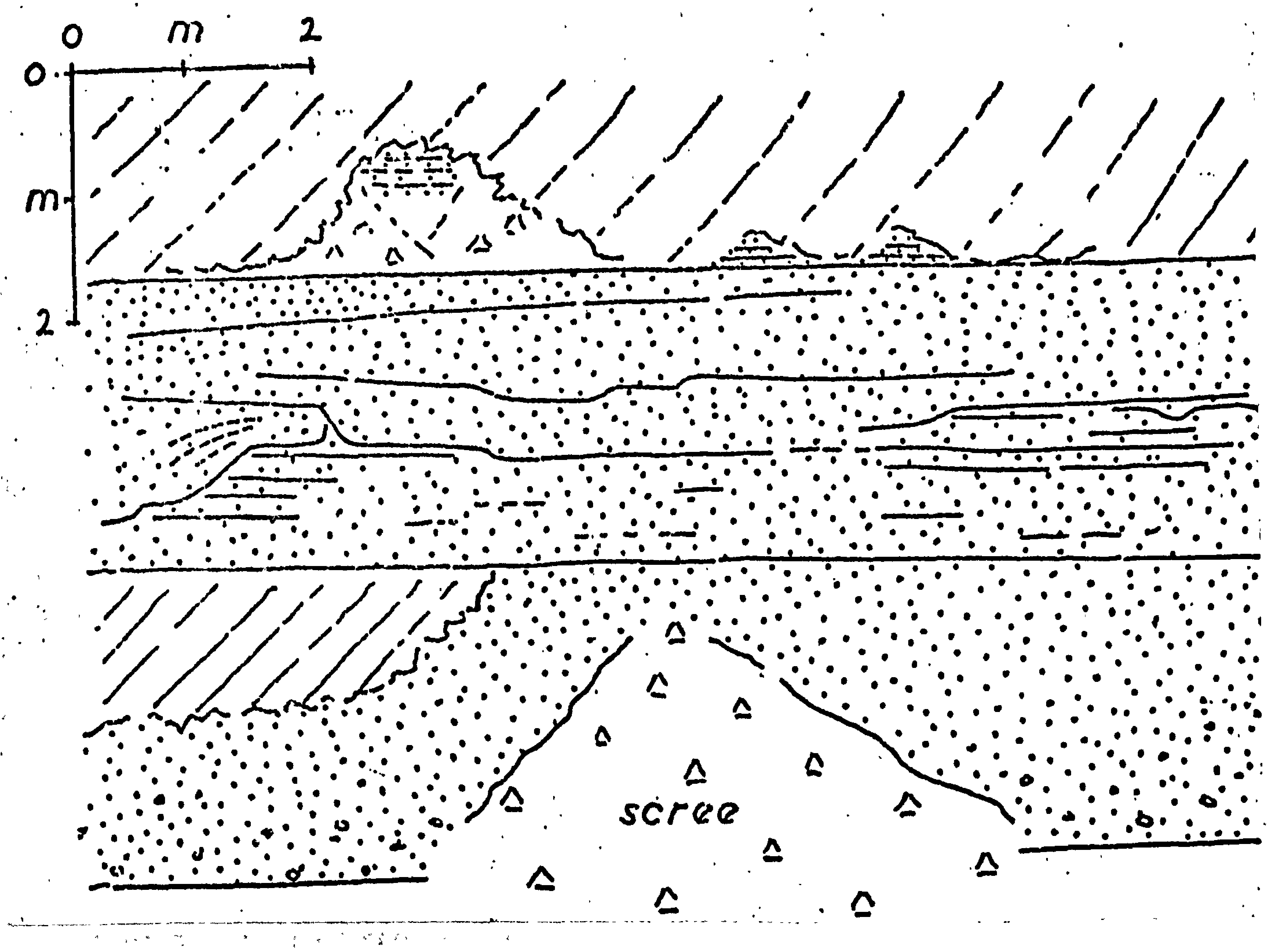


Fig. 12.

Facies 8, Parallel bedded sandstones.

The scour-like surfaces may be due to preferential weathering allied with diagenetic alteration. Slope Association. Waterfall Gill (SD98545679), Rylstone Fell.

although this is not directly seen because of scree and vegetation. The basal two metres is extremely coarse grained and pebbly and has an orange and crumbling weathered texture. No structures can be discerned apart from a rather irregular horizontal plane near the top. Immediately above this massive layer are a series of laterally continuous coarse grained, thin parallel bedded horizons. These beds split along the bedding planes and show a well developed primary current lineation on their horizontal surfaces. Wood fragments are aligned parallel to the azimuths recorded from the primary current lineation. Progressively higher in the sandstone unit, more and more horizons show what appears to be irregular scours. Horizontal surfaces, accentuated by weathering appear to cut down into lower beds (Fig.12). The amount of erosion is small and in most cases, only 10 to 20 cm, but one example shows a 100 cm deep scour. The top of the bed is flat and sharp and shows extensive bioturbation.

3.9.2 INTERPRETATION

Collinson (1969) describes beds of a similar nature from the R_{1C} Gundslow Shales as "facies 9 - Horizontal Bedded Coarse Sandstone." He suggests that the beds are deposited from "strong traction currents" because of the coarse grain size and the well developed bedding. The development of horizontal bedding and primary current lineation is taken to indicate that the flow responsible was in the lower part of the upper flow regime. (Allen 1964a; Simons <u>et al</u> 1965). The massive unit and the weather accentuated scour-like surfaces are problematical but may be caused by a diagenetic alteration of the matrix cement along preferred horizons.

3.10 <u>FACIES 9. ROPY WEATHERING SANDSTONES</u>

3.10.1 DESCRIPTION

This facies consists of very coarse and pebbly sandstones, which have a characteristic weathering pattern giving the sandstone its name (Bromehead <u>et al</u> 1933, p. 14 and Stephens <u>et al</u> 1953, p. 22). The weathered sandstone is a dark grey to dark brown colour but is pink to light grey when fresh. The sandstone is poorly sorted and contains well rounded white, rose and smoky quartz pebbles at all levels, some measuring up to 3 or 4 cm in diameter. Mud flakes, or their weathered out impressions, are also found at most levels. Grading is either absent or very poorly seen in the field.

The base of the sandstone is always sharp, either flat or with large squamiform loads.

Outcrop surfaces can show a weather-accentuated texture of anastomising laminations, forming a horizontal to sub-horizontal lensitic pattern (Photos 23, 24 and 26). These lenses vary in size, both laterally and vertically. Towards the base of an outcrop, the horizontal weathering planes are comparatively widely spaced and laterally continuous. Dimensions vary considerably with lens thickness, ranging between 14 and 24 centimetres. However, progressively higher up the outcrop, the lenses become smaller and thinner and seemingly more accentuated by weathering. Here, typical lens thicknesses range between 4 and 10 centimetres. Occasionally, some outcrop shows an even thinner development of lenses towards the top where the lenses are only 2 to 4 centimetres thick (see Photo 24).

There are several instances where the outcrop is capped by a 20-30 cm development of smooth sandstone where ropy weathering has not formed (Photo 24).

Fresh, vertical faces of recently worked sandstone show a slightly different development of the horizontal and sub-horizontal planes. They do not show the same degree of fine lensing, rather, the planes are either laterally continuous, or the sandstone has a blocky jointing pattern (see Photos 27 and 25 respectively).

3.10.2 INTERPRETATION

It is suggested that these coarse and pebbly sandstones were deposited from either a turbidity current or some type of high density gravity flow. The origin of the ropy weathering lenses is conjectural and whilst the lenses bear a superficial resemblance to dish structures (c.f. Wentworth 1967, Stauffer 1967), they differ in scale, detailed morphology and grain size. A detailed interpretation of the processes of deposition is not possible from internal evidence.

The facies is further discussed in terms of its overall context in Chapter 4.2.5.

3.11 FACIES 10. MEDIUM SCALE CROSS-BEDDED SANDSTONES

3.11.1 DESCRIPTION

Medium scale cross-beds are formed in medium to extremely coarse and pebbly sandstones. Mudstone and siltstone clasts are common as are small log and branch impressions. These coarse sediments are arranged in 'trough' shaped sets which may take one of two main forms, Type A or Type B, although there are intermediate forms (Fig. 13).

Features common to both types of medium scale cross beds are:-

1/ Sets have tangentially based foresets. Angular based foresets are uncommon (Figure 14).

2/ Grading of the foresets is nearly always normal.

3/ Pebble lag conglomerates occur along the lower bounding surfaces (Figure 15).

3.11.2 TYPE A

Type A trough sets are characterised by:-

1/ their horizontal laterally extensive lower bounding surface,

2/ the fill of the 'scoop' is symmetrical in section perpendicular to the current longitudinal section,

3/ the set is elongate parallel to the flow direction with adjacent set axes nearby perfectly parallel,

4/ individual sets are laterally extensive, up to 10 m in length parallel to the palaeocurrent.

3.11.3 TYPE B

Type B trough sets have:-

1/ distinct concave up or 'scoop' shaped lower bounding surfaces,

2/ only a short lateral extent,

3/ the fill of the scoop can either be asymmetric or symmetric when viewed perpendicularly to the current direction.

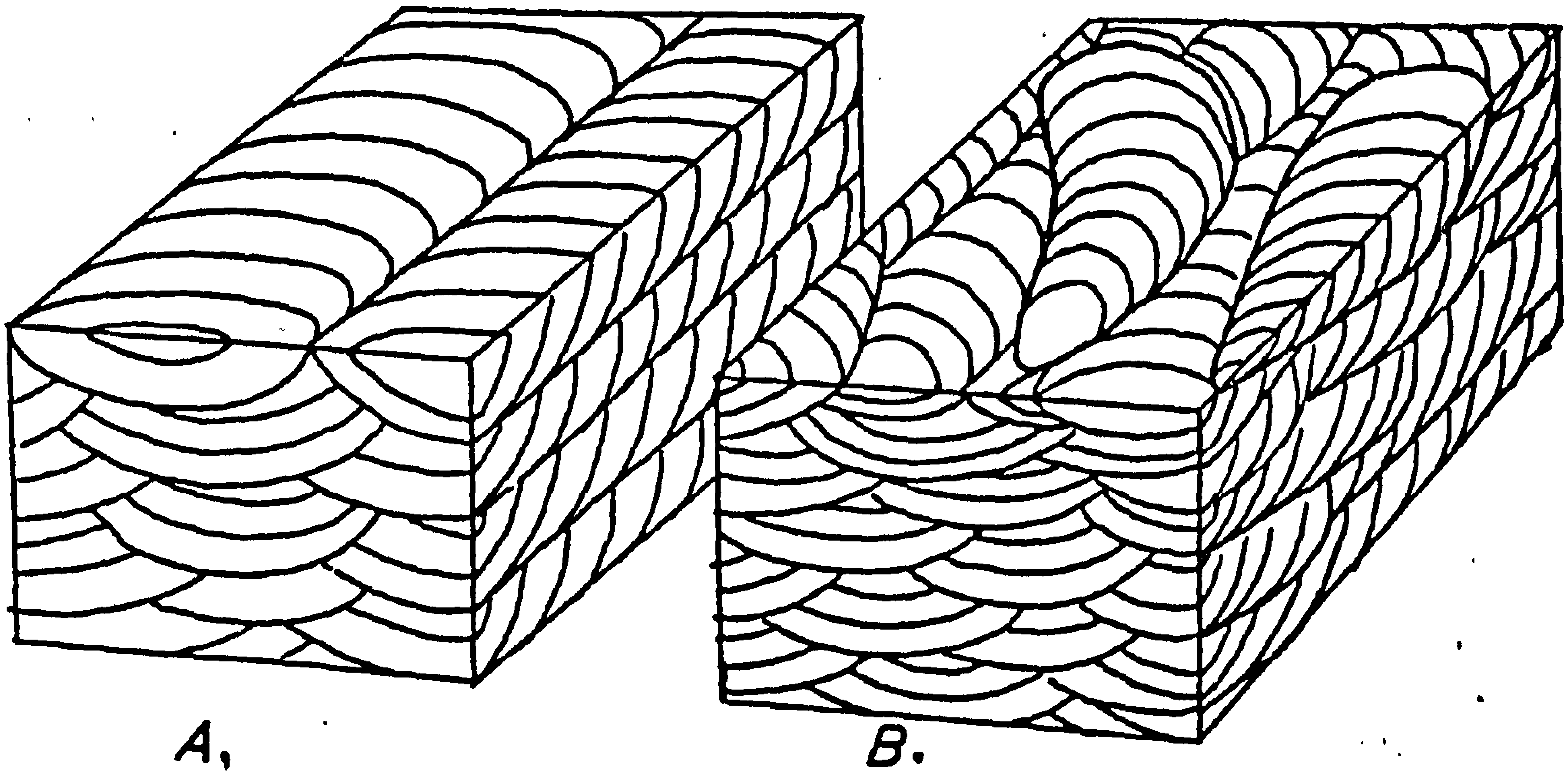


Fig. 13. Block diagrams of facies 10, Medium scale cross-bedded sandstones showing the two main types of coset organisation.

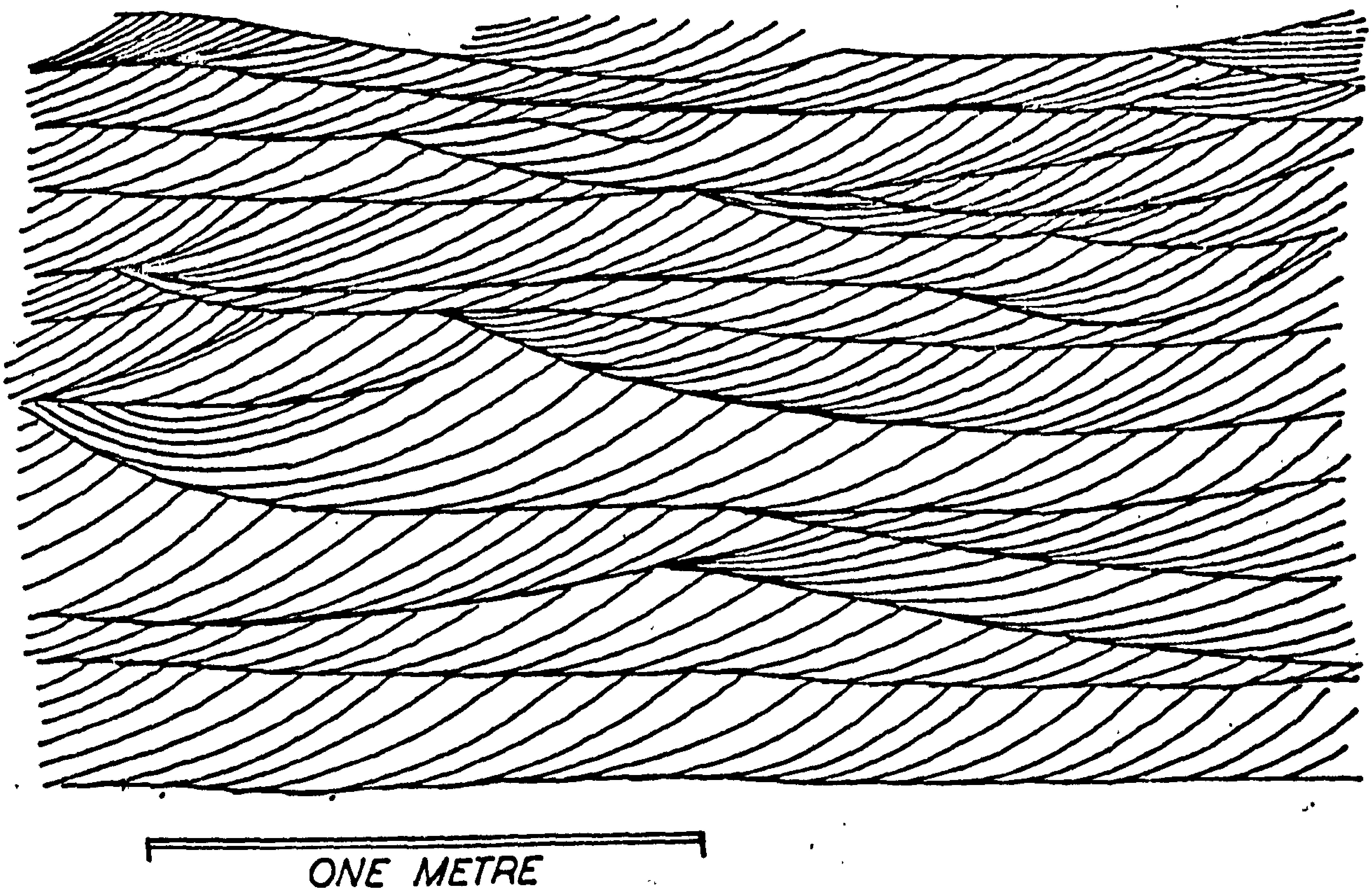


Fig. 14. Field sketch of facies 10, Medium scale cross-bedded sandstones showing the scoop-shaped nature of the lower bounding surface. Pockstones Moor (SE10176040).

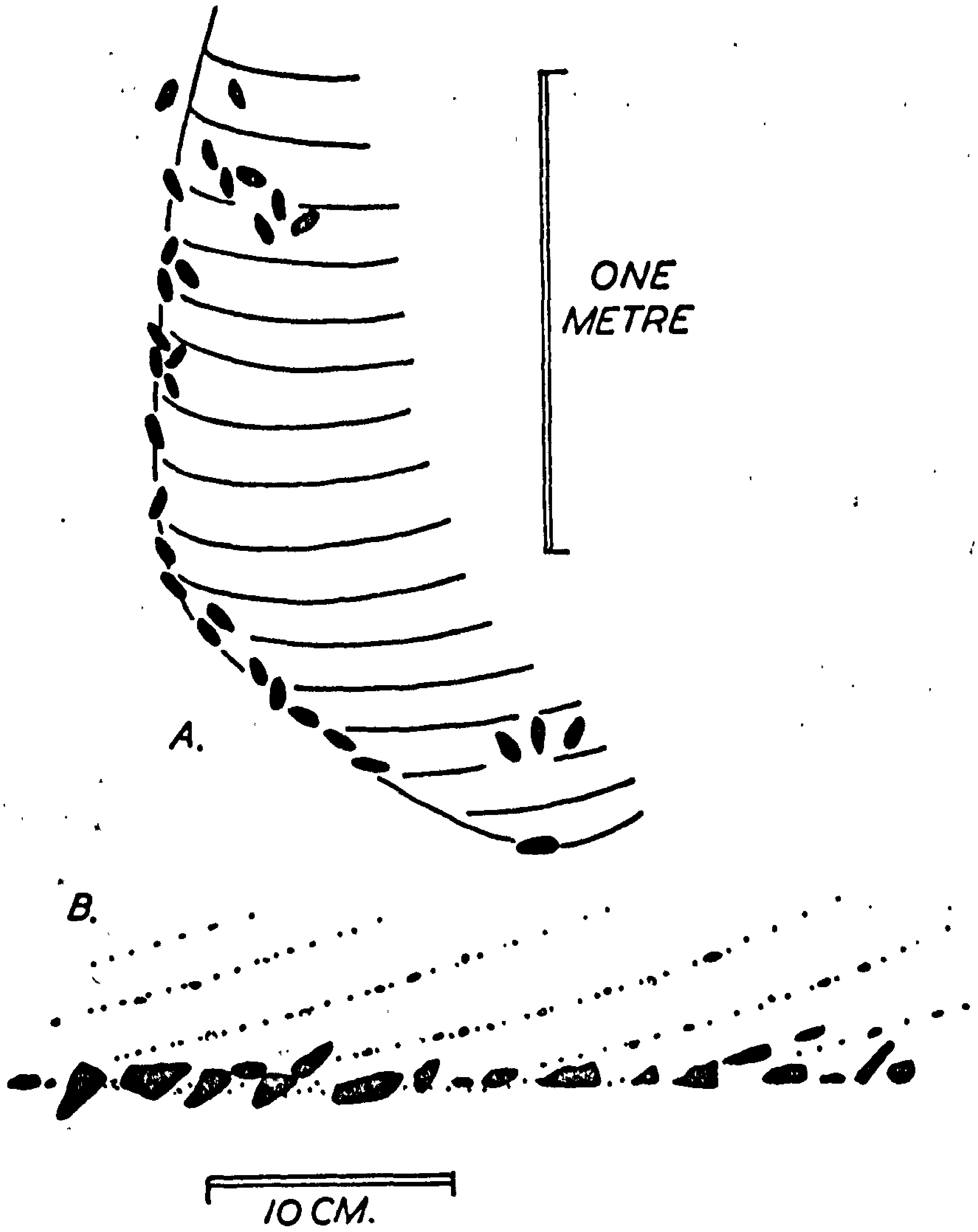


Fig. 15. Two field sketches showing pebble imbrication and orientation in relationship to the erosive margins of facies 10, Medium scale cross-bed sets. A/. Deer Gallows Ridge (SE999556), B/. High Bradley (SE003496).

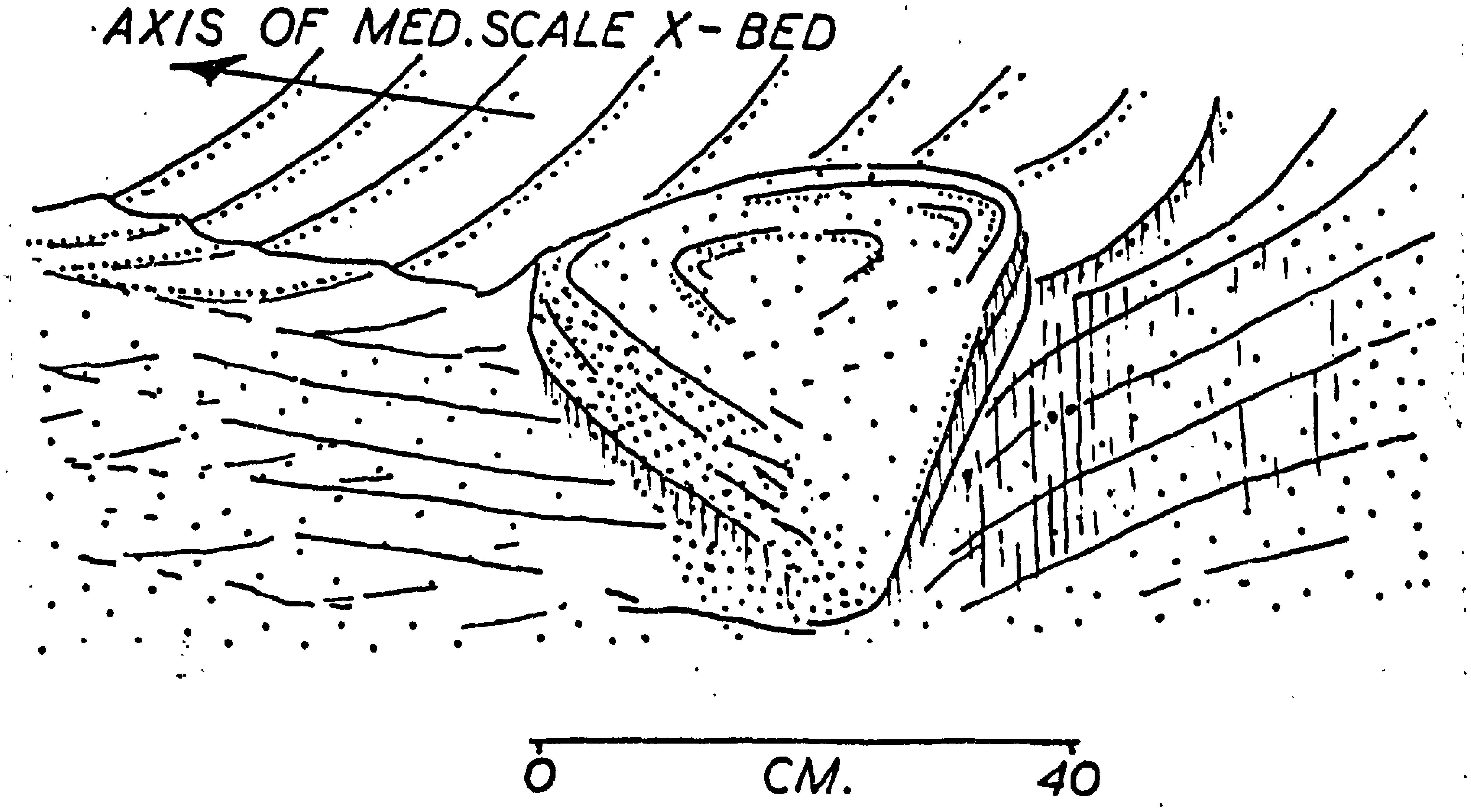


Fig. 16. Sketch of facies 10, Medium scale cross-bedded sandstone showing a dewatering structure. Delta Top Association. Fancarl Crag (SE065626), Appletreewick.

3.11.4 DEWATERING STRUCTURES

Dewatering structures, whilst not common, are distinctive, and several forms are commonly developed.

The first type is an arrangement of vertical 'pipes' which truncate the cross bedding. Each pipe consists of concentrically spaced ribs of sandstone which weather differentially. Photo 30 shows a cross section of one such pipe where six of these ribs pass vertically through foreset laminae of medium scale X-bedding. There is little or no sign of distortion of the foreset laminae immediately adjacent to the pipe structure. Normally, the structure is incompletely preserved. Width dimensions vary from 90 cm to 40 cm whilst the maximum height of the ribs recorded was just over 2 metres. In those examples examined in the field, no obvious direction of penetration can be detected (Photo 32), (Fig. 16).

This is not the case in the second type of dewatering structure. Here, disruption of the sediment is upwards in a circular volcano-shaped diapir (Photo 33).

A third type consists of a non-truncating upward disturbance. There is no defined pipe; instead, individual foresets of medium scale X-bedding are elongated and distorted (Photo 34).

A fourth type takes the form of simple upward disturbances. These manifest themselves as symmetric or symmetric anticlinal kinks in the foreset laminae. Normally these are only a few centimetres high and are spaced in either a regular or irregular pattern (Photo 35).

Finally, one example of "balling" of the sediment has been found. Here, the disruption or contortion of sediment appears to have been caused before succeeding beds were laid since overlying cosets rest on an irregular surface (Photo 36).

3.11.5 INTERPRETATION

The exact genesis of medium scale trough X-bedding is still equivocal. On the one hand, it has been attributed to a migration of large scale ripples or dunes containing hollows within their geometrical pattern (Allen 1963a), whilst on the other, a less rigid geometrical association is involved (Harms et al 1965), where there is a 'scour and fill' mechanism.

Allen (1968, for review) and numerous other workers found that sandy river beds were dominated by transverse catenary large scale ripples. The downstream migration of these caused simultaneous erosion and deposition within the three dimensional pattern. Trough scours appear related to the lobes in the ripple crest.

Simons et al (1961) note that large scale ripples are formed by lower flow regime currents flowing at relatively high flow intensities.

An alternative hypothesis is that the scouring element is due to a "kolk" like macroturbulence (Matthes 1947) whereby the scour is independent of the separation zone and vortices of the dunes.

It is suggested that the Type A X-beds described above might be related to the migration of large ripple and dune bedforms whilst the Type B X-beds, with their more irregular fill, may be related to macroturbulence scour and subsequent fill. Intermediary forms are related to the degree of organisation of migratory bedforms and associated lee side vortices and turbulence elements.

With regard to the "Dewatering structures", Coleman (1969) noted in his study of the Brahmaputra River, that virtually every outcrop of channel sediment showed some type of primary or secondary distortion. He observed that the rapid rise and fall on the river level, combined with the heavily sediment-laden currents, produced a variety of contorted bedding types. Williams (1970), working on Australian ephemeral stream deposits, also noted that a local or regional raised water table was necessary before bed stability and liquefaction of the sediments occurred.

In the case of the examples shown in Photos 30 and 32, the exact mechanism responsible for the organisation of the sediment into discreet penetrative 'ribs' is not understood.

3.12 FACIES 11. LARGE SCALE CROSS-BEDDED SANDSTONES

3.12.1 DESCRIPTION

Two types of large scale cross-bedding are distinguished. Table 4 lists the major distinguishing features. Both types are characterised by being formed from poorly sorted, extremely coarse and pebbly sandstone. Mudstone clasts and wood debris are common.

TABLE 4. Contrasts in sedimentary features of large scale cross beds.

	TYPE A	TYPE B
Angle of foresets.	Maximum 28°, Av. 22°.	Maximum 27°, Av. 17°.
Lateral length of foresets.	Short, concave upwards.	Long, straight or gently concave.
Strike of foresets.	Straight.	Convex down current.
Sedimentary features.	Massive or normal grading.	Normal grading.
Internal erosion surfaces.	Steep, up to 40°.	Long, gently inclined.
Intrasets.	Planar or trough type.	Planar type dominate.

3.12.2 TYPE A

Dimensions of Type A large scale cross-beds are listed in Table 6 (see Section 4.4). In longitudinal section, the foresets are steep, comparatively short in length, concave and have fairly well defined tangential toeset beds (Photo 37). Foresets, up to 0.5 metres thick, are parallel sided and are laterally extensive. They usually show normal grading. However, in the upper portion of many large scale sets, beds have a massive weathering appearance (Photo 38). In some instances, the external surface weathering pattern is similar to "Ropy" and "Blocky" weathering sandstones described in facies 9 and 12 respectively (Photo 44). In the lower portions, individual foreset laminae are well defined. On the upper surface of the laminae are occasional small solitary sets. This type of solitary set has been referred to as "intra-sets" by Collinson (1968). He reports only a trough shaped set from the R_{1C} large scale cross-beds. The E_{1C} beds show two types, a trough-shaped set and wedge-shaped planar set. The trough-shaped intrasets have scoop-shaped lower bounding surfaces and tangential foresets with normal grading(Photo 45).

The tabular intrasets are laterally more extensive and appear wedge-shaped in three dimensions. Widths and lengths are in the order of two or three metres. In several instances, the intraset clearly shows preservation of toesets, foresets and topsets (Photos 39 and 40).

The trough type of intraset can be randomly orientated but usually azimuths are down the major foreset slope. The wedge-shaped tabular intrasets always show azimuths facing down the foreset slope.

Type A large scale cross beds also show internal erosion surfaces. These are not always conspicuous, especially where beds are massively weathered (Photos 42 and 43). The erosion surfaces are steep, up to 45° and are not as laterally extensive as illustrated by Collinson (1968) or McCabe (1975a). Overlying foresets dip parallel to the erosion surface (Photo 41).

3.12.3 TYPE B

Dimensions are listed in Table 6 (see Section 4.4). This type of large scale cross-bed has long straight or gently undulatory inclined foresets (Fig. 17 and Photo 48). The foresets may show small intrasets. These are thin, 10 to 20 cm thick, parallel sided, tabular sets. Azimuths are always down the foreset slope. Only one trough shaped intraset has been observed.

Grading of the major foresets is normal. Internal erosion surfaces are long and laterally extensive and appear similar to those described by Collinson (1968) and McCabe (1975a).

3.12.4 DEFORMATION STRUCTURES

Several examples of Type A large scale cross-beds show a disruption of the foresets by vertical to sub-vertical "shear" planes (Fig. 18, Photo 47). The amount of disruption is comparatively small, not exceeding 50 cm, and in all of the outcrops examined, the strike of the "shear" plane

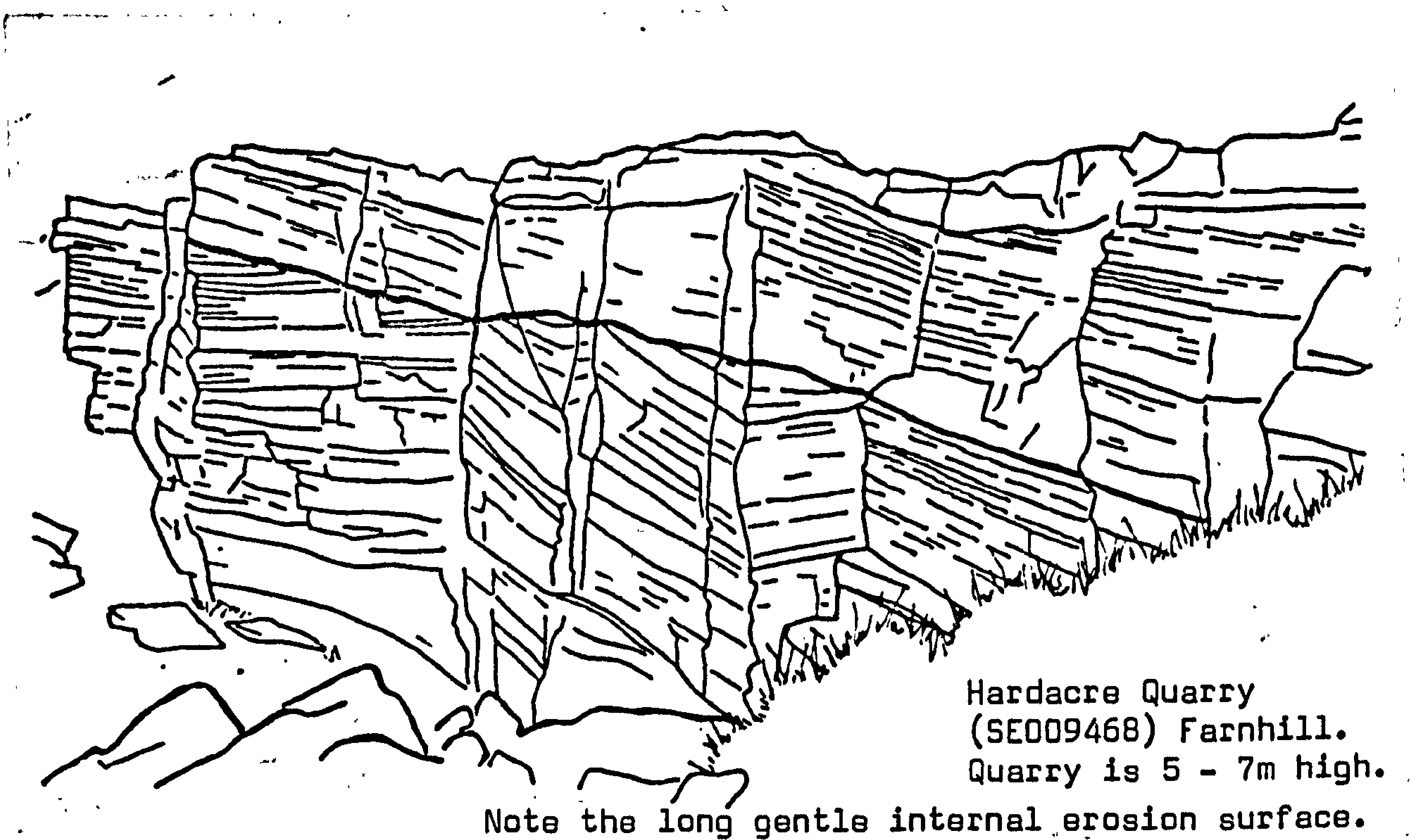


Fig. 17. Field sketch of facies 11, Large scale cross-bedded sandstones (Type B). (See also Photo 48).

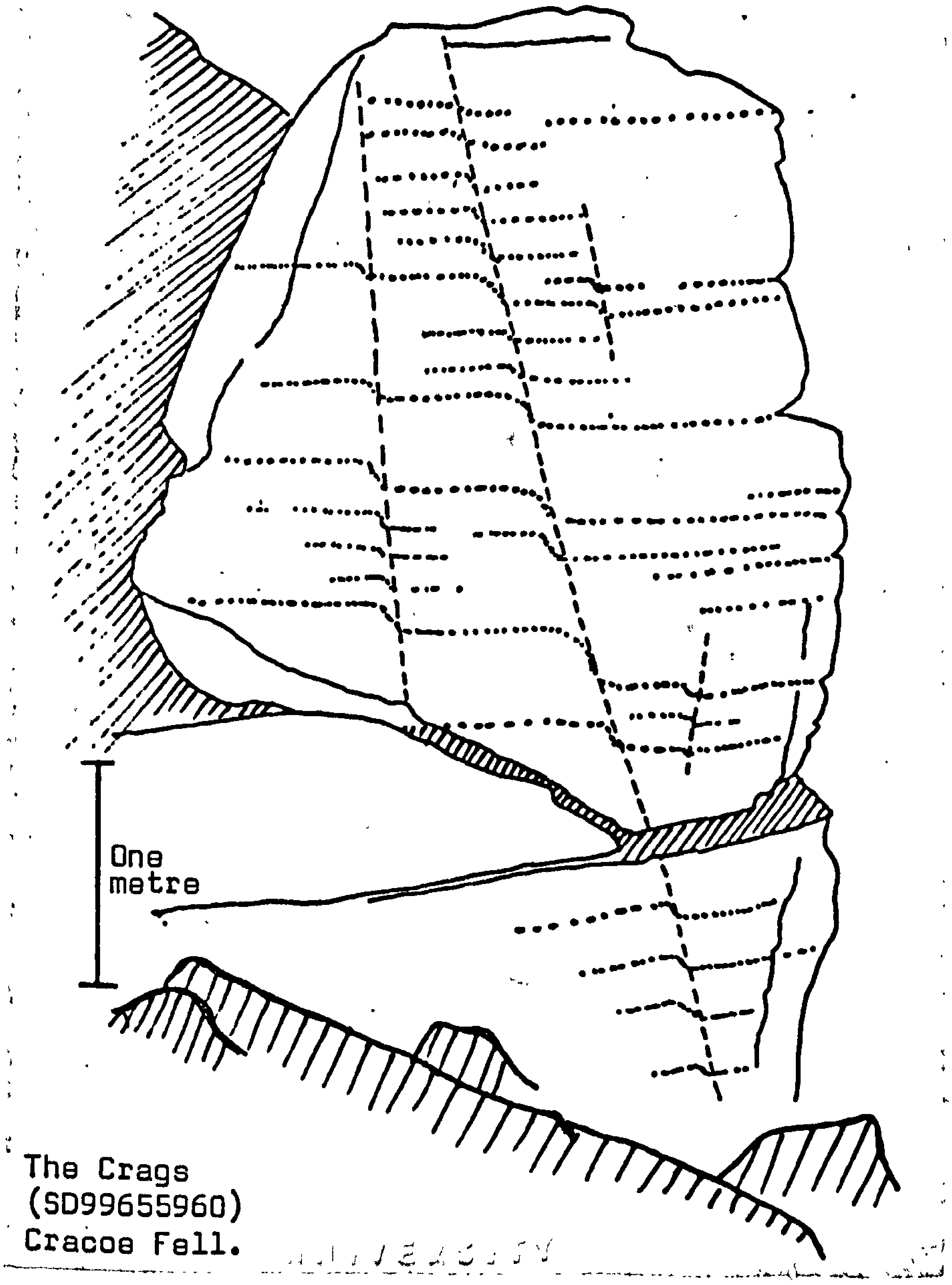


Fig. 18. Field sketch of shear deformation structures in facies 11, Large scale cross-bedded sandstones (Type A).

is perpendicular to the major foreset azimuth. Photograph 46 shows the only example of multiple disturbance.

3.12.5 INTERPRETATION.

The large-scale cross beds are broadly analogous with those produced by asymmetric current ripples, except the scale is greatly magnified, and internal erosion and smaller superimposed sets complicate the picture. Coarse sediment and carbonaceous debris have been carried to the crest line of the foreset and have cascaded down the lee slope. Deposition at this crest line was extremely rapid, consisting of mass dumping and almost simultaneous avalanching, with mass slippage distributing material lower down the lee slope. Only deceleration on the lower parts of the lee slope allowed any form of bed organisation. Separation eddies and water turbulence boils cause reworking of material on the slip-face, hence the intrasets. The random orientation of many of the trough-shaped intrasets suggests that separation eddies occur randomly and sporadically.

As regards the contrast between Type A and Type B large scale cross-beds, these are left to a fuller discussion in Chapter 4.4, Facies Association.

Collinson (1969) attributed the formation of large scale cross-bedding seen in the R_{1C} as being the product of outward building deltaic sedimentation units. However, as is discussed in Chapter 4.4, the large scale cross-beds are regarded in terms of migrating fluviatile bed forms (see also McCable 1975a).

The deformation structures (shear planes) are considered to have formed almost simultaneously with deposition of the foreset. Fig. 18 shows that the planes of disruption are vertically discontinuous. Why they form is not understood but it is thought that they may be related either to failure, due to mass loading, or partial collapse of the main lee face.

3.13. FACIES 12. MASSIVE SANDSTONES

3.13.1 DESCRIPTION

This facies includes those sandstones and conglomerates which can only be described as having a "massive" or structureless appearance in the field. These so-called massive beds, are dominantly composed of poorly sorted, coarse and pebbly sandstones with ubiquitous, large, randomly orientated, mudstone and siltstone clasts. Log casts are also common. Field exposures of the massive sandstone are often large, usually cliffs, prominent crags or quarries. Outcrop faces weather from a dark rust brown to a dull matt grey. Fresh and unweathered specimens of rock are difficult to obtain as weathering and chemical leaching often penetrate up to 50 or 60 cm. In fresh specimens, the rock is often light grey to pink in colour.

Many outcrops show a distinctive weathering phenomena. This is either a hexagonal or blocky surface texturing (Photo 49, 50 and 51) very reminiscent of the so-called "Ropy weathering" pebbly sandstone of facies 9.

Careful examination of weathered and fresh specimens show that this texturing is superficial and is not related to any internal sedimentary organisation.

3.13.2 INTERPRETATION

The massive, seemingly structureless and ungraded nature of the pebbly sandstone, along with the numerous large mudstone and siltstone clasts, and the obvious poor sorting of the sediments, suggest that "powerful currents are involved" (Collinson 1969, P. 203). Massive sandstones with a similar description are cited by Klein et al (1972) as occurring on the front of the Cretaceous Reconcovo Delta. Klein et al consider that the poor sorting and mudstone clasts are indicative of sedimentation from "..... a fluid medium characterised by a high collision rate of grains in transport under conditions of high sediment concentration" (cf Bagnold 1954). They suggest a similarity with mass flow phenomena as described by Dott (1963) and Morgenstein (1967).

The author concurs that these sediments are the result of a high energy regime, but is inclined to believe that they are more related to traction currents than mass flow phenomena, even though traction current structures are absent. This argument is developed more fully in Chapter 4.3.

A final note concerns the question as to whether or not one should call the sandstones "massive." J. R. L. Allen (1971b) is critical of Collinson's (1970) application of the term massive and considers it necessary to "suspend judgement upon their nature, mode of origin and environmental significance."

Nevertheless, numerous authors, including the writer, use the term "massive" sandstone as a convenient field term.

3.14 FACIES 13. COAL AND SEATEARTHS

3.14.1 DESCRIPTION

Coal and seatearths are described together because of their close association, small volumetric importance and poor exposure (cf Collinson 1969). Very few exposures of seatearth have been found. Perhaps the best example is seen a few metres upstream ofthe ford at Agill Well on Barden Moor (SE08135790). It is recognised by the presence of small dark rootlets penetrating a medium grained ripple cross-laminated sandstone. The rootlets are apparently in their growth position. The thickness of the seatearth cannot be accurately determined, but does not appear to exceed 10 cm.

Small coal seams are widespread throughout much of the Grassington Grits and northern lateral equivalents and have also been reported from the Warley Wise Grits (Bray 1927). The coal seams themselves are of poor quality (A. Raistrick, Personal Communication) and are not very thick, usually less than 30 cm, although on Threshfield Moor, it was considered thick enough to warrant pit-mining (Williamson 1960).

3.14.2 INTERPRETATION

The implications of this facies are considerable. Reading states "Although limited in amount, this association is of disproportionate importance because it is the one certain indicator of depth, proving if not actual emergence, very shallow water" (Reading 1970, P. 22).

The presence of the seatearth indicates that vegetation was growing in the area and that much of the associated coal probably had an autochthonous origin. An allochthonous origin (i.e., drifting and consequent entrapment of plant debris) for some of the coals is also a possibility, certainly when one considers the large numbers of logs and pieces of wood which are found in the coarse pebbly fluviatile sandstones.

CHAPTER 4. FACIES ASSOCIATIONS

4.1 INTRODUCTION

The thirteen facies described above, have been grouped into three broad Facies Associations.

A. THE TURBIDITE ASSOCIATION

B. THE SLOPE ASSOCIATION

C. THE DELTA TOP ASSOCIATION

Collinson (1969) considered that the grouping of genetically related facies into Facies Associations was necessary since only then could the spatial relationships be understood. From these appreciations, a palaeoenvironmental reconstruction could be made.

In a similar fashion, each association is described and interpreted in turn. Then an overall environmental resume is made (Chapter 6) incorporating the interpretations from this chapter and the Palaeocurrent data from Chapter 5.1.

One of the problems besetting the study of Facies Associations in the E_{1C} succession has been the difficulty in defining the field boundaries between each association. In nearly all instances, the boundaries are gradational. However, in order to illustrate the differences between associations in the accompanying maps, diagrams and cross sections, arbitrary boundaries have been defined.

Within the Skipton area, each Facies Association approximates to a stratigraphical formation, i.e.:-

Delta Top Association = Grassington Grit Formation

Slope Association = Pendle Shale Formation

Turbidite Association = Pendle Grit Formation

The relationship is illustrated here as a reminder and cross reference with the Stratigraphy detailed in Chapter 2.3.

At the end of each Facies Association section, a brief review is made of the various boundary problems. Also, a consideration is made of those horizons outside of the mapped area that are thought to be lateral equivalents. Since previous work in these areas concentrated solely on stratigraphic and structural relationships, a re-interpretation is made in terms of Facies Association, utilizing the lithological descriptions of the earlier authors.

4.2. TURBIDITE ASSOCIATION

4.2.1 INTRODUCTION

For descriptive purposes, the Turbidite Association has been divided into three sub-associations:-

A. Mudstone and thin turbidite sub-association

B. Composite sandstone sub-association

C. Ropy sandstone sub-association

Sub-associations B and C usually form marked topographical features (Figs. 19, 20. Photos 56, 57).

4.2.2 MUDSTONE AND THIN TURBIDITE SUB-ASSOCIATION

Dark mudstones (facies 1) intercalated with thin siltstones (facies 4) and thin turbidites (facies 6) form the dominant part of the Turbidite Association. However, exposure is poor and they tend to form "slacks" (marshy hollows) or long steep scree and vegetation covered slopes. In many ways, the term Pendle Grit is a misnomer, but since it is only the grits that are normally exposed, the term Pendle Grit is retained to differentiate this formation from the overlying Pendle Shales.

Detailed examination of an outcrop of intercalated mudstones, siltstones and turbidite sandstones shows the following relationships. Contacts between the thin turbidites and the mudstones are always sharp, whilst contacts between the siltstones and the mudstones are either sharp or gradational, usually the latter. In those parts of the succession where micro-laminated siltstones (facies 3) are developed (i.e. towards the top of the Upper Bowland Shales), thin sections show the base of the micro-laminated siltstone as being sharp, whilst the top is gradational.

Colour code;- purple - Upper Bowland Shales; dark green - Turbidite Association (Pendle Grits); light green - Slope Association (Pendle Shales).

Fig. 19. Oblique aerial view of Skipton Moor, looking southwards towards Standard Crag and Draughton Moor. The topography is controlled by a series of channels (see Fig. 20 for map), (see also Photos 56, 57 & 58).

Fig. 20. Geological map of the northern flank of Skipton Moor.

The thin turbidite sandstones may be developed either as a single bed or in amalgamated units of several beds. When traced laterally, some of these amalgamated units become more expanded in thickness and eventually pass into what is classed as facies 7, Composite sandstones.

(The distinction between small developments of amalgamated beds and a Composite bed is very subjective. Classification is normally based on an overall impression of thickness).

4.2.3 COMPOSITE SANDSTONE SUB-ASSOCIATION

Composite sandstones (facies 7) may be arranged in multiple units of up to 40m in thickness (Photo 52). Erosive bases and amalgamations within the unit are common and four base types have been recognised (cf. Lovell 1969).

Mud clast conglomerates are concentrated either towards the top or bottom of the amalgamated bed, and are often the only indication of the former presence of an interbedded mudstone horizon. In one instance, the mudstone clasts are seen to be imbricated, giving a crude palaeocurrent direction (Photo 53).

The multiple units of Composite sandstones tend to form features, and detailed mapping, indicates that they form large irregular lenses up to 500m wide. Photo 28 (Jenny Gill Quarry - SE00355095) shows that the base of the multiple unit can be markedly channelised. On a regional basis, the multiple units can also occur at different stratigraphical levels within the Turbidite Association. For instance, one multiple unit is seen resting directly on Upper Bowland Shales at Jenny Gill Quarry (SE00355095) on Skipton Moor (Photo 52), whilst in Kex Beck, just above Deerstones, a multiple unit is seen directly below the Slope Association (SE09025296).

Finally, it was noted that there were instances where thin turbidite sandstones became more expanded and were finally classed as Composite sandstones. Likewise, some of the Composite sandstone developments seem to show transitional forms with the Ropy weathering sandstones (facies 9), (Fig. 22).

4.2.4 ROPY WEATHERING SANDSTONE SUB-ASSOCIATION

Erosive into both the mudstone and turbidite sandstone sub-association and the Composite sandstone sub-association are channels filled with facies 9, Ropy weathering sandstones (Fig. 21 a-e). These channels are best developed on Skipton Moor (Photos 56, 57 and Figs. 19, 20). The channels vary in thickness between 2 and 15m whilst their maximum exposed width may be over 100m. The bases of the channels are rarely exposed but examples of the contacts usually show them to be flat and structureless. The edges of the channels are particularly poorly exposed, but field relationships suggest that they are comparatively steep, e.g. 30 to 40°.

Field mapping has also suggested that there may be channels on a larger scale. Two features especially seem to fall into this category. The first is the Cracoe Fell spur (SD992599), a large topographic ridge on the north-western flank of Cracoe Fell. The second is the large mass of Sandstone forming the conspicuous rib at Bolton Abbey (SE07505405). However, both structures are somewhat inaccessible and need further study before a firm conclusion is reached.

Some of the outcrops classed as Ropy weathering sandstones, show characters similar to the so called facies 12, Massive Sandstones, which are developed in the overlying Slope Association succession. An overall impression is gained that there is a continuum of bedding types from the thin turbidite sandstones through Composite sandstones and Ropy weathering sandstones to the Massive Sandstones.

4.2.5 INTERPRETATION

The dark mudstones of the Upper Bowland Shales are considered to have been deposited in comparatively deep water, or at least in water below an effective wave base. Deep water conditions persisted throughout the deposition of the Pendle Grit Formation, though with a persistent introduction of clastic material into the Central Pennine Basin.

Norton Tower Hill
(SD97645711)

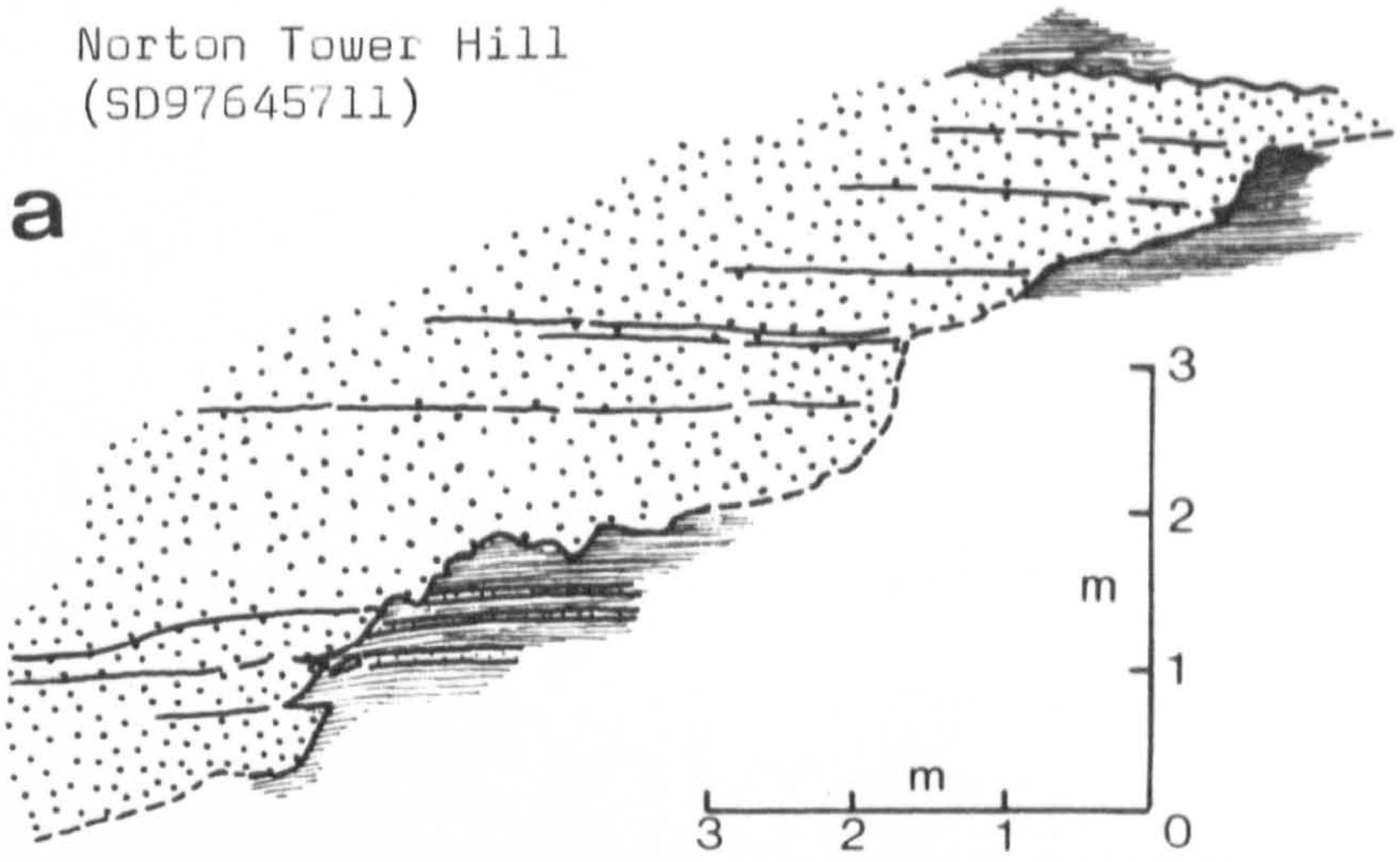
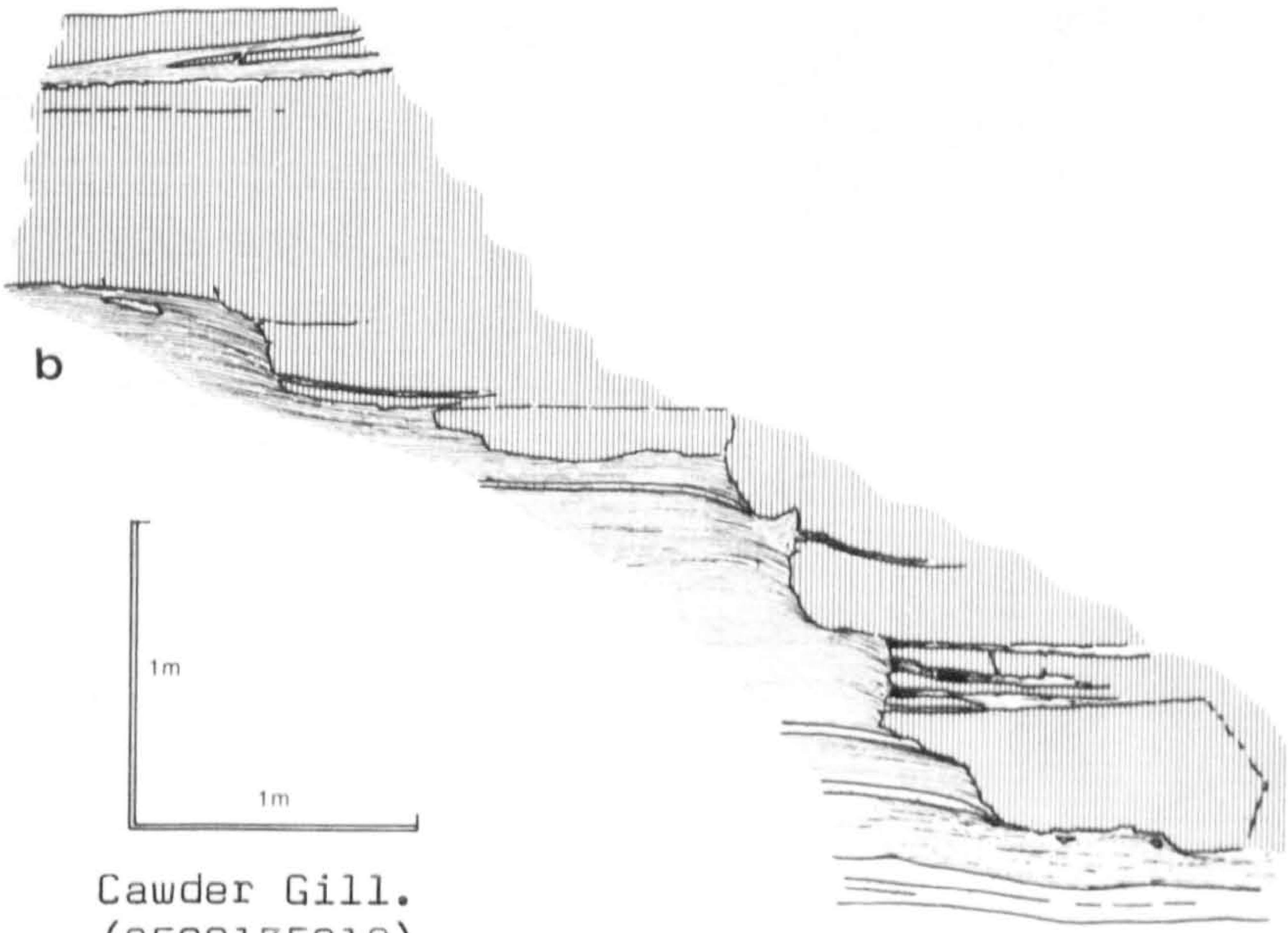
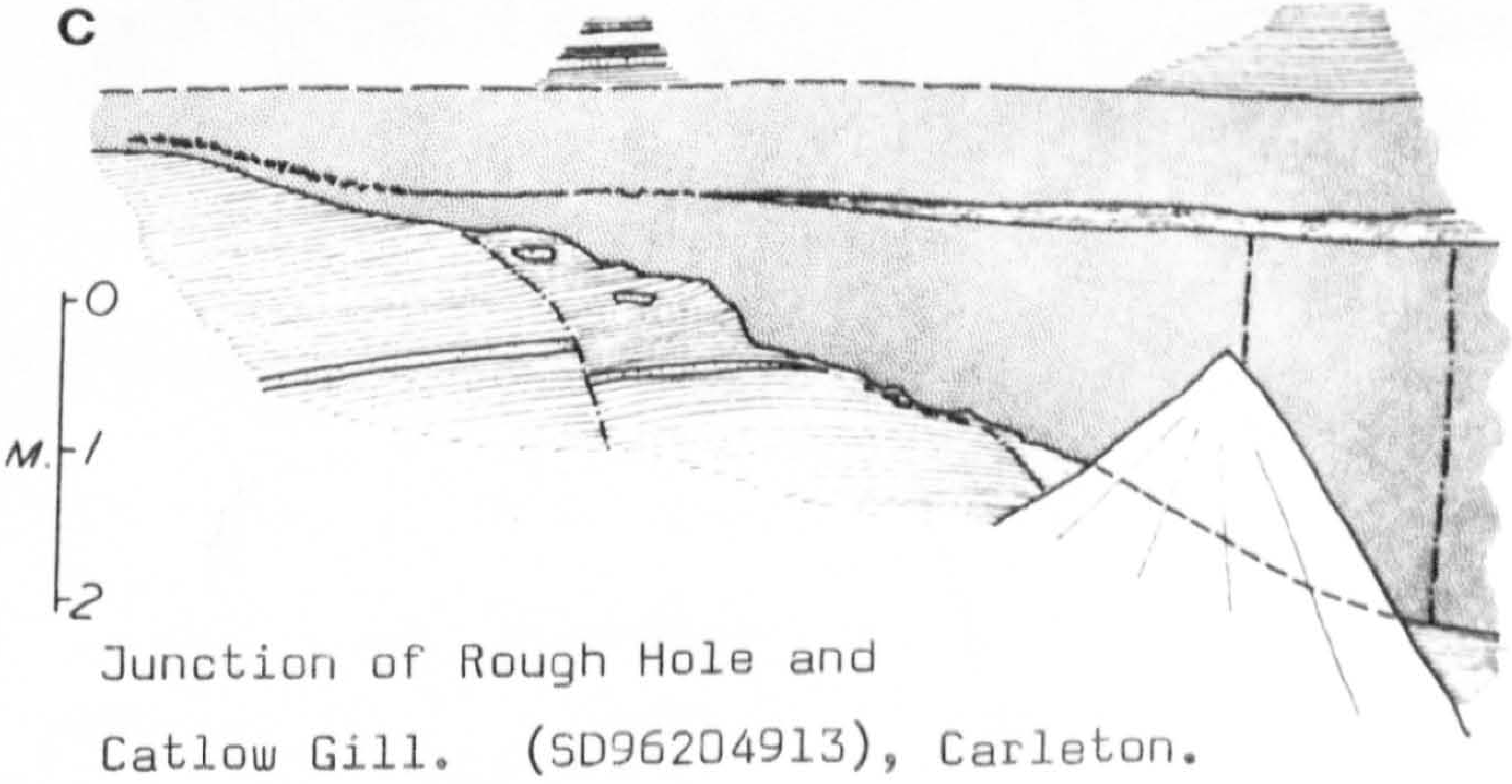


Fig. 21 (a - e). Channels in the Turbidite Association filled with facies 9, Ropy weathering sandstones and facies 7, Composite sandstones.



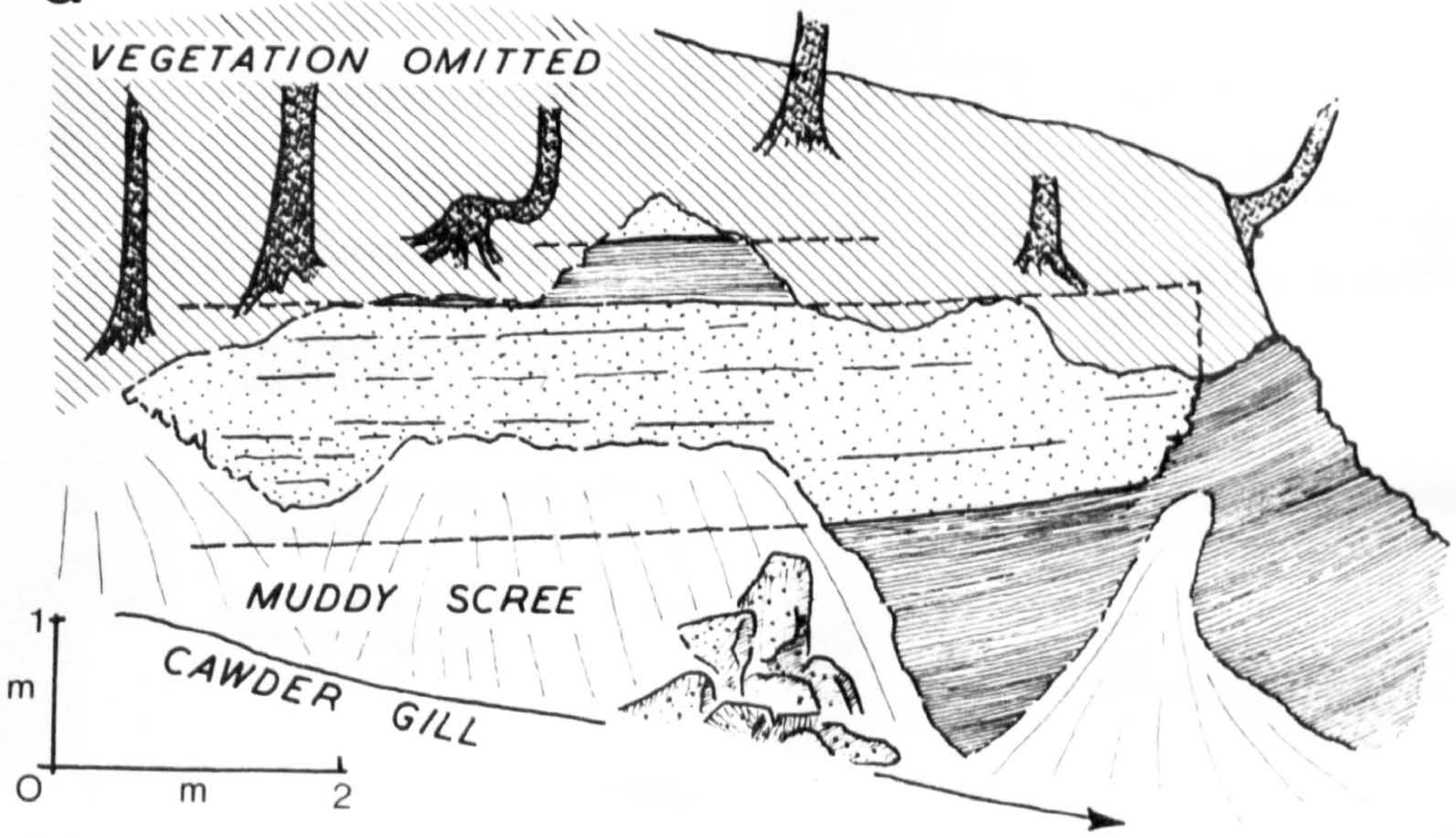
Cawder Gill.
(SE00135018)
Skipton.



Junction of Rough Hole and

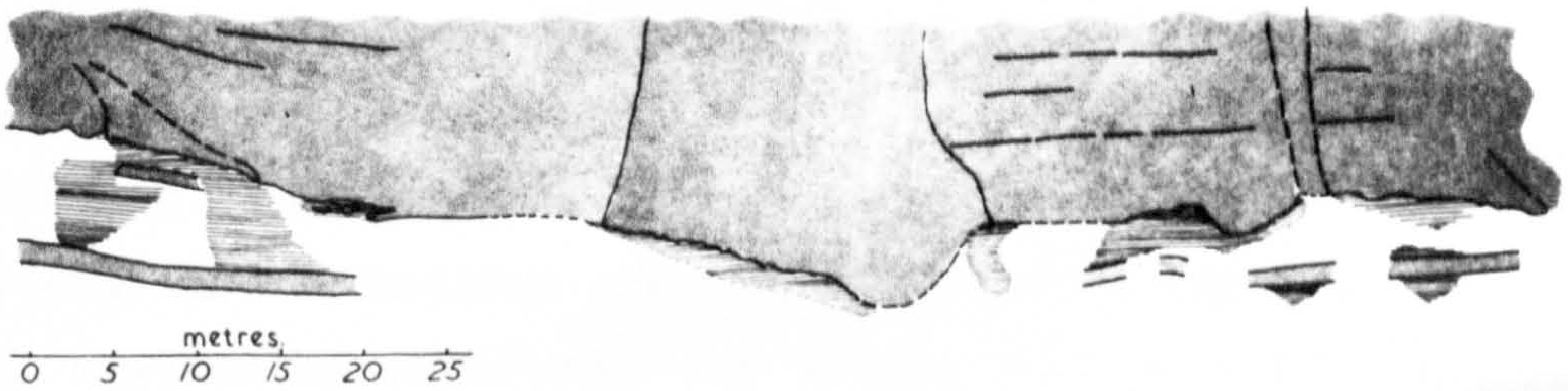
Catlow Gill. (SD96204913), Carleton.

d



Cawder Gill (SE0001509)
Skipton Moor.

e



Cat Crags (SE07765441), Beamsley.

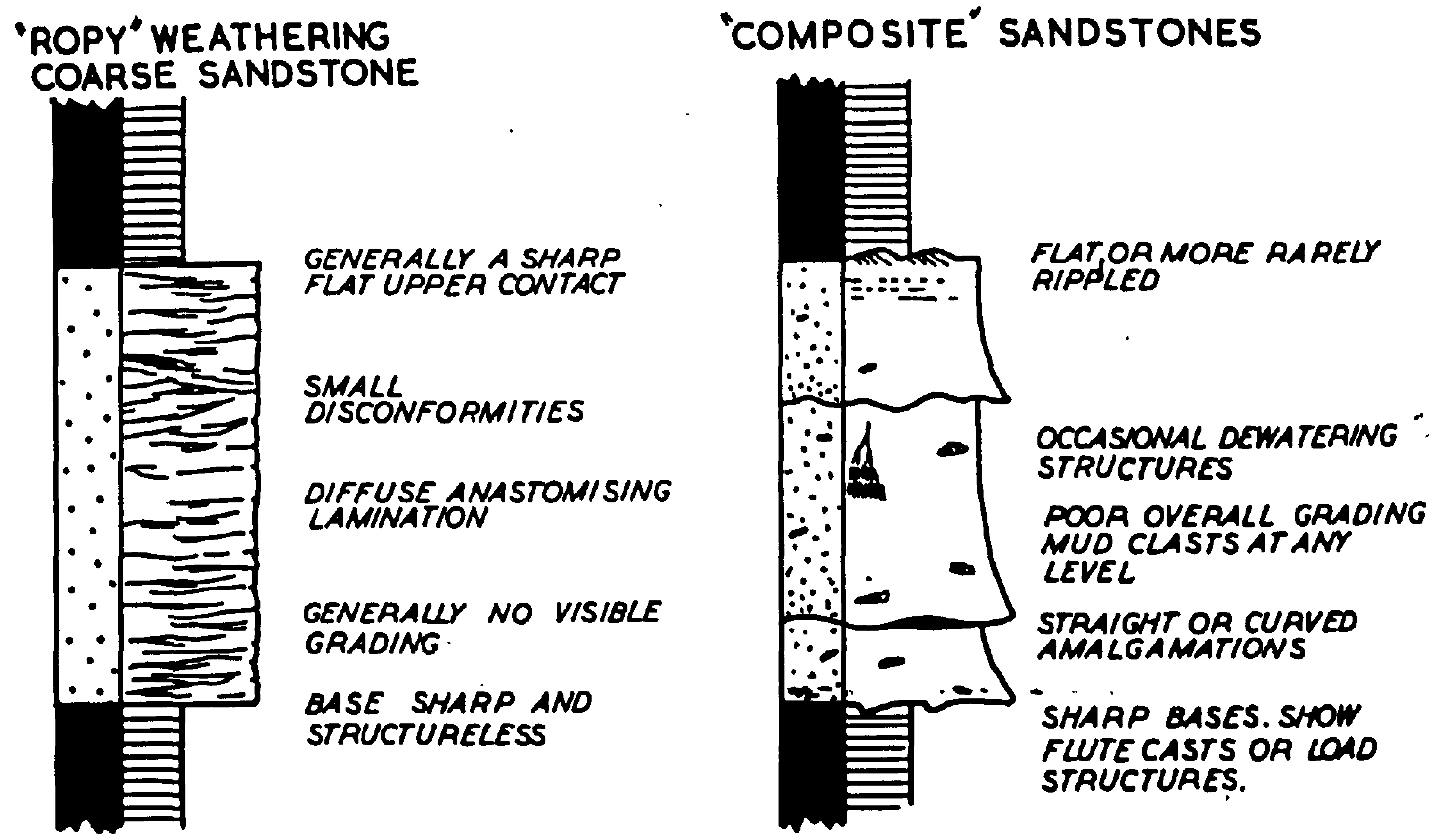


Fig. 22. Two sketches demonstrating the comparisons and contrasts between facies 9, Ropy weathering sandstones (left) and facies 7, Composite sandstones (right). Both have sharp erosive bases but the Composite sandstones are more likely to have sole markings, usually flute casts or large squamiform load markings. The Ropy weathering sandstones do not normally show any upward organisation whereas the Composite sandstones may show grading (frequently difficult to detect), dewatering structures (elutriation columns) and occasional bow-shaped linguoid ripples. The Ropy weathering sandstones are interpreted as occurring in submarine feeder channels whilst the Composite sandstones were probably deposited as part of a delta front fan. (Note: field mapping has shown that there is a continuum between the two types.)

In the mudstone and thin turbidite sandstone sub-association, the mudstone represents a "background" sedimentary regime. The environment is comparatively quiet and mud and fine silt gradually fall out of suspension. The thin turbidite sandstones however represent part of the periodic invasions of clastic material. The thin turbidites are distal in aspect, though they may represent the thin lateral marginal deposits of larger influxes of material elsewhere. Likewise, the development of the micro-laminated mudstones (facies 3) also indicates a distal position.

The Composite Sandstones are regarded as a more proximal development. As such, they compare closely to the "Massive Sandstones" seen in the Shale Grit (Walker 1966, P. 99). Walker initially describes them as 'Facies 'C' sandstones, but later as'Facies B_2 Massive Sandstones without Dish Structures' (Walker and Mutti 1973, P. 129) (Compare Fig. 7 in Walker and Mutti with Photo 52).

Walker (1965) considered that this type of sandstone was deposited from "immature or semi-mature" turbidity currents in which there was little vertical and lateral grain segregation. Reading (1970, P. 24) has suggested that "immature turbidites" could be recognised as a "sub-association" and that this type of deposit could include beds brought in by mechanisms such as "grain flow" or "inertia flow".

The multiple units of Composite sandstone are here interpreted as submarine fan deposits. Whilst Walker and Mutti (1973) suggest that the 'Facies B_2 Massive Sandstones' (R_1 Shale Grits) were deposited in a "middle fan environment", it is suggested that the E_{1C} examples are not so readily categorised. The reasoning behind this suggestion is that as yet, in Restricted basin, Turbidite Fronted Deltas (see Chapter 6.1.4), the typical model suggested for deep water submarine fan systems (e.g. Normark 1970) may not be applicable. It is suggested that further research is needed to establish a new model more relevant to restricted basin environments.

The Ropy weathering sandstones occur as channel fills within the turbidite sequence, and their deposition is therefore probably from turbidity currents or from currents associated with them. In many environments, the most powerful and highest density currents are often confined to channels, and with high density flows, the depositional processes may often involve other elements than deposition from suspension. In particular, the development of a traction carpet in which grain flow conditions operate, may occur. The superficial comparison of the ropy weathering with the products of alleged grain flows has already been noted, but it must remain uncertain whether or not such processes played an important role in the deposition of the Ropy weathering sandstones.

4.2.6 FIELD BOUNDARY DEFINITION

In the area mapped, defining the base of the Turbidite Association initially proved difficult. Normally the base of the Skipton Moor Grits (i.e. the base of the Pendle Grit Formation in this thesis) was defined by Stephens _et al_ (1953) as starting at the top of the Upper Bowland Shales. However, in making a palaeoenvironmental reconstruction, it is considered more logical to include the mudstones forming the Upper Bowland Shales in the Turbidite Association.

There are two reasons for this. To start with, the clastic material forming the base of the Pendle Grit Formation occurs at markedly different stratigraphical levels. Defining a natural mapping datum over a wide area is extremely difficult.

Secondly, the mudstones of the Pendle Grit Formation are volumetrically the dominant constituent and are considered as a direct continuation of the mudstones forming the Upper Bowland Shales. Furthermore, the base of the Upper Bowland Shales is defined by the _C. malhamense_ Marine Band. This provides a more readily recognisable datum level and consequently is used in the construction of cross sections and maps (e.g:- Enclosure 1).

The upper limit of the Turbidite Association is also difficult to define since there is an extremely gradual upward passage of the succession dominated by mudstones, to the section dominated by siltstones. However, as the Turbidite Association has a preponderance of topographically defined channels, then, where these become less frequent, an arbitrary field boundary is defined (Fig. 23).

4.2.7 LATERAL CORRELATIVES

To complete the regional picture of the distribution of the Turbidite Association, a brief reference is made to the regions west of the surveyed area. The descriptions of several authors give enough information to ascribe their lithologies to the Turbidite Association.

For example, Moseley (1952) described steep-sided channels at or near the base of the Pendle Grits in the area west of Caton. These channels were cut into black shales and D. Moore (pers. comm.) noted that the channels were over 15m deep and were infilled with irregular bedded sands. Shale clasts up to 1m in length were also common, as were pebbles of dark limestone. (Note: these quarries have been subsequently infilled).

The rest of the Pendle Grit succession, Moseley described as consisting of "rapid alternations of thin micaceous sandstone and sandy shale". These are considered to be part of the Turbidite Association, as are the thin interbeds of sandstone and shale reported by Earp (1955, 1961) and Price *et al* (1963).

Between Lothersdale and Cowling, Bray (1927) reports that the base of the Pendle Grit appears to be erosive into the shales below. He also describes coarse "knobbly" or "gnarled" sandstones that form impersistent bands. His description would seem to compare with that of the facies 9, Ropy weathering Sandstones.

Fig. 23. Four sketch maps of the E_{1C} succession in the Skipton area showing the distribution of the three main Facies Associations. See over (P. 69) for details.

Fig. 23 (continued).

A. Skipton Moor (see Enclosure G).

B. Beamsley Area (see Enclosure F).

C. Carleton Area (see Enclosure H).

D. Rylstone and Embsay Moor (see Enclosure D).

Colour Code:-

Purple - Upper Bowland Shales.

Dark Green - Turbidite Association (Pendle Grits).
(V. Dark Green - Feeder Channels).

Light Green - Slope Association (Pendle Shales).
(Dark Light Green - Feeder Channels).

Light Orange - Delta Top Association (Grassington Grits).
(Dark Orange - Fluviatile Channels).

4.3 SLOPE ASSOCIATION

4.3.1 INTRODUCTION

The sediments forming the Slope Association are predominantly fine-grained in nature and as a consequence are poorly exposed. They form long featureless steep slopes and are invariably overlain by protective cappings of coarse and pebbly sandstone. The latter form long continuous crags and skyline scarps, which are prone to cambering and rock-falls. Large landslips often mask minor features on the slopes, although coarse-grained massive sandstones within the Slope Association itself form prominent crags and spurs.

4.3.2 DESCRIPTION

The dominant constituents of the Slope Association are dark mudstones (facies 1) and parallel bedded, micaceous and striped siltstones (facies 4). The lower part of the Slope Association sequence is more argillaceous, but passes gradationally upwards into progressively siltier horizons.

The dark mudstones are only rarely exposed, but the laminated siltstones, being more resistant, form small ledges or cliffs. The siltstones usually have a rapidly gradational upper and lower contact with the mudstones. Ichnofauna traces are abundant in contrast with the dark mudstones, where they are absent.

Interbedded with the mudstones and siltstones are thin turbidite sandstones (facies 6). These are similar to those described in the Turbidite Association. Towards the bottom of the Slope Association, the turbidite sandstones are very common (fig. 27). However, higher in the succession they become more scarce (fig. 30). It is noteworthy that in the lower part of the succession their internal organisation and external appearance are similar to those in the Turbidite Association but progressively later, turbidite sandstones are less well organised. Very conspicuous is the lack of organisation of the bow-shaped linguoid ripples. Rippling, whilst present, is more haphazard and accurate current flow directions are difficult to obtain.

Amalgamation of turbidite sandstone beds is less common, and is restricted to minor developments such as that seen in Fig. 26.

Ichnofaunal activity is very common and many of the very thin turbidites show extensive reworking.

Field mapping suggests that the facies 12, Massive Sandstones are erosive into the finer grained deposits and they occupy large channels. The actual channel shape and margin is nowhere clearly seen, since the surrounding fine grained sediments tend to weather-back, leaving the more resistant massive sandstones forming a topographical feature covered with scree and vegetation. However, oblique aerial photography, combined with field mapping, shows the channelised massive sandstones having channel orientations broadly similar to those of the Ropy Sandstone channels of the Turbidite Association.

The number of channels seen is considerably less than for the Turbidite Association, and overall dimensions vary considerably, although delineating the section of the channel is difficult for the reasons described above. Perhaps the most spectacular channel is that forming Embsay Crag (SE00485505) (Fig. 24). This channel appears to be about 550m wide and approximately 36m deep. Another channel of this type can be seen on Cracoe Fell, in the crag below the "Stone Man" (SD98255760) which is possibly over 1000m wide (Fig. 46b). Large mudstone clasts (up to 1m wide) and logs (over 150cm long) are common in the Stone Man channel.

Smaller scale wide, but shallow channels are seen in the crags of Beamsley Beacon (SE09655230), Standard Crag (650m wide) on Skipton Moor (SE00905035) and Crags Bottom (400m wide) on Embsay Moor (SE00605502). These channels are usually less than 20m deep, but may be laterally extensive; in the case of Beamsley Beacon, possibly over 1000m. They are filled with massive sandstone (facies 12) that has a highly characteristic

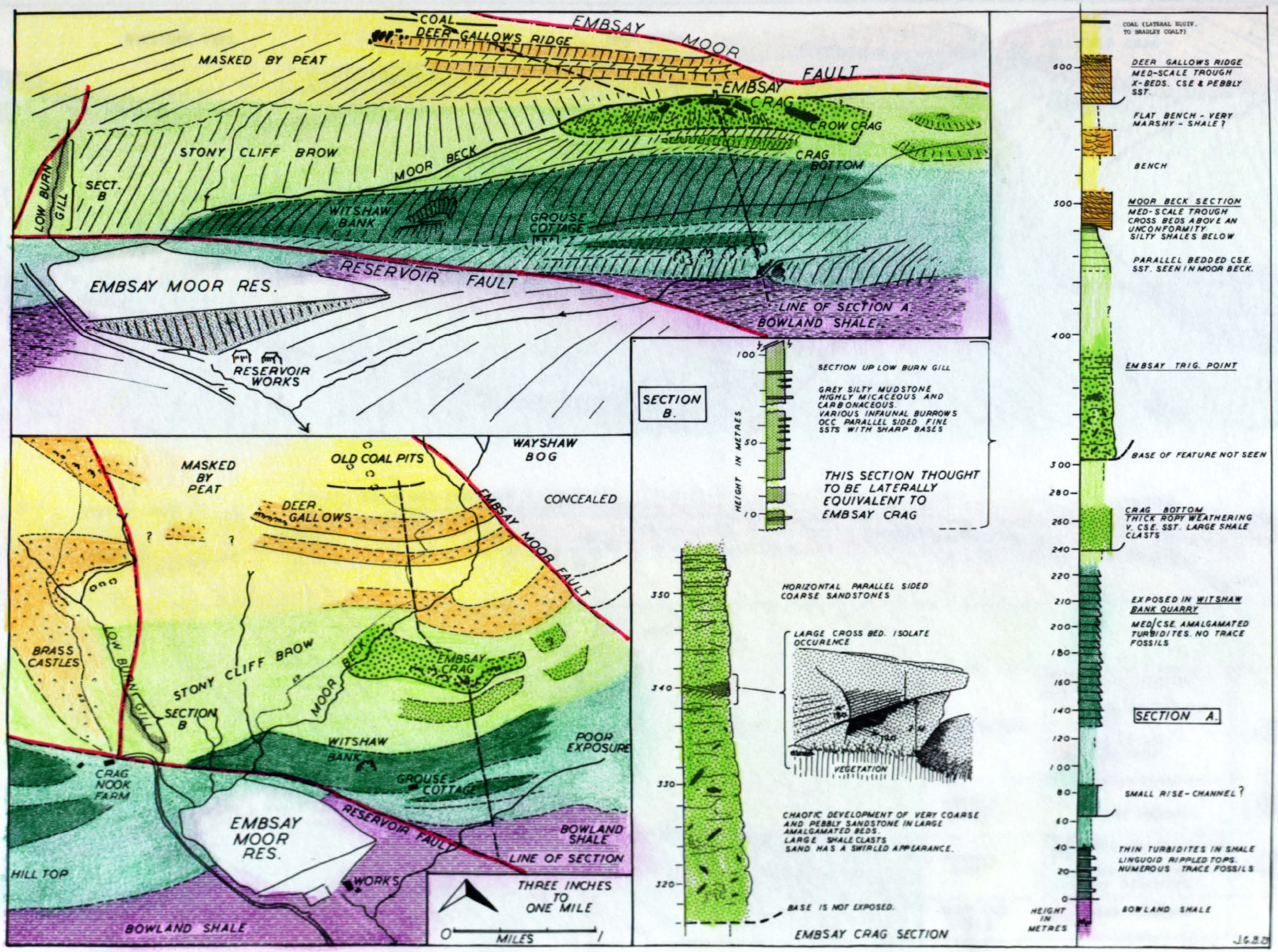


Fig. 24. Oblique aerial view of Embsay Crag showing the stratigraphical and sedimentological relationship. (See also Enclosure D).

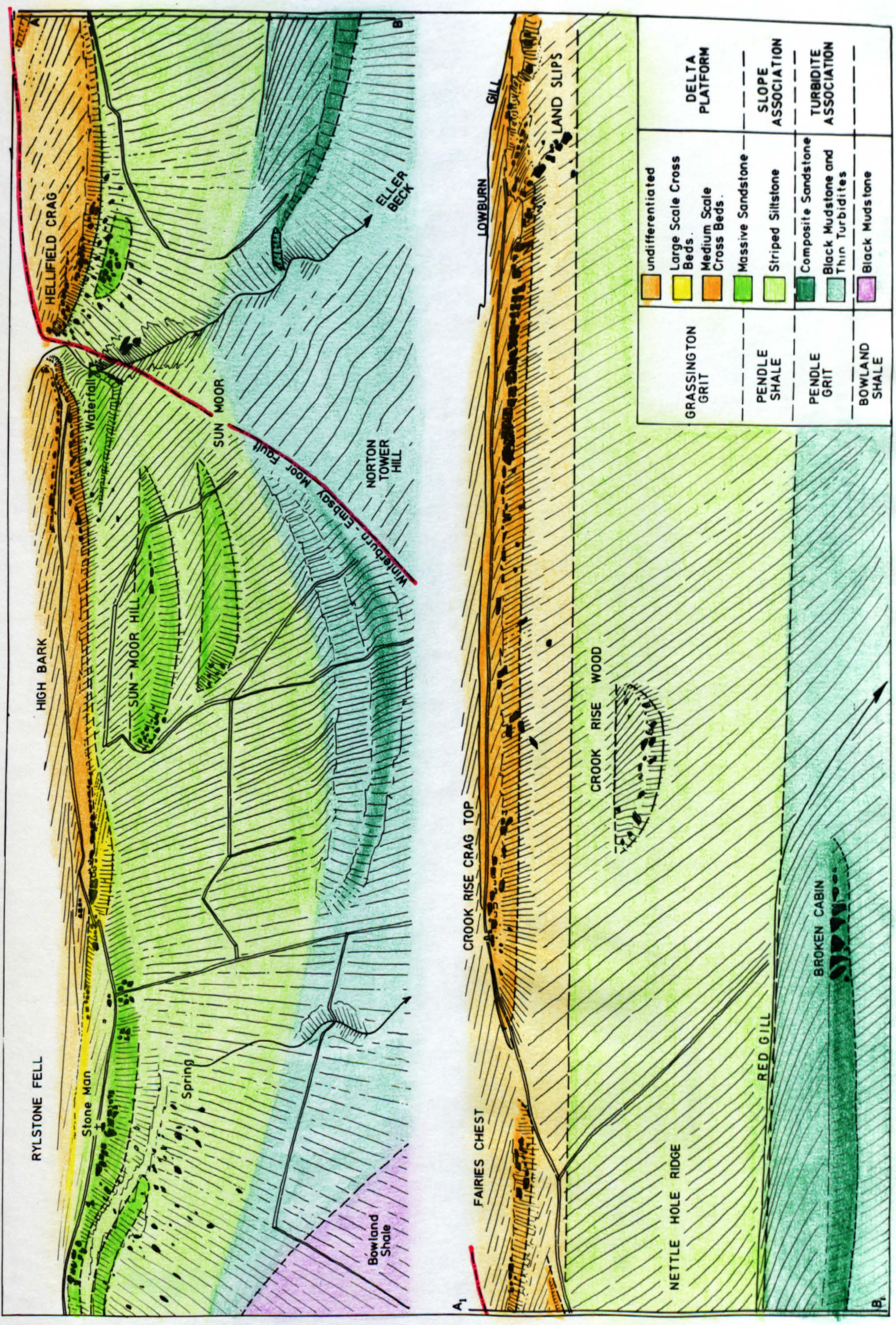


Fig. 25. Oblique aerial view of Rylstone Fell and Crook Rise Crag Top showing stratigraphical and sedimentological relationships. (See also Enclosure D), (See also Fig. 30 for measured section

Fig. 26. Field sketch of a series of amalgamated facies 6, Thin turbidite sandstones seen in Bareshaw Beck (SD983485), Carleton.

Fig. 27.
Section at
Snaygill Stone
Bridge
(SD99524954)
Lower Slope
Association.

"hexagonal weathering pattern" (Photo 50, 51).

4.3.3 INTERPRETATION OF SLOPE ASSOCIATION

The well developed dark mudstone sequences in the lower part of the Slope Association are considered to be a direct continuation of the quiet deep water mudstones of the Turbidite Association.

However, the introduction of progressively more silty facies indicates a subtle change in environment. Initially, only thin horizons of striped siltstones (facies 4, Type A) are intercalated with the mudstones, but these siltstones become progressively more well developed up the section, at the expense of the mudstones. These striped siltstones are similar to sediments described by Coleman and Gagliano (1965) from the active part of the Mississippi Delta. They consider that the textural and colour variations seen in the Mississippi striped silts are due either to segregation of particles by differential settling or from changes in water chemistry. Either processes could apply to the E_{1C} Slope Association as will be seen in part of the discussion below.

Coleman and Gagliano also noted that, in those areas proximal to the source, silty parallel laminations are common, whilst in more distal areas, the laminations become thinner and less frequent. The E_{1C} Slope Association succession, probably responds in a similar fashion with the very homogeneous siltstones (facies 4, Type B) reflecting close proximity to supply. The E_{1C} Slope Association also invites close comparison with the R_{1C} Slope Association where Walker (1966) and Collinson (1969) interpret the broadly coarsening up sequence of the Grindslow Shales as being the deposits of a prograding slope below wave base.

It is necessary at this stage to put the comparison of the facies 4, siltstones with the Mississippi siltstones into an environmental perspective. The implication from Coleman and Gagliano's work is that the silty material is introduced from a deltaic source. Likewise, as higher levels of the E_{1C} Slope Association are described, so the emphasis on deltaic and fluviatile processes becomes more prounounced.

Walker (1966) and Collinson (1969, 1970b), when interpreting the R_{1C} Slope Association also emphasise the importance of deltaic and fluviatile processes when interpreting their facies relationships. Collinson (1970b) put forward the following hypothesis which is considered critical especially in the appreciation of the processes responsible for the thin turbidite sandstones (facies 6) and the Massive Sandstones (facies 12) of the E_{1C} Slope Association.

> "The term 'fluviatile' was not.... restricted to deposits of the alluvial plain.... but included deltaic channels and their offshore extensions so long as energy was derived from the river gradient. ....in cases of high suspended load.... the fluviatile current developed into a turbidity current. (Collinson 1970b, p. 517) (present author's underlining).

In the facies interpretation of the Massive Sandstones (facies 12), it was stated that sedimentation had been from powerful currents. In addition in the Slope Association description, it was noted that the Massive Sandstones occurred in channels. It is proposed that these coarse, massive sandstones are in fact part of a submarine continuation of subaqueous fluviatile channels (see following Delta Top Association), and that they represent part of the continuum outlined in the Turbidite Association description. (See also Table 9, P. 136).

Furthermore, a situation is envisaged whereby rivers, at periods of high discharge are capable of continuing down the slope as density currents. Collinson (1970b, p. 513) outlines two recent analogies where similar processes are thought to take place, namely, the Congo River (Heezen et al 1964) and the River Rhone (Houbolt and Jonker 1968). Collinson has also inferred that a similar situation occurred in the R_{1C} succession, although direct proof was still lacking. McCabe (1975b) thinks, however, that a fluctuating river discharge would give an opportunity for there to be a build up of sediment at the distributary mouth, especially at low stage, whilst at high stage the sediment was flushed out over the delta slope to form turbidity currents.

If the sediment is flushed out of the river mouths, then the origin of the thin turbidite sandstones within the E_{1C} Slope Association can be put in their full context. It can be envisaged that any large transfer of clastic material from a sub-aqueous fluviatile channel down the basin slope is going to result in a considerable dispersion of fine grained material. Whilst the main flow of material will be down the Slope channels, it can be expected that 'clouds' of suspended sediment overflow the channel margins and spread down the slope flanks. Sedimentation from the decelerating turbid clouds will be in the form of turbidites, i.e. sharp based and graded. In the case of the facies 6 turbidite sandstones, the bow shaped linguoid rippling seen on the upper surface is produced by the entrainment of water behind the main sediment flow (Middleton 1969, Walker 1967). The more disorganized rippling noted towards the top of the succession probably resulted from being in close proximity to more divergent fluviatile currents.

Reading (1970) has also interpreted turbidites as originating from river mouths during flood stages, as have van de Graaf (1971), Gould (1960), Walker (1967) and Heezen <u>et al</u> (1964).

It should be noted that these thin turbidites of the Slope Association are in a more proximal position relative to the source area than the Composite Sandstones facies of the Turbidite Association. Strictly speaking, it is incorrect to refer to these thin turbidites as being distal even though they have all the attributes of distal turbidites as defined by Walker (1967).

Finally, it was mentioned above that Coleman and Gagliano (1965) thought that several processes might be responsible for textural and colour variations in the siltstones. The processes outlined depended on there being periodic variations in either current velocity or chemistry. Such variable conditions may well have existed in E_{1C} Slope Association times, especially when considered with the recognition of fluviatile current processes mentioned above. Nelson (1970) in describing the discharge of the Po River, Northern Italy, noted that fresh and turbid plumes of water extended far out to sea. These fresh water suspensions mix and become progressively saltier and thinner. Initially, siltstone and clay particles remain in suspension but as the velocity decreases, so progressively smaller sized particles fall out of suspension. As well as vertical grading, there is also a rapid lateral gradation in particle size away from the front of the delta.

4.3.4 FIELD BOUNDARY DEFINITION

In the area mapped, the boundary of the Slope Association with the underlying Turbidite Association is gradational, as has been mentioned above. Therefore, field boundaries are arbitrary and can only be defined where a major break in topographic featuring occurs. Such a break is defined where the multiple channels of the Turbidite Association become less frequent. Fig. 23 illustrated some of these boundaries. For instance, on Skipton Moor, the base of the Slope Association is defined at the intersection of the Gas Pipeline with Cawder Gill (SE5152543) (Fig. 23a). To the east on Beamsley Moor (Fig. 23b) the boundary is located at the confluence of Howgill Sike with Kex Beck (SE09225313). In the area south-west of Skipton, the Slope Association forms the so-called "slack ground" of Earp _et al_ (1961) to the north of Cononley Moor (Fig. 23c). North of the Skipton Anticline, the Slope Association thins dramatically towards the North Craven Faults. The base is defined as in Fig. 23d and 25. On Embsay Moor (Fig. 24) the junction is extremely arbitrary.

The upper contact with the Delta Platform Association has been even more difficult to define. Not only are outcrops scarce, but there is the added complication of an apparent unconformable relationship in one area and not in others. North of the Skipton Anticline, the Delta Platform Association appears to rest unconformably on the Slope Association. Fig. 29 illustrates the field relationships. However, south of the Skipton Anticline, the relationship appears to be more conformable.

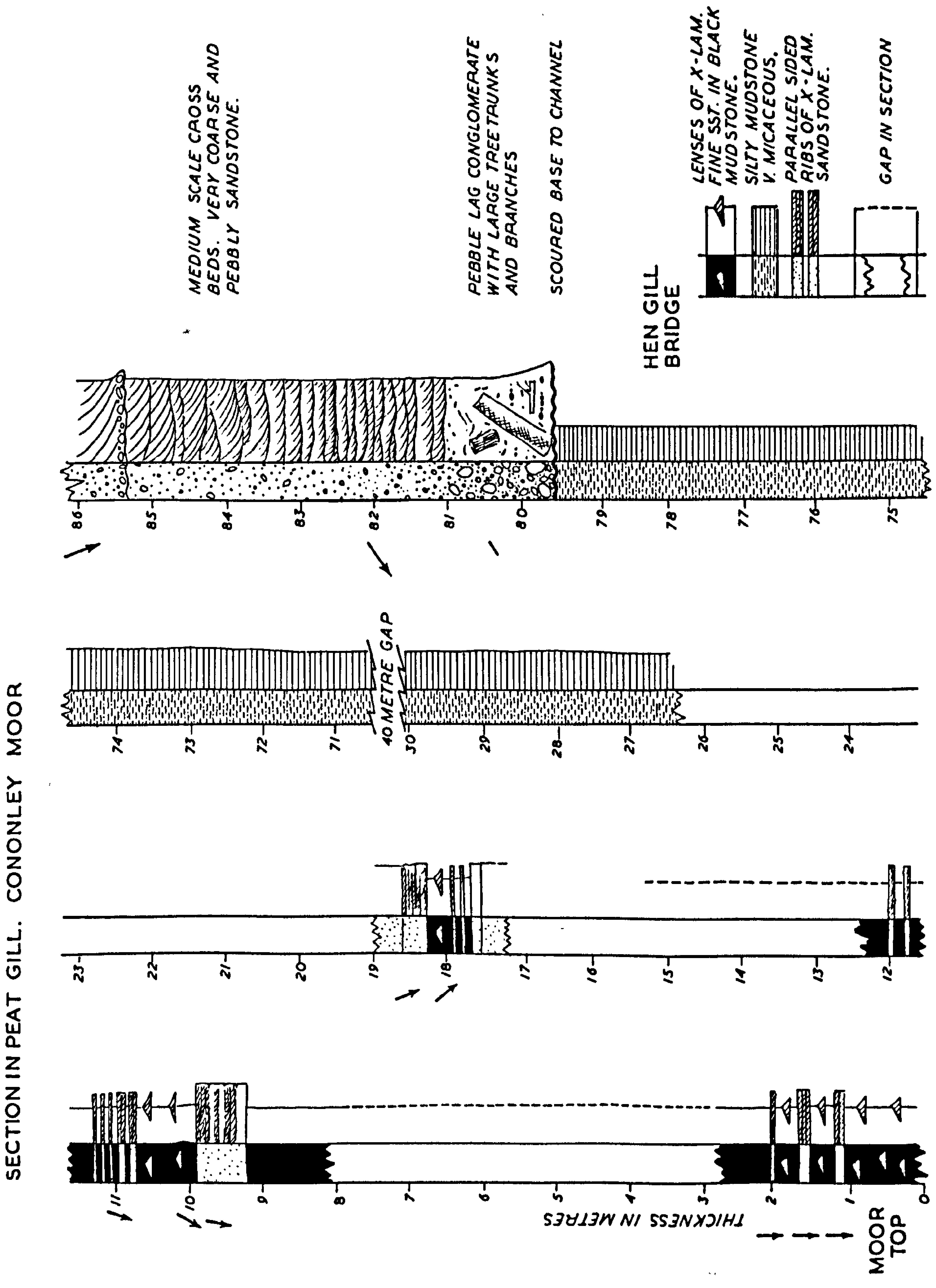


Fig. 28. Measured section up Peat Gill (SD97734730) Cononley Moor, showing the upward passage from mudstones and thin turbidites into a siltstone sequence (Slope Association) finally overlain by a channelised sequence of Medium scale cross-bedded sandstones (Delta Top Association.)

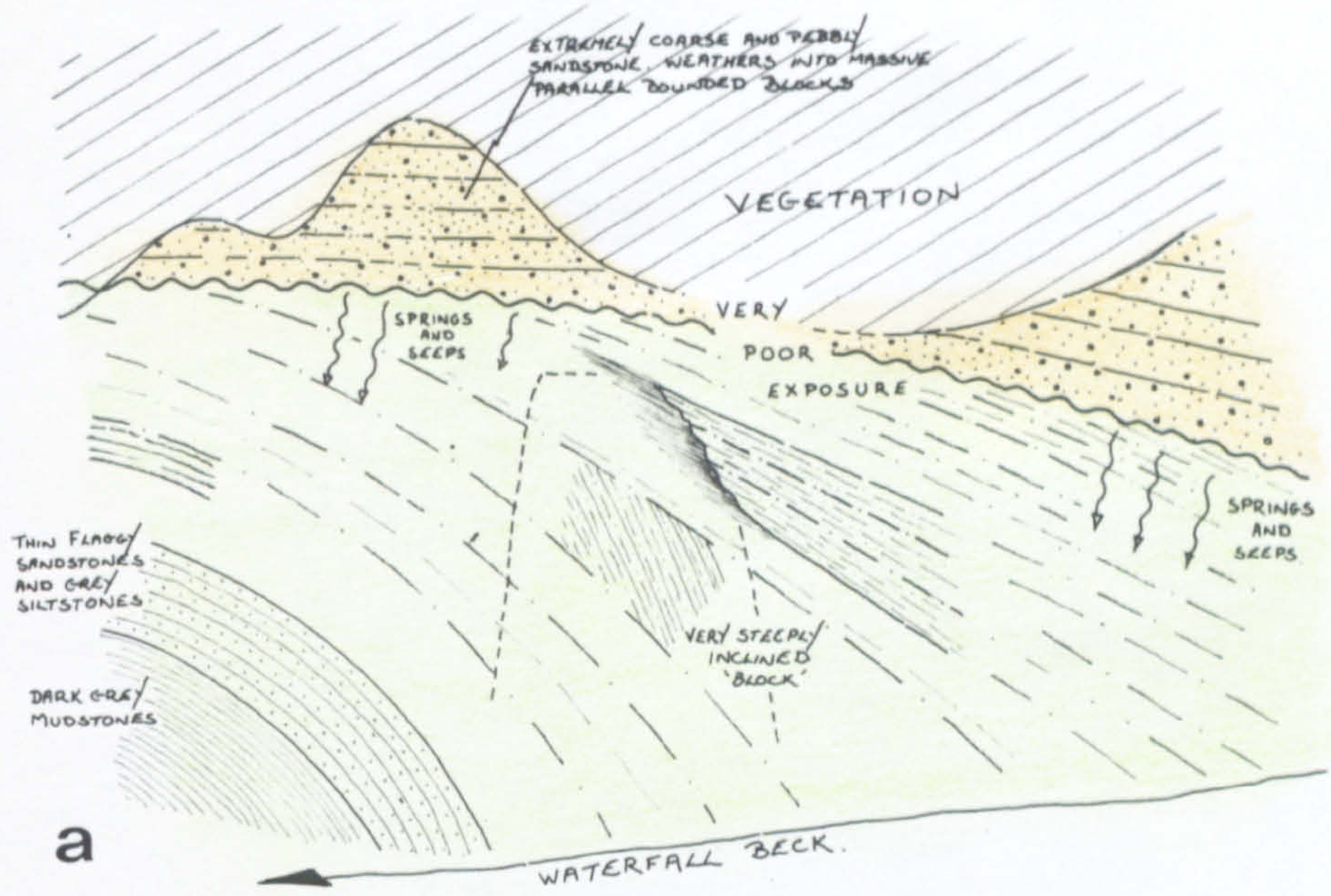
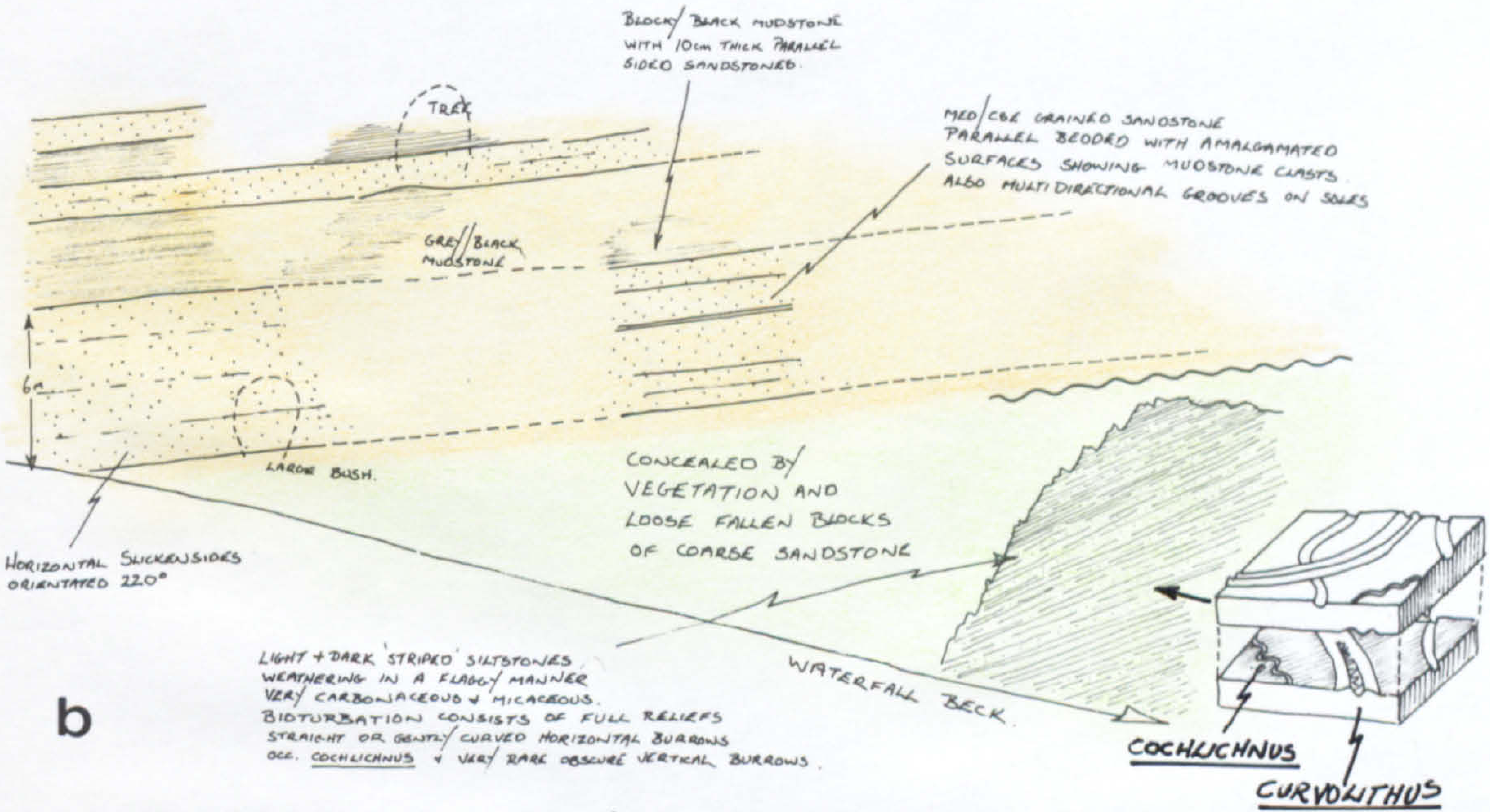


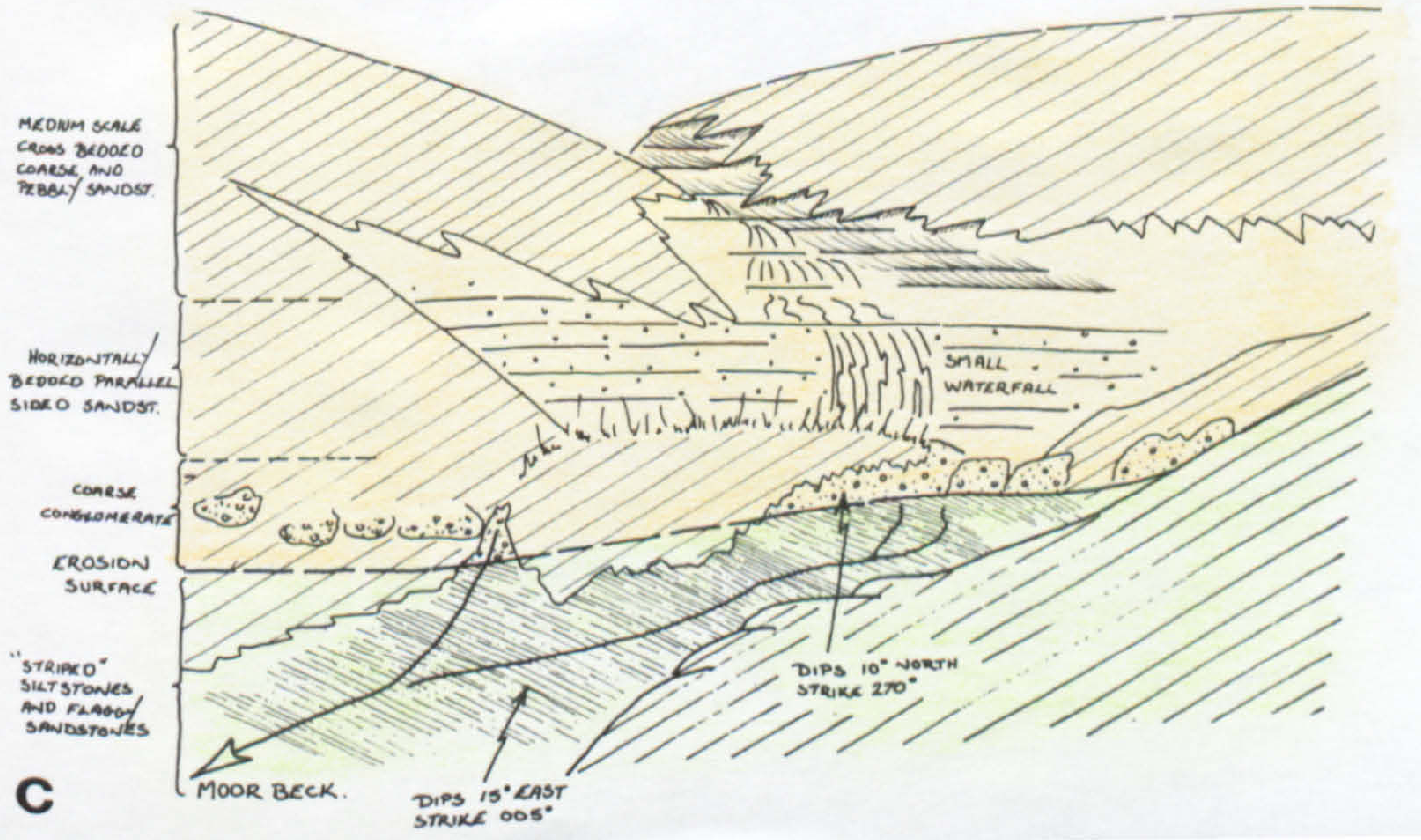
Fig. 29. Three field sketches showing the relationship of the Slope Association with the Delta Top Association. (See Enclosure D for their relative positions.)



A/. Waterfall Beck (SD984568) - north bank. Rylstone Fell.

B/. Waterfall Beck (SD984568) - south bank. Rylstone Fell.

C/. Moor Beck or Crag Gill (SE00325530), Embsay Moor.



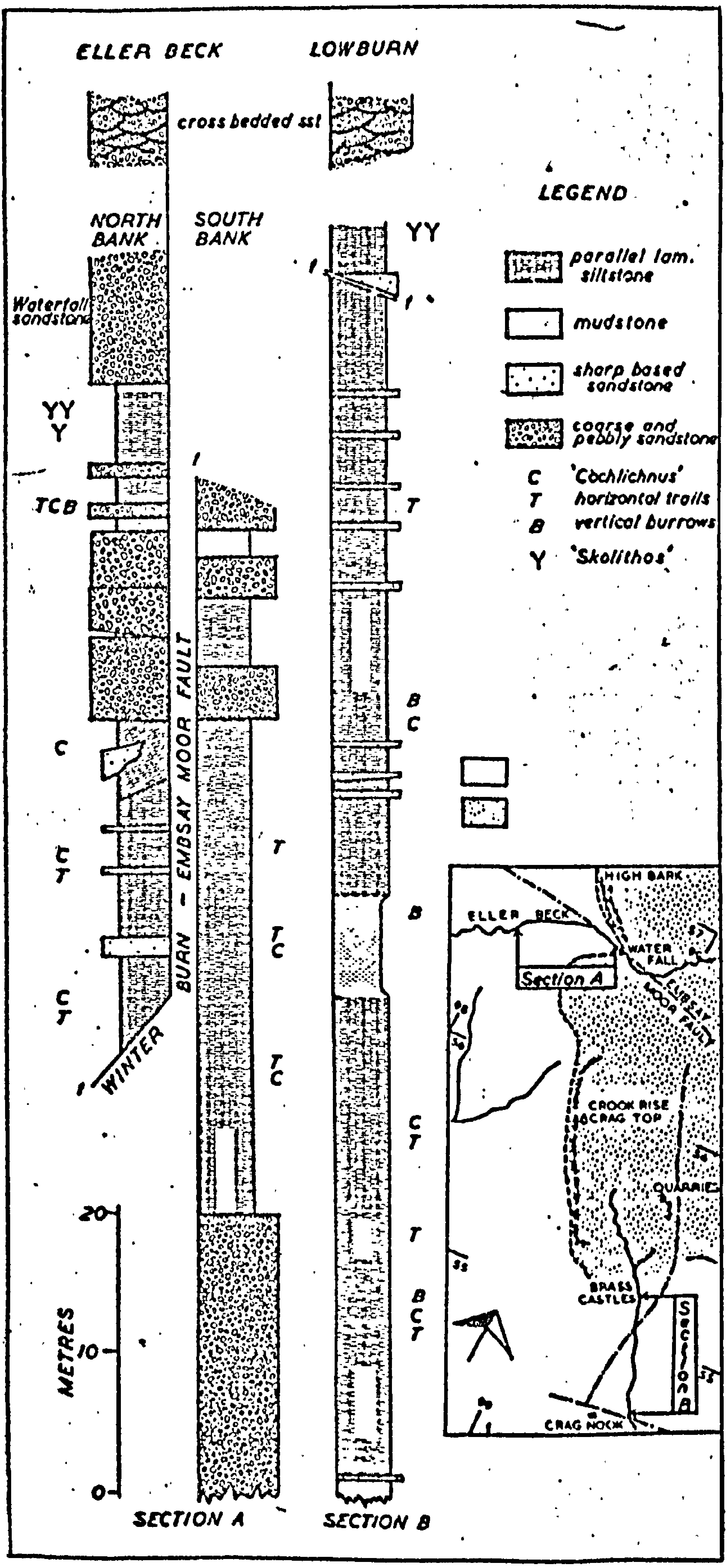


Fig. 30. Measured section through the Slope Association (Pendle Shales) near Crook Rise Crag Top. (See Enclosure D). The section in Eller Beck/Waterfall Gill is complicated by the Embsay Moor Fault.

Figure 28. shows the base of a fluviatile channel resting directly on Slope Association siltstones with no apparent structural misalignment.

The problems concerning syn-sedimentary tectonics as a possible cause for the relationships described above, are explained in more detail in Chapter 4.5.

4.3.5 LATERAL CORRELATIVES

Outside the mapped area, the Slope Association can be recognised from the descriptions of several authors. Bray (1927) describes the Surgill Shales, some 243m thick as consisting of "thin bedded rippled flagstones, followed by sandy micaceous shales." To the south-west, the Geological Survey record that in the Clitheroe area "....the upper part of the Pendle Grit (their definition) becomes progressively more shaly when traced upwards and includes two beds of micaceous shale ...." (Earp et al 1961).

In the extreme south-west of the outcrop, the Geological Surveys of Wright et al (1927) and Price et al (1963) report that the Lower Whilpshire Grits (here equated with the Pendle Grits) pass upwards into "a belt of shales" with an estimated thickness of 61m. (Fig. 4).

South of the main surface outcrop, data concerning the Slope Association is restricted to borehole records only. The Boulsworth B. H. shows arenaceous beds (here interpreted as being equivalent to the Pendle Grits), passing rapidly up into a thin argillaceous sequence some 180m thick. The sequence consists mainly of mudstones, siltstones and fine grained sandstones. These assemblages are considered to be indicative of the Slope Association.

To the north of Clitheroe in the Slaidburn area, Earp (1955) inspected the succession exposed in the construction of the Bowland Forest Tunnel. He reports that the upper 182m of the Pendle Grit is "predominantly argillaceous" and that the "major component is grey micaceous silty shale."

4.4 DELTA TOP ASSOCIATION

4.4.1 INTRODUCTION

The Delta Top Association is arbitarily divided into two broad regional areas by the North Craven Faults. For convenience of description, the sediments north of the faults are referred to as the "FLOOD PLAIN ASSEMBLAGE" whilst the area to the south is referred to as the "DELTA PLATFORM ASSEMBLAGE." The Flood Plain Assemblage is reviewed from the literature only, and is dealt with at the end of the Chapter (4.4.14).

4.4.2 DELTA PLATFORM ASSEMBLAGE+

The Delta Platform Assemblage is comparatively complex and is divided into three sections. Each section is described in turn and the same order is followed in the interpretative section.

1. Deep channels with i) Facies 11, Large scale cross-bedded sandstones (Type A).
   ii) Facies 11, Large scale cross-bedded sandstones (Type B).
2. Shallow channels with facies 10, Medium scale cross-bedded sandstones.
3. Interdistributary sub-association.

4.4.3 DESCRIPTION

Coarse and pebbly sandstones of facies 10, Medium scale cross-beds and facies 11, Large scale cross beds form conspicuous sky-line features throughout the mapped area. These features take the form of long crags separated by shallow marshy hollows or "slacks." Exposure within the slacks is almost completely absent.

4.4.4 DEEP CHANNELS WITH FACIES 11, LARGE SCALE CROSS-BEDDING (TYPE A).

On Cracoe Fell (SD994593), a series of prominent but discontinuous crags are aligned in a northeast-southwest manner. These crags are formed from large scale cross-beds of coarse and pebbly sandstone and as such occur as discreet mappable units (Fig. 31). The field sketch shows a typical view of the channels and their relationships to one another. It is suggested that the base of these channels is slightly asymmetric with one side deeper than the other although this is not directly seen. In one example, the sides of the channel appear to be quite steep, e.g.:- Rolling Gate Nook (Fig. 31) (SE001602). Here the juxtaposition of two adjacent channels suggests that their edges have a slope in the order of 40 to 45 degrees.

Channel depths are measured from the assumed base of the channel to the base of overlying facies 10, Medium scale cross-beds.

Dimensions of the channels are tabulated in Table 6. The width of the channels is difficult to ascertain due to lack of exposure. Frequently, associated topographic features die away completely or are complicated by adjacent featuring. In several examples, there are no obvious features associated with the outcrop at all, e.g.:- Simonseat (SE084598) and Pockstones Moor (SE100604). Here the large scale cross-beds occur in large isolated masses. Where the channel edge can be discerned, the foreset azimuths of the contained large scale cross-beds are parallel to the channel edge. In other words, the strike of the lee face of the large scale cross bed is at right angles to the edge. This relationship is seen in the outcrops at the eastern end of The Crags (SD99805975) on Cracoe Fell, and to a lesser extent on Barden Fell, in the vicinity of Great Agill Beck (SE080585) (Fig. 32).

From Fig. 31, it can be seen that the individual channels occur at different stratigraphical levels. On Cracoe Fell, they occur over a 300m vertical range and the channel depths appear to gradually decrease

COLOUR CODE. Purple- Bowland Shale; Dark blue- Reefal Lst.; Light blue- Lwr. Carb. Lst.; Light green- ?Slope Association/ Pendle Shale; Light brown- Facies 11, Large scale cross-bedded sandstones; Dark orange- Facies 10, Medium scale cross-bedded sandstones; Light orange- Interdistributary sub-association.

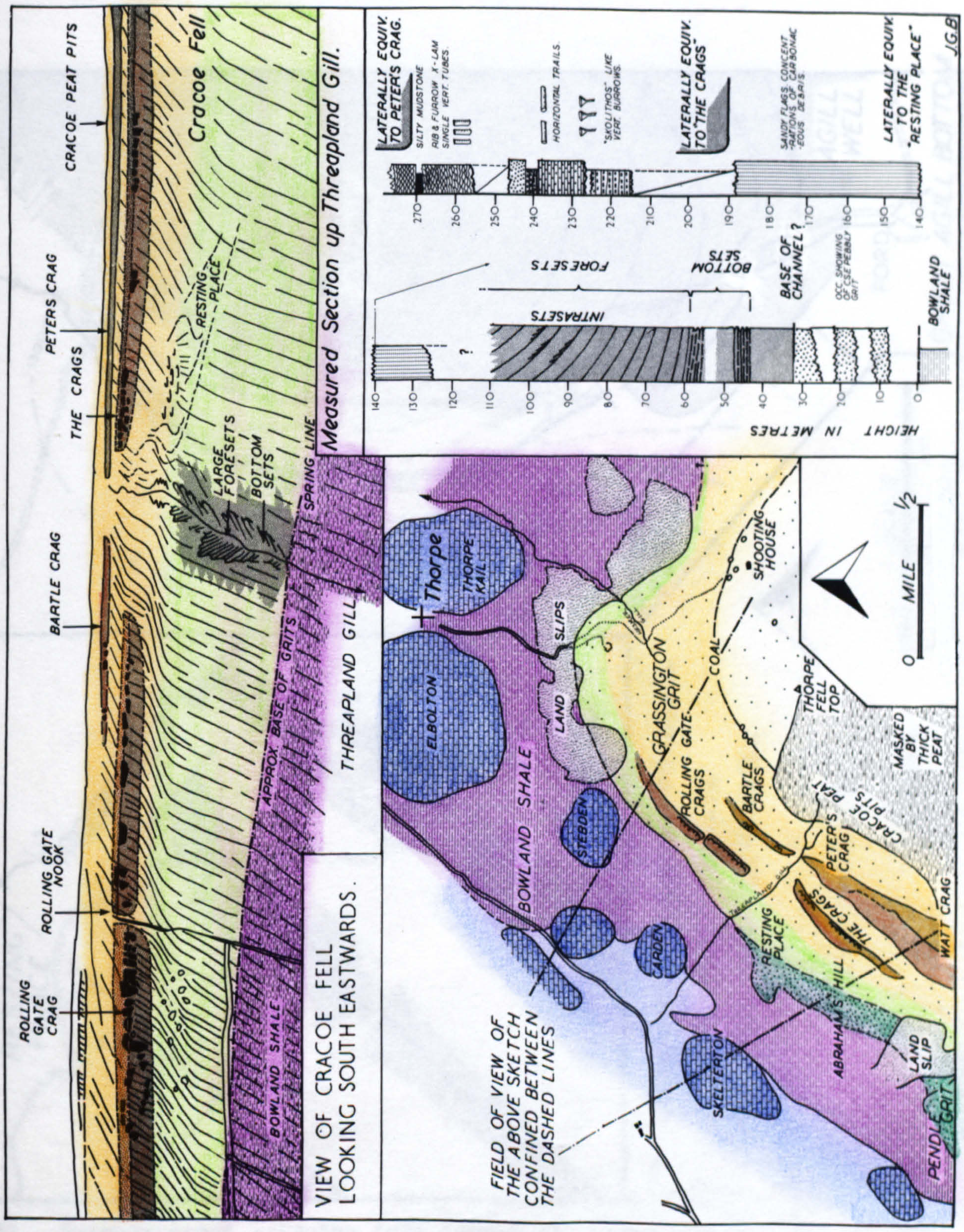


Fig. 31. Map and field sketch of Cracoe Fell showing the relationship of topographic features to possible fluviatile channels. The section in Threapland Gill is probably more complex than shown in the composite section. (See also Enclosure D).

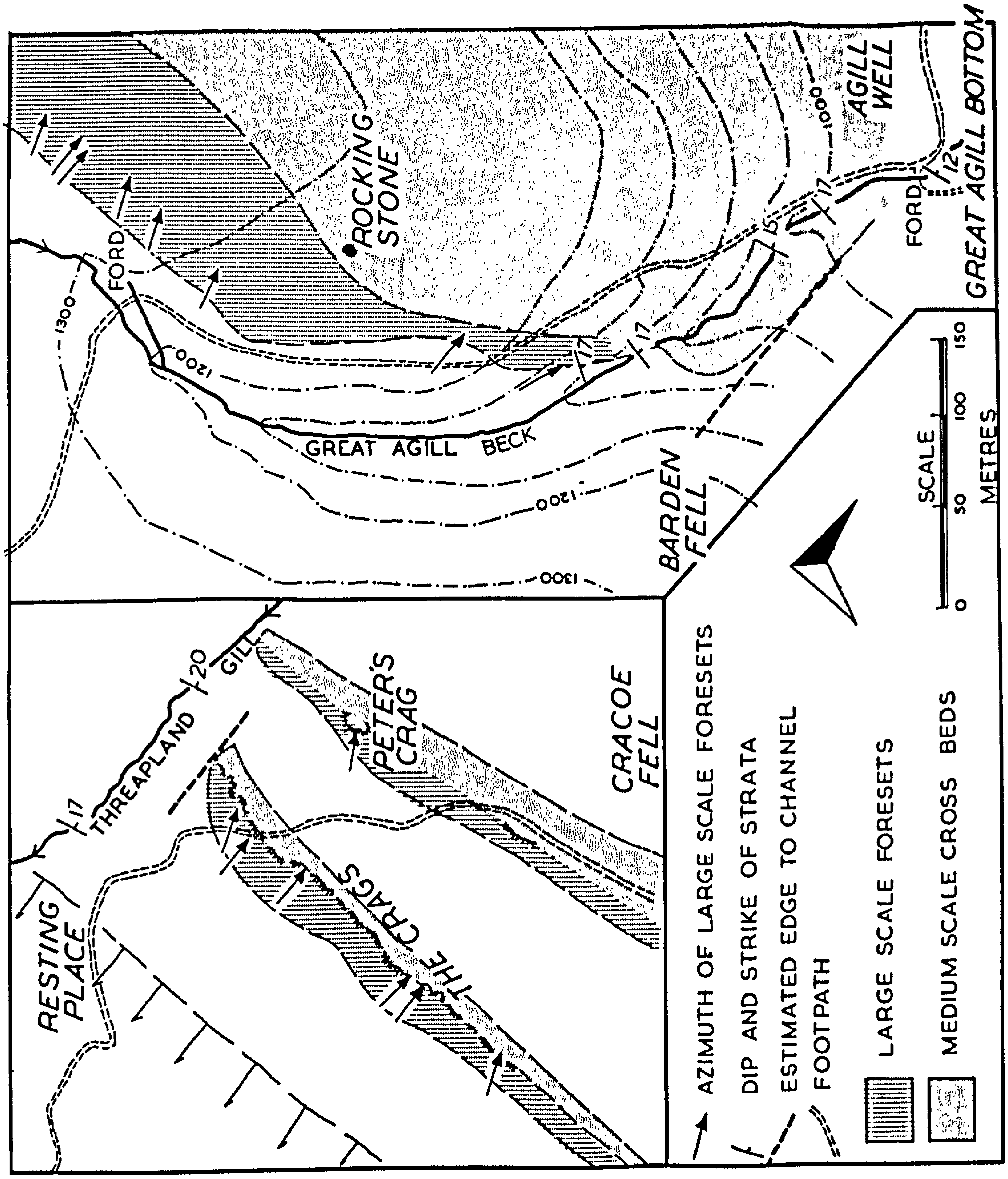


Fig. 32. Palaeocurrent azimuths from facies 11, Large scale cross-bedded sandstones. Left- The Crags (SD998597); right- Barden Fell (SE081585). Note also the orientation of the inferred channel edge. In the case of The Crags, the facies 10, Medium scale cross-bedded sandstones appear to be confined to the same channel as the large scale cross beds.

TABLE 6 FACIES 11, LARGE SCALE CROSS-BEDS

	TYPE A.						TYPE B.
	The Crags (SD996595)	Rolling Gate (SD999600)	Halton Crag (SE033552)	Carncliff Top (SE071584)	Long Crag (SE081587)	Lords Seat (SE085599)	Farn Hill Moor (SE009468)
HEIGHT OF SET	@ 8m	25m	18m	6m+	8m+	10m+	7-8m
WIDTH OF CHANNEL	700m+	300m	700m+	300m+	800m+	150m+	100m+
INTERNAL EROSION SURFACE			✓	High Angle		Low Angle	Low Angle
STRIKE OF FORESETS	Straight	Straight	Straight		Straight	Straight	Curved
EROSIONAL TOP	✓	✓	✓	✓	✓		✓
TYPE OF SET ABOVE	M.S	M.S	M.S	M.S	M.S		M.S

✓ = PRESENT
M.S = FACIES 10 MEDIUM SCALE CROSS-BED

upwards. The largest channel, very crudely estimated to be 55m deep is seen in Threapland Gill (SD99706005), directly above the junction with the Upper Bowland Shales, whilst the smallest channel, only 5m deep is seen at Bartle Crags (SE00125998) just to the north of the Cracoe Peat Pits. One implication of this is discussed in Chapter 4.5 Syn-sedimentary Tectonics.

4.4.5 DEEP CHANNELS WITH FACIES 11 LARGE SCALE CROSS-BEDDING (TYPE B)

On Farnhill Moor, north of Hardacre Quarry (SE009468) (Fig. 33), there is an unusual pattern of small topographical ridges separated by shallow slacks. The ridges are only 4 to 5m wide and are formed from coarse and pebbly sandstones, which are parallel sided and are estimated to have a depositional dip of up to 22°. These units are interpreted as Facies 11, Large scale cross-beds.

Separating the ridges are small depressions, Unfortunately, these are devoid of any exposure. At the southern end of this series of features is Hardacre Quarry (SE009468). Here, 7 to 8m of facies 11, Large scale cross-bedding,(Type B) is exposed (Photo 48, Fig. 17).

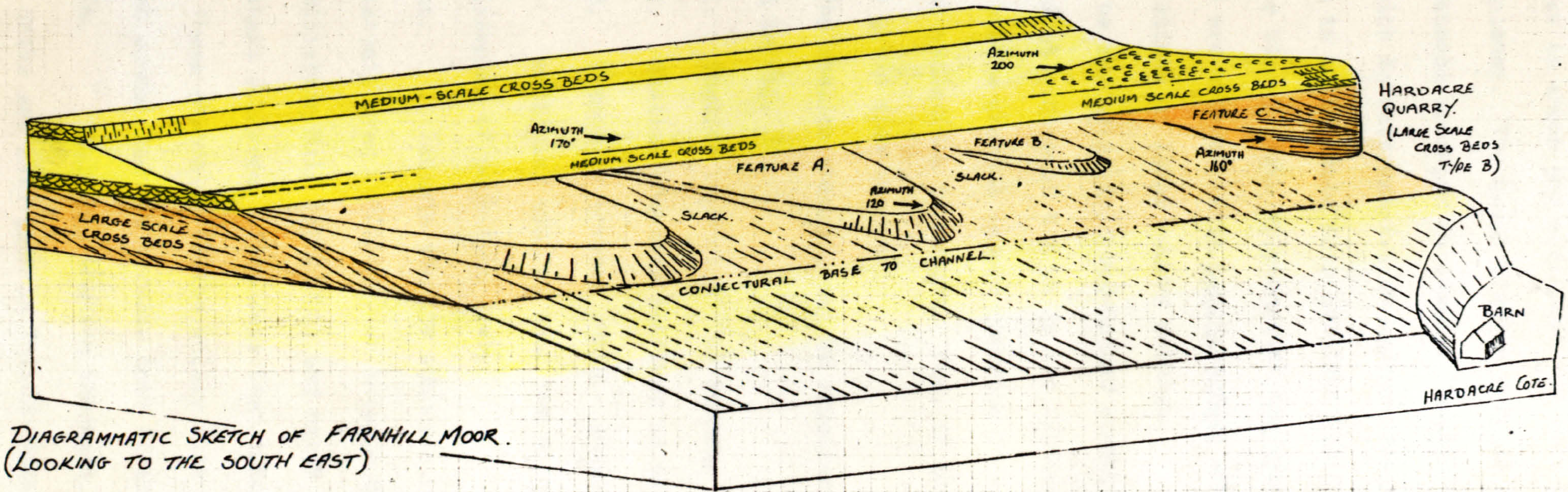
Immediately overlying the large scale cross-beds is a development of facies 10, Medium scale cross-beds and by tracing these across the fell, they can be seen to rest directly on the ridges of dipping sandstone mentioned above.

The actual channel aspect of these large scale cross-beds is not readily apparent and for a full appreciation of their significance, a comparison must be made with similar facies described by McCabe (1975a).

4.4.6 SHALLOW CHANNELS WITH FACIES 10, MEDIUM SCALE CROSS-BEDDING

Medium scale cross-beds (facies 10) are the dominant facies of the Delta Platform and Flood Plain assemblages. These cross-bedded sandstones form units which vary considerably in thickness and lateral

Fig. 33. Field sketch of facies 11, Large scale cross-bedded sandstones (Type B) and their topographical expression on Farnhill Moor. Hardacre Quarry (photo 48 & fig.17) is on the right (SE009468).



DIAGRAMMATIC SKETCH OF FARNHILL MOOR.
(LOOKING TO THE SOUTH EAST)

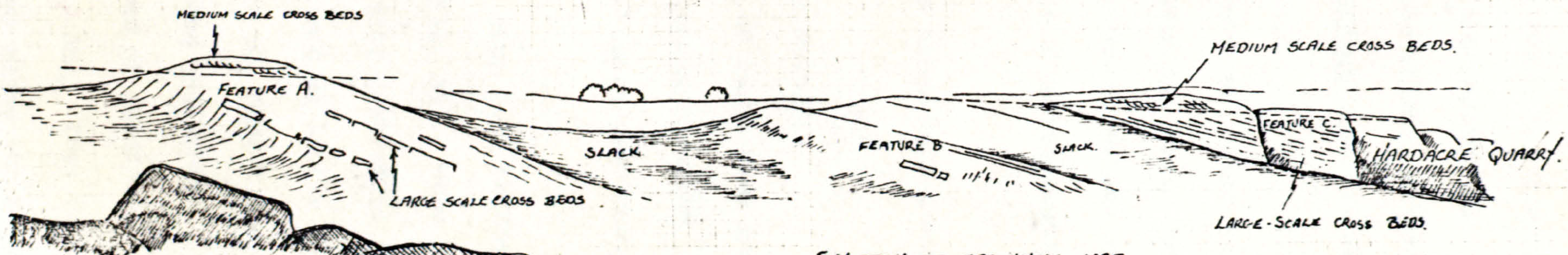


FIG 33

SKETCH OF FARNHILL MOOR
(ADAPTED FROM A COMPOSITE PHOTOGRAPH)

extent. A typical vertical section through one such unit would show that the base is sharp and erosional and that when traced laterally, is broadly planar. The basal erosion surface is succeeded by coarse and pebbly sandstones arranged in cosets. Occasionally, a broad sandstone is found which is more massive in appearance, e.g.:- Gill Head Quarry on the Skipton to Lothersdale Road (SD97904711). Here the channel is erosive into black, silty mudstones of the Slope Association. Within the massive bed are several large Lepidodendron and Calamites logs, as well as concentrations of large quartz pebbles.

The medium scale cross-bedded sandstones have set heights of up to 1m whilst widths of 0.5 to 2m are typical towards the base. Whilst some units show a gradual upward decrease in set thickness, others show quite random variations in height. Few, if any, show a corresponding decrease in grain size upwards.

The shallow channels may be organised into three main groups as illustrated in Fig. 34.

1. Shallow channels: a) isolate b) multiple
2. Shallow channels confined to the top of large deep channels.
3. Composite channel units - shallow channels (usually multiple) erosive over the margins of large deep channels.

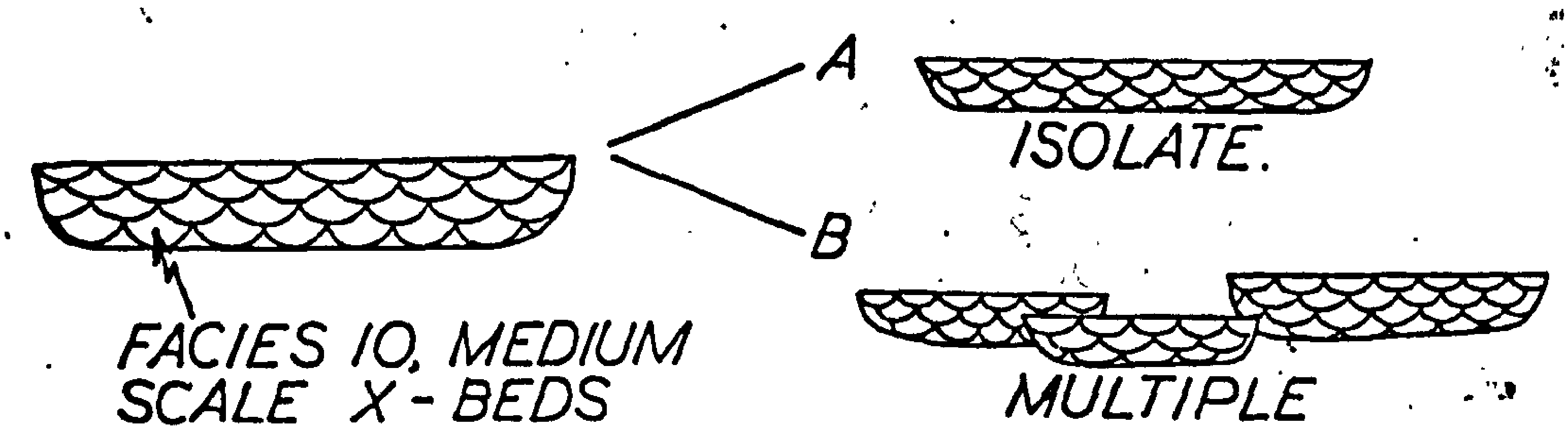
Examples of each type are:-

1a. Isolate shallow channels can be seen just to the south of Standard Crag (SE011504) on Skipton Moor (Fig. 35). Here the channels, Millstone Hill (SE013502) and Horse Shoe Hill (SE011501) form small resistant outcrops, often less than 100m wide and as little as 3 to 4m thick. These channels, filled solely with facies 10, Medium scale cross-bedded sandstones are erosive into finer grained sediments.

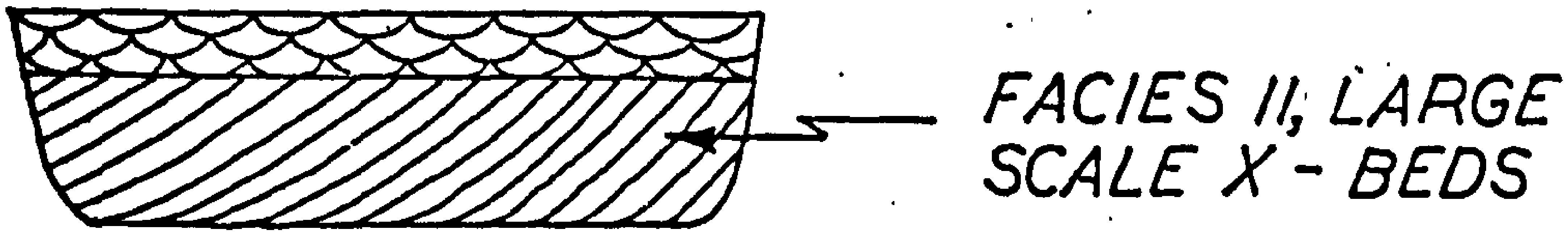
1b. Multiple shallow channels, formed of laterally coalescing units are also seen on Skipton Moor (Fig. 35). They form the long continuous feature of Burn Banks (SE008499) just below the Bradley Coal. Similar, multiple channels of facies 10, Medium scale cross-bedded

FIGURE 34.

1 SHALLOW CHANNELS



2 SHALLOW CHANNELS CONFINED TO THE TOP OF A DEEP CHANNEL.



3 COMPOSITE UNIT - SHALLOW CHANNELS EROSIVE OVER THE MARGINS OF A DEEP CHANNEL.

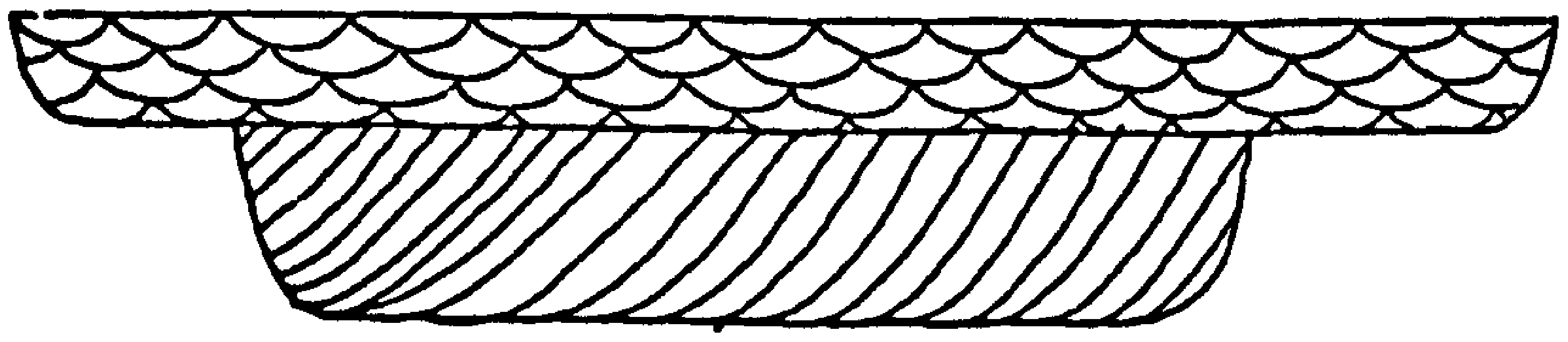
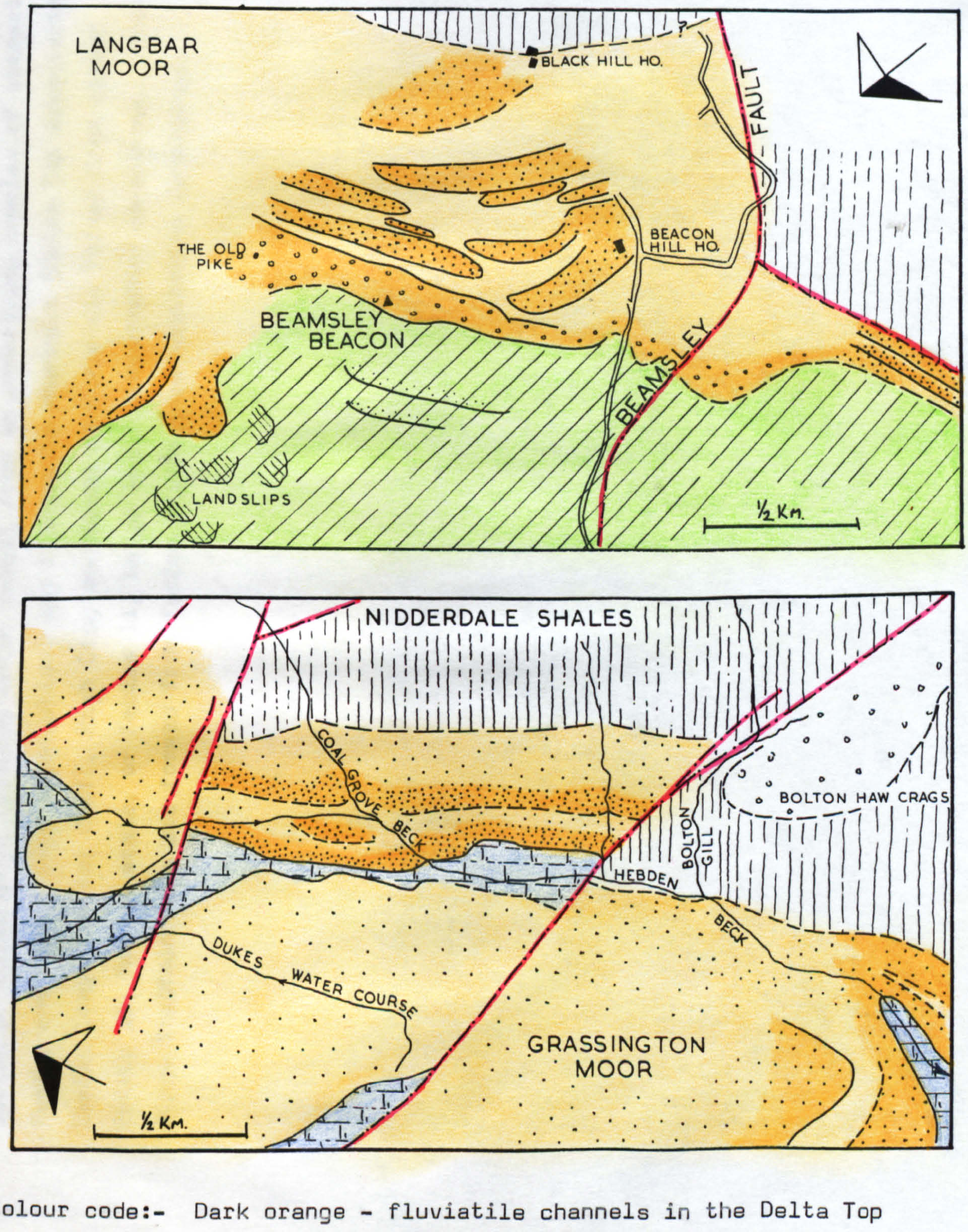


Fig. 35. Detail of the geology of the area south of Standard Crag (SE011504) Skipton Moor, showing variations in shallow channel types in the Delta Top Association.

Fig. 36. Top - sketch map of the geology of Beamsley Beacon (SE099524) illustrating the channels in the Delta Top Association.

Bottom - sketch map of Grassington Moor showing two possible channels which equate with the sub-division Lower Grassington Grit and Upper Grassington Grit (Black 1960).



Colour code:- Dark orange - fluviatile channels in the Delta Top Association.

- Light green - Slope Association sediments.
- Blue - Lower Carboniferous limestones.

Fig. 37. Oblique aerial view of Eastby Crag (SE022549) and Halton Height (SE031553) showing a series of topographic features which result from an underlying complex of submarine feeder channels (Slope Association) and fluviatile channels (Delta Top Association). Eastby Crag, Shelter Cliff, High Crag and Black Hill are all formed from either facies 10, Medium scale, or facies 11, Large scale cross-bedded sandstones. Features above Studfold Farm are formed from facies 12, Massive weathering sandstones.

Colour code:- Purple- Upper Bowland Shales; light green- Slope Association mudstones and siltstones; darker green- feeder channels; light orange- fine grained sediments of the Delta Top Association; darker orange- fluviatile channels.

sandstones are widespread throughout much of the Grassington Grits. Many of the long dip slopes are undoubtedly formed from these channel sandstones but due to lack of exposure, the actual channel remains undefined.

2. Deep channels, filled with both large scale and medium scale cross-bedded sandstones can be seen well displayed on the north facing flanks of Cracoe Fell (Fig. 31). Rolling Gate Crag (SE001603), Peter's Crag (SD999596), Bartle Crag (SE002590), and The Crag (SD996595) all show the lower part of the channel outcrop to be large scale cross-beds. These are immediately overlain by facies 10, Medium scale cross-beds confined to the same channel. The medium scale cross-bedded sandstones have planar erosive bases and truncate the foresets of the large scale cross-beds (Photo 37).

3. Composite channel units are defined where a channel of the facies 10, Medium scale cross-bedded sandstones can be seen completely cutting across the top of a deep channel filled with facies 11, Large scale cross-bedded sandstones. This situation is thought to occur on Pockstones Moor (SE101604), and Simonseat (SE084599).

4.4.7 INTERDISTRIBUTARY SUB-ASSOCIATION

Exposures of Interdistributary facies are extremely poor since their present distribution is invariably on poorly drained dip slopes.

Facies thought to be involved in the interdistributary sub-association include facies 5, Micro cross-laminated sandstones; facies 8, Parallel bedded sandstones; facies 13, Coal and Seat Earths; facies 4, Carbonaceous siltstones, and finally, dark mudstones, similar to facies 1.

Where exposed, the mudstones and siltstones are extremely carbonaceous and probably formed widespread thin sheets of sediment. Coarser developments of micro cross-laminated sandstone and parallel bedded sandstone are occasionally seen to have erosive basal contacts with underlying finer sediments. These somewhat coarser facies are also thinly developed, usually less than 1m, and may have more localised distribution. The micro cross-laminated sandstones can have either a regular and uniform orientation of azimuths, or a more random distribution. These two styles are reminiscent of those seen in facies 10, Medium scale cross-bedded sandstones.

Seat earths and Coal facies (the Bradley Coal) are known to have a widespread lateral distribution, but present exposure is confined to one small adit near The Folly, Kildwick Hall (SE01604633), Farnhill Moor. Here the coal is very thin and is intercalated with dark mudstones.

Bioturbation is often intense, especially in the flaggy weathering siltstones and finer sandstones.

The poor exposure has made it impossible to detect any order or pattern in which the facies succeed one another (cf. Collinson 1969).

4.4.8 INTERPRETATION

As previously stated in the introduction of the Delta Platform Assemblage, three sections are distinguished.

1. Deep channels with large scale cross-beds.
2. Shallow channels with medium scale cross-beds.
3. Interdistributary sub-association.

These three sections are interpreted in this order, but first it is necessary to examine how channels may be cut in the delta top in the first place.

4.4.9 CHANNEL CUTTING PROCESSES

In a classic study, Coleman (1969) made a detailed examination of the channel processes and sedimentological regimes of the Brahmaputra River. He noted, for instance, that with the annual increase in river flow, the water levels of the river rose abruptly. To accommodate this increase, the channels were considerably widened and deepened by scouring, Coleman cites examples of as much as 15.2 metres of scour. He also observed that when the peak flood had passed, it was this deep scour channel that became the major site of deposition once the lower flood regime was established. He also noted that where banks were formed of cohesive material, then lateral migration of the bank was restricted and even deeper scouring occurred. Lane and Borland (1953) have also noted comparable scour depths from the Middle Rio Grande. Here they recorded scouring by floods in excess of 18.3m. At Yuma, Arizona, they noted that the Colorado River showed "....great depths of stream bed lowering ....such streams are scoured deeply at flood stage" (Page 309).

A similar model of channel cutting by annual floods is invoked to explain the deep channels in the E_{1C} Delta Top Association. (See Chapter 6 for a full discussion of the overall implications.)

4.4.10 DEEP CHANNELS WITH LARGE SCALE CROSS-BEDS

Collinson (1968, 1969) described large scale cross-beds from the R_1 Lower Kinderscout Grits and interpreted them as classical Gilbert type deltaic sedimentation units (Gilbert 1883). However, subsequent field work by McCabe (1975a) and the author demonstrates that the large scale cross-beds are confined to large channels. McCabe (1975a) proposed four possible models to illustrate how large scale cross-beds might originate in deep channels.

MODEL A. Confluence Deltas - can occur when a tributary with a high bed load enters a large relatively slow moving river.

MODEL B. Channel infill delta - abandoned river channels may be filled with a classical Gilbert-type delta.

MODEL C. Fluviatile sand waves - the most well documented are those described by Coleman (1969) from the Brahmaputra River.

MODEL D. ALTERNATE BARS - large bedforms with consecutive bars being attached to opposite banks and with their own slipfaces.

McCabe considered that Models A and B were too localised in extent and as such would not account for the widespread occurrence of the large scale cross-bedding seen in the R_1 succession. However, he considered Models C and D as more applicable. This seems reasonable in the light of the evidence in the E_1 sequence and therefore these are examined in more detail.

FLUVIATILE SANDWAVES (Model C). Coleman (1969) as well as describing the initiation and scouring of channels during floods also detailed the formation and movement of large bedforms within the channels. He noted that once the peak discharge had passed, then deposition took place and he describes the four dominant groups of bedforms which formed. These are tabulated below:-

TABLE 5	WAVELENGTH	HEIGHT	MAX.SIZE (HT)
1. Ripples	---	A few cm to 0.30cm	0.3m
2. Megaripples	3.04 - 152m	0.3 - 1.52m	1.5m
3. Dunes	42.6 - 487.6m	1.52 - 7.6m	7.6m
4. Sandwaves	182.8 - 914m	7.6 - 15.2m	15.2m

The dunes, and especially the sandwaves, are of a size and magnitude that begin to compare with some of the bedforms described in the E_{1C} and R_1 successions.

Coleman (1969, P. 190) states that "Sandwaves develop most commonly at peak flood and falling stage." Initially the bedforms have extreme rates of movement but as the river stage falls, so the movement decreases until the bedform is all but stationary.

The Brahmaputra River sandwaves have foresets with lengths of up to 7m and crests that, as well as being curved downstream, <u>are also</u>

straight (author's emphasis).

INTRASET FORMATION. Regarding the formation of the intrasets in the E_{1C} large scale cross-beds, it is interesting to note that Coleman (1969, P. 192) has recorded the common occurrence of small turbulance boils with "cell" diameters of 15 to 45 metres and occasional larger turbulance boils with diameters of up to 243m.

The E_{1C} intrasets, which have azimuths contrary to those of the large scale cross-bed foresets, are regarded as being formed from "back-flow ripple" processes.

In the case of the tabular intrasets with azimuths down the foreset slope, a different origin is postulated. The occasional preservation of topset beds in the intraset would seem to indicate extremely rapid deposition. There may well have been currents flowing down the large scale cross-bed foresets which were stronger than normally anticipated currents associated with lee-face avalanching. Lane and Eden (1940) have observed material which not only moved down slope by gravity processes but was also propelled by "down-ward moving water currents." The origin of these currents is still conjectural but they too may be related to turbulance boils.

TRANSVERSE BARS (Model D). McCabe (1975a) envisaged the R_1 large scale cross-beds as being part of large alternate bars which were attached to opposite banks in an alternate fashion. The E_{1C} Type B, large scale cross-beds are thought to have a similar origin. McCabe considered that the long low angle foresets would be formed by strong lee-side eddies resulting from the bars having skewed crest lines.

McCabe (pers. comm.) described experiments where the eddies sweep the sediment down the foresets giving dips less than normal angle of rest. Downstream migration of the alternate bars would result in the cross-bedding and internal erosion surfaces as illustrated in Fig. 17 and Photo 48 (see also Collinson 1968, Fig. 10).

The E_{1C} Type A large scale cross-beds with straight crests and steep foresets, more closely resemble the transverse bars as defined by Kennedy <u>et al</u> (1966) in that they are continuous crested features occupying nearly the full channel width with their crests orientated across the channel perpendicular to the direction of flow.

To conclude, the large scale bedforms described from the E_{1C} are as large as, or greater than the sandwaves described by Coleman. These sandwaves are organised into alternate and transverse bars.

4.4.11 SHALLOW CHANNELS WITH MEDIUM SCALE CROSS-BEDS

Medium scale cross-beds were described as occuring in two channel associations. These are:-

A. Shallow, single (multiple sheet) channels filled solely with medium scale cross-beds.

B. In association with large scale cross-beds (in partially filled deep channels).

An analogy of channels filled with both large scale and medium scale cross-beds from the E_{1C} can be made with Coleman's examples from the Brahmaputra River. He describes small bedforms, i.e.:- megaripples (see table 5 for dimensions) which migrate along the stoss side of the larger bedforms. This is thought to occur in the E_{1C}.

The shallow, isolated or multiple sheet channels filled with medium scale cross-bedding only are similar to the tabular units described by Collinson (1969, P. 212). He suggests that this type of channel unit fits the general model of fluviatile sedimentation proposed by Allen (1964b) and Visher (1965a and b). Their model was based on a consideration of a meandering or sinuous river where the laterally accreting bank was a point bar surface. However, Leeder (1973) describes a bedform (which he designates 'facies association two') from the O.R.S. of the Scottish Borders similar to the E_{1C} medium scale cross-beds. He considers that the point bar origin for the cross-beds must be rejected if the fluviatile bedforms do not show an upward decrease in grain size or a change in stratification type. Instead he thinks that stream channels with a low sinuosity are more likely to be responsible and they can be either braided or non-braided (see also Leopold and Wolman, 1957; Nedeco, 1959; Harms and Fahnstock, 1965).

A direct comparison can be made between the E_{1C} medium scale cross-beds in their channels and Leeder's (1973) facies association two model. As previously noted, there is no noticeable upward decrease in grain size or upward change in stratification scale or type in the E_{1C} medium scale cross-bed cosets.

In the E_{1C}, as noted above, the medium and large scale cross-beds which are confined to the same channel have similar azimuths. The Type A large scale cross-beds were inferred to be occupying comparatively straight channels and this would accord with the observation made by Coleman (1969, P. 202), that large bedforms are usually confined to straight reaches.

In conclusion, the medium scale cross-beds in both small and large channel associations, are of low sinuosity origin.

4.4.12 INTERDISTRIBUTARY SUB-ASSOCIATION

The general lack of exposure makes an interpretation of this part of the Delta Top Association very difficult. However, a comparison of the E_{1C} with the better exposed and comparable R_1 facies is made. Collinson (1969) and McCabe (1975b) interpret this facies association as representing generally shallow interdistributary bay and upper slope environments. Collinson notes the similarity of many of the sedimentary features with those seen in modern interdistributaries (cf. Coleman and Gagliano 1965).

Coleman *et al* (1964) has defined an interdistributary bay as the area between deltaic distributaries, irrespective of whether the bays are open to the sea or partially closed. The lack of evidence of tidal processes and beach and barrier deposits in the E_{1C} (and R_1, McCabe 1975b) suggests that the interdistributary areas were open to the sea but that fluviatile processes were dominant.

Elliott (1974a) documents some of the processes involved in flood generated incursions from distributaries. The overall effect of these processes is to produce a series of small "coarsening-up" sequences which represent the infilling of the bays.

The presence of a widespread coal (the Bradley Coal) is taken to indicate an overall colonisation of the delta top by vegetation, and is an important indicator of depth (cf. Reading 1970). Its widespread nature and lateral continuity is also important since it probably represents part of an 'abandonment facies' (Elliott 1974b). Elliott demonstrates that there is a genetic link between coal horizons and marine bands. This is of considerable relevance bearing in mind the apparent absence of the low E_{2a} *Cravenoceras cowlingense* marine band in the Skipton area.

4.4.13 FIELD BOUNDARY DEFINITION

Some of the problems concerning the delineation of the boundary between the Slope Association and the Delta Top Association have been outlined in the corresponding section - Slope Association. In addition, there are several areas, notably the western flank of Rylstone Fell, where it has been difficult to differentiate between channels belonging to the respective associations. The prograding fluviatile regime of the delta top, has been responsible for bringing coarse channel material into direct juxtaposition with channel material in the underlying Slope Association. The problem is compounded in areas close to the basin edge, especially where channelling is intense. Also, it is difficult to differentiate channels when only topographic features are available.

The upper boundary of the Delta Top Association is perhaps the most complex of all. Chapter 3 (Stratigraphy) outlines the controversy as to whether the Bradley Flags are to be included or not. In the absence of a well defined marine band, either because of non-deposition, or non-preservation, an arbitrary datum has been taken at a slightly lower level, namely the level of the Bradley Coal.

4.4.14 LATERAL CORRELATIVES

Finally, to complete the regional picture of the Delta Top Association, the lateral equivalents outside the area mapped are examined.

North of Grassington Moor, several authors have mapped the Grassington Grit Group. Wilson (1960) and Thompson (1957) both report that in the area immediately north of Hebden Moor, beds overlying the E_1 unconformity are massive, coarse grained, current bedded and with foresets indicating currents from the north east. These beds are considered to be medium scale cross-beds confined to channels. Further north, Wilson also notes that shales become more dominant. These shales are probably some form of overbank deposit, with "laterally impersistent coarse sandstone beds representing channels cutting through them."

North of Hawes, Rowell and Scanlon (1957) equate the Grassington Grit with the Lower Howgate Edge Grits. Their description of gannisters, fire clays and thin coals, all grouped under the term Mirkfell Gannister, indicates overbank or abandonment facies, whilst impersistent sandstones and grits represent fluviatile channels.

4.5 SLUMPING AND SYN-SEDIMENTARY TECTONICS

Two scales of slumping have been recognised in the E_{1C} succession.

1. Small scale (in beds less than one metre thick).
   e.g:- Facies 6, Thin turbidite sandstones show flow-roll structures. Although numerous, the axes of folding have not been measured.

2. Medium scale (in beds between one and ten metres thick).
   One good example has been found. Photo 61 shows a

slump involving facies 1, Mudstones and facies 7, Composite sandstones. This slump occurs towards the top of the Turbidite Association and can be seen in Kex Beck near the confluence with Howgill Sike (SE09185313). The sense of slump movement is in broad agreement with the other palaeocurrent indicators.

Rotational slumps and slump scars of the type noted by Laird (1968) have not been identified. This is largely due to poor exposure and to the fact that "without the presence of associated rotated slump packets, it is difficult to prove that dish-shaped discordances with draped fill represent slump scars ..... such features ..... mistaken for channels (Laird 1968, P. 119)."

Very large scale slumping and syn-sedimentary deformation structures of the type commonly recognized in the Mississippi delta (cf. Coleman et al 1974) have not been clearly identified in the field area. However, the relationship of the Delta Top Association with the top of the Slope Association can be shewn to be quite complex. Figure 29 shows there are instances where angular discordance is quite noticeable. The discordance may be explained by contemporaneous faulting associated with movement on the Craven Faults.

CHAPTER 5. REGIONAL STUDIES

5.1 PALAEOCURRENT DATA

5.1.1 INTRODUCTION

The palaeocurrent data is presented on a series of regional maps (Figs. 38, 39, 40 and 41) as well as on the left hand side of each of the vertical measured sections displayed in Enclosure 1. Of the four maps presented, two are related to data from the Slope and Turbidite Associations, whilst two are related to data from the Delta Top Association.

On both the maps and cross sections, the palaeocurrent data has been plotted on circular rose diagrams. Readings have been grouped in 15 degree intervals and all the readings presented are corrected to "Grid north".

A statistical analysis of the palaeocurrent data has not been attempted, principally because of the restricted and uneven distribution of the outcrops.

Interpretations and implications from the presented diagrams are discussed more fully in Chapter 6.

5.1.2 SLOPE AND TURBIDITE FACIES ASSOCIATION

Figure 38 illustrates the azimuthal directions taken from the bases of facies 6, Turbidite sandstones. The majority of readings are from those turbidites within the Turbidite Association but also includes several readings from thin turbidite sandstones within the lower part of the Slope Association. Most of the sole markings have been made by tools and include bounce, skip and prod marks. In those instances where a specimen shows several directions, an average reading has been taken.

Figure 39 shows the azimuths taken from the rippled tops of the facies 6, Turbidite sandstones. Readings have only been taken from those

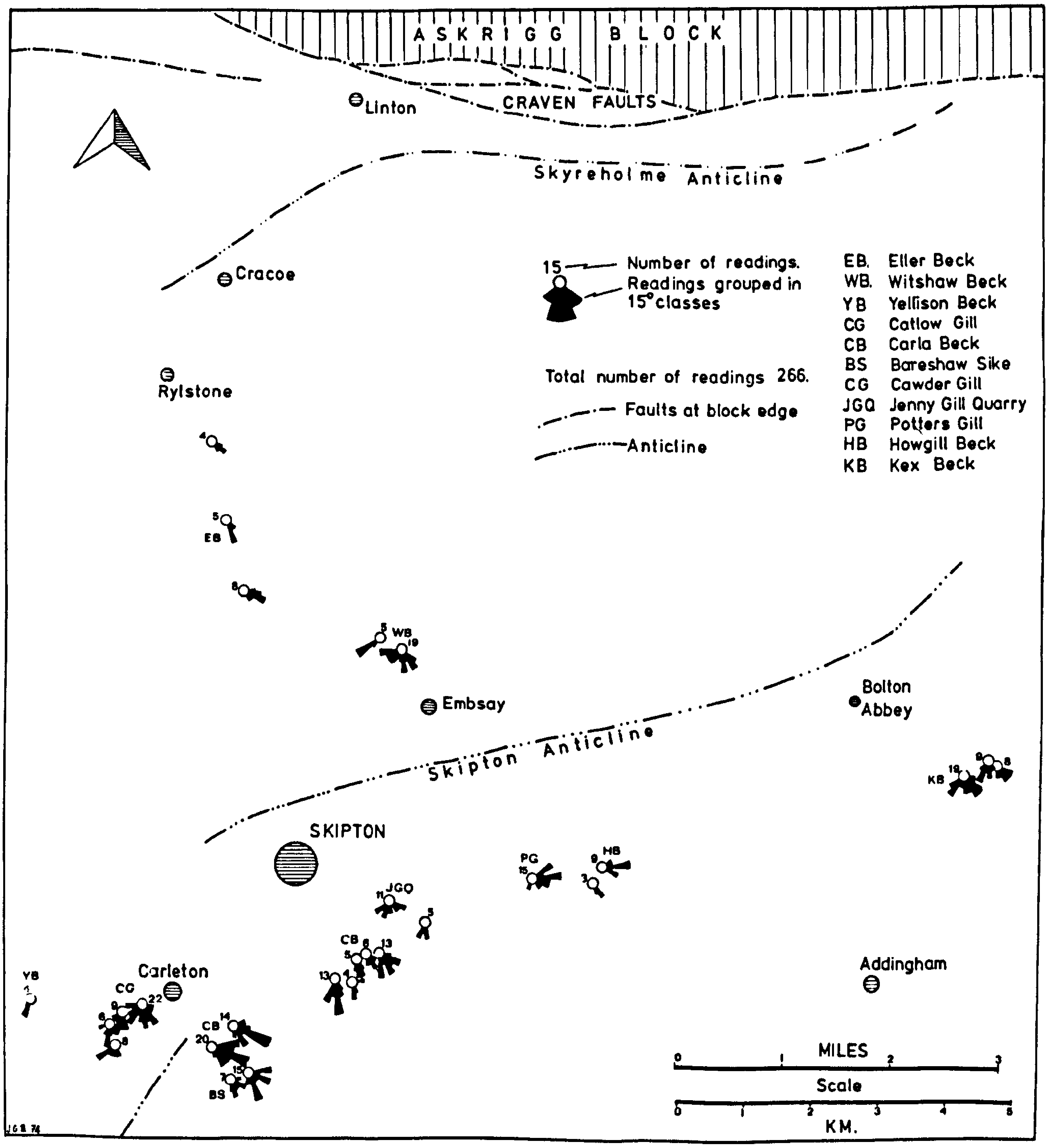


Fig. 38. Palaeocurrent azimuths from the sole markings of facies 6, Thin turbidite sandstones in the Turbidite and Lower Slope Associations. Compare with Fig. 39, the azimuths taken from the bow-shaped linguoid rippled tops of facies 6, Thin turbidite sandstones.

Note that the palaeocurrents are all broadly directed to the south.

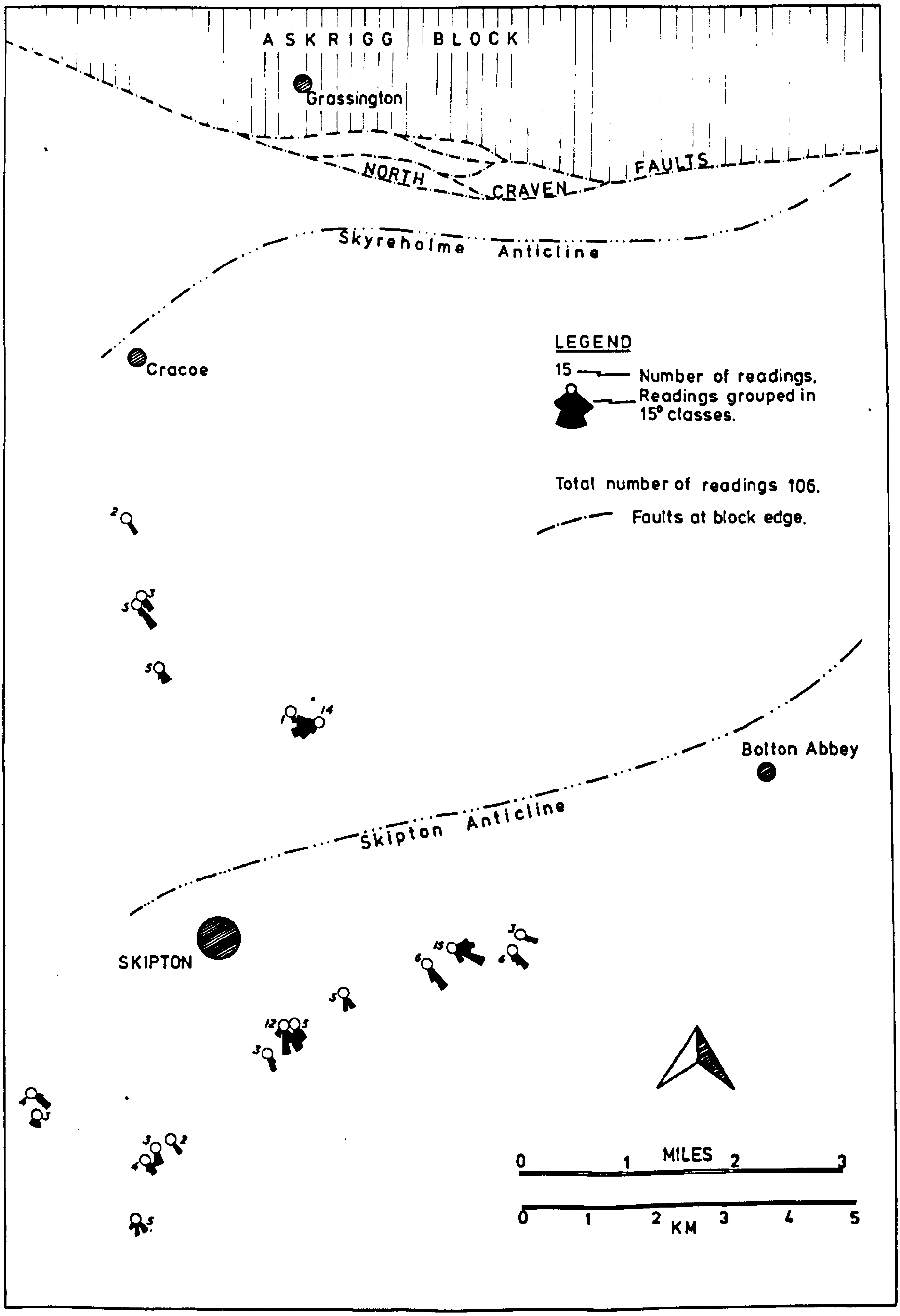


Fig. 39. Palaeocurrent azimuths from the bow-shaped linguoid rippled tops of facies 6, Thin turbidite sandstones. Turbidite and lower Slope Associations.

Fig. 40. Palaeocurrent azimuths from facies 11, Large scale cross-bedded sandstones (Type A). Delta Top Association - Grassington Grits.

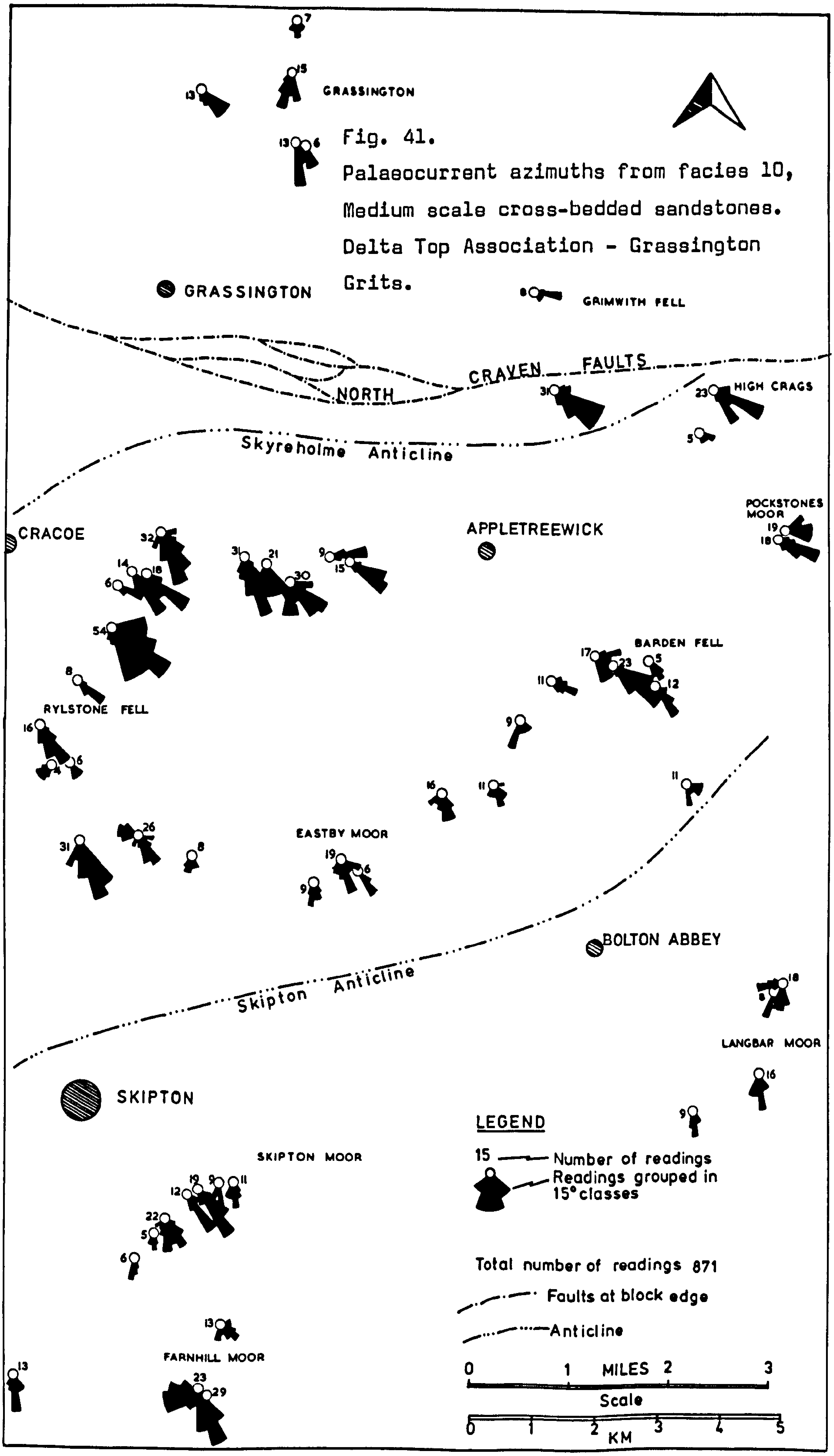


Fig. 41.
Palaeocurrent azimuths from facies 10, Medium scale cross-bedded sandstones. Delta Top Association - Grassington Grits.

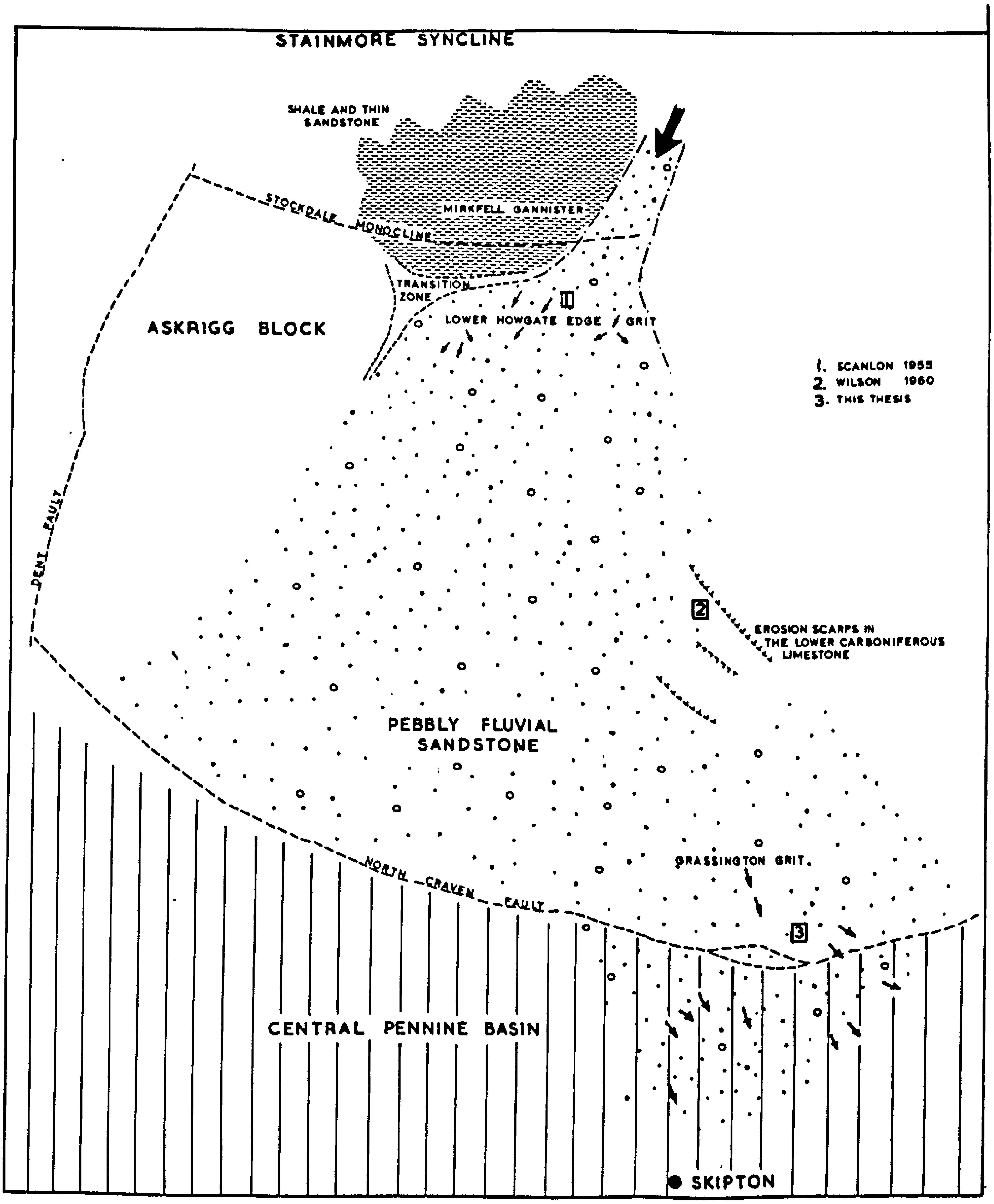


Fig. 42. Generalised palaeogeographic map of the Askrigg Block during E_{1C} Namurian times. Based on information from Scanlon (1955), Wilson (1960) and D. Moore (personal communication).

examples where the full crestal geometry of the bow-shaped linguoid ripple could be seen. As can be appreciated from a study of Figure 7, any attempt to take a measurement from the flank of the ripple would give an anomalous result.

It was found that in nearly all instances, there was a close correspondence in both the sole and ripple azimuths from any one bed. The implication of this is discussed in Chapter 6. The general conclusion was that there was an entrainment of water caused by the passage of a turbidity current and this effectively reworked the upper surface of the turbidite.

5.1.3 DELTA TOP AND PLATFORM ASSOCIATIONS

Figure 40 shows the azimuths taken from the lee faces of facies 11, Large scale cross-beds. Outcrops influenced by cambering and solifluction were ignored. Measurements were made as close to the top of the foreset as possible and the measurement is assumed to represent the dip direction of the lee face of the large sand wave responsible.

Figure 41 shows the azimuths taken from facies 10, Medium scale cross-bedding. Unfortunately, sampling of these cross-beds is biased to those outcrops showing good three-dimensional aspect.

There is a marked conformity in readings between the large scale cross-beds and the medium scale cross-beds in the vicinity of the North Craven Faults.

Figure 42 is a synthesis of palaeocurrent data from the E_{1C} delta top sediments with palaeocurrent information available from the Askrigg Block.

5.2 REGIONAL MAPPING

5.2.1 INTRODUCTION

Each of the field map areas (see Figure 43 for their relative locations) is briefly discussed. Relevant studies of the areas are listed, as well as the comparative status of the present research, i.e. detailed mapping and research or reconnaissance survey only. Constant reference is made to those diagrams and photographs that best illustrate the stratigraphy and sedimentology of the area, and the more important outcrop localities are also listed. Reference to the measured sections 1-31 recorded on Enclosure 1 are abbreviated thus:- (Encl. 1.5).

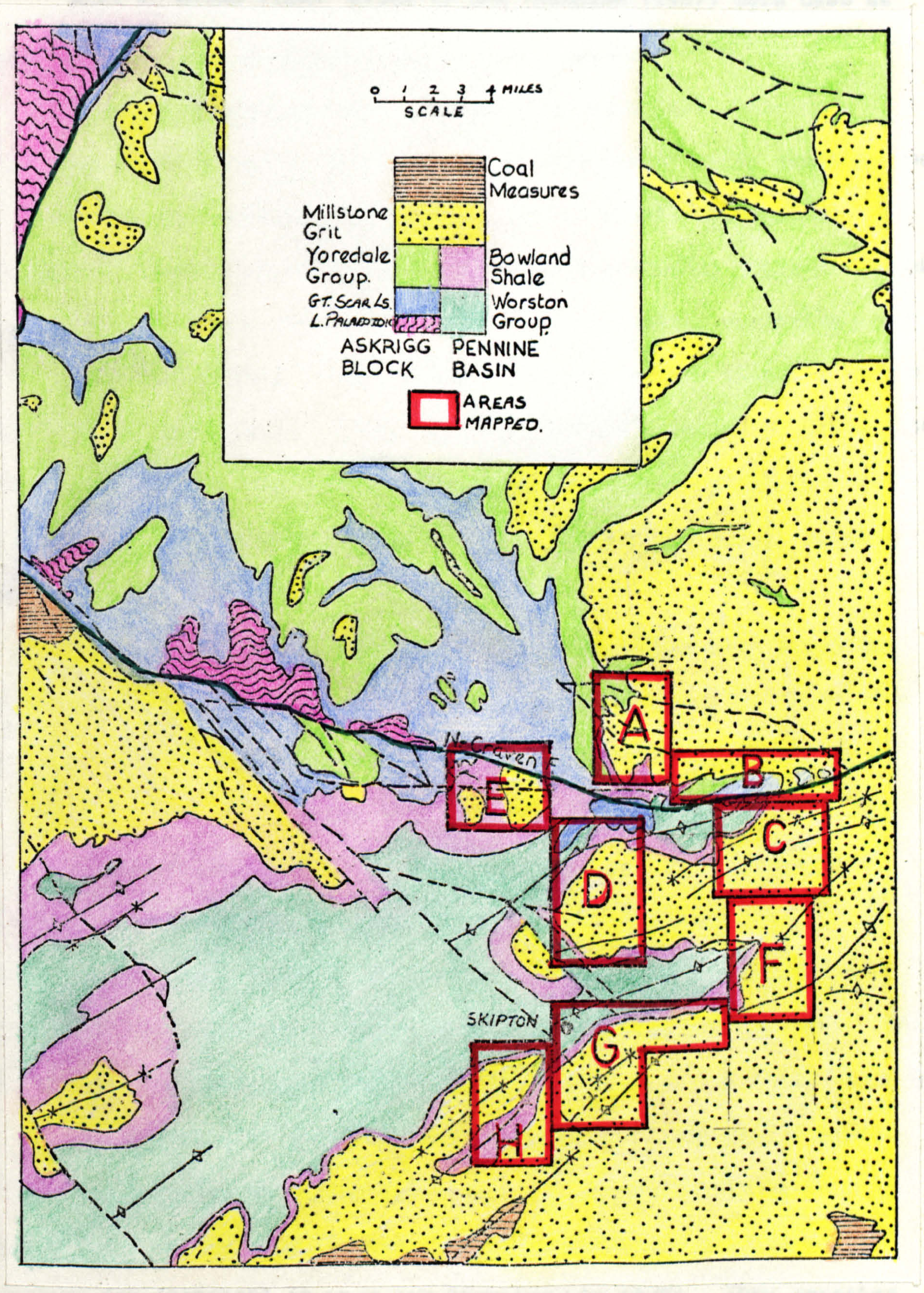


Fig. 43. Map indicating the relative locations of Enclosures A - H (included in the back of Volume 2).

5.2.2 AREA A. GRASSINGTON AND HEBDEN MOOR

Grassington Moor and Hebden Moor lie to the north of the North Craven Fault (Enclosure A). A brief, but essential, survey gave an appreciation of the sedimentary facies on the southern margin of the Askrigg Block.

Maps by Black (1950, Plate 5) and Thompson (1957) were used as a guide. An amendment to Black's map is noted below.

The Lower Carboniferous succession has been left undivided. North of the Yarnbury Fault, the Grassington Grit unconformity overlies the Lower Carboniferous Limestone, whilst south of the fault, the basinal development of Bowland Shale is preserved as an intervening horizon. Black (1950) demonstrated that the Bowland Shales were deposited against a pre-E_1 scarp. He located this E.S.E - W.N.W. trending feature slightly to the south of the Yarnbury Fault. Black also divided the Grassington Grits into two "leaves." However, in view of the present sedimentological interpretation (i.e. one of laterally impersistent fluviatile channels), Black's division is discounted.

The unconformity at the base of the Grassington Grit Group is quite irregular, due to the scour of the fluviatile currents. Part of a channel edge can be seen at Green Hill Knoll (SE 0089 6760), north of Downs Pasture (Fig. 44) (Black 1950, Joysey 1955).

Figure 45 illustrates two major channel sequences which form conspicuous features on the fell side, south of Coal Grove Beck, (SE 0245 6625). These features are terminated and brought into juxtaposition with the overlying Nidderdale Shale succession (SE 028 655). This interpretation disagrees with that of Black (see Black's map 1950, Plate 5).

The Grassington Grits are estimated to be 87 m thick (see Enc. I.1) although locating the upper datum, the E_{2a}, Cockhill Marine Band is difficult. The marine band has been reported however in a trial pit in Bolton Gill (SE 03176538) (Dunham and Stubblefield 1945). They reported finding Cravenoceras cowlingense and Eumorphoceras bisulcatum mut.

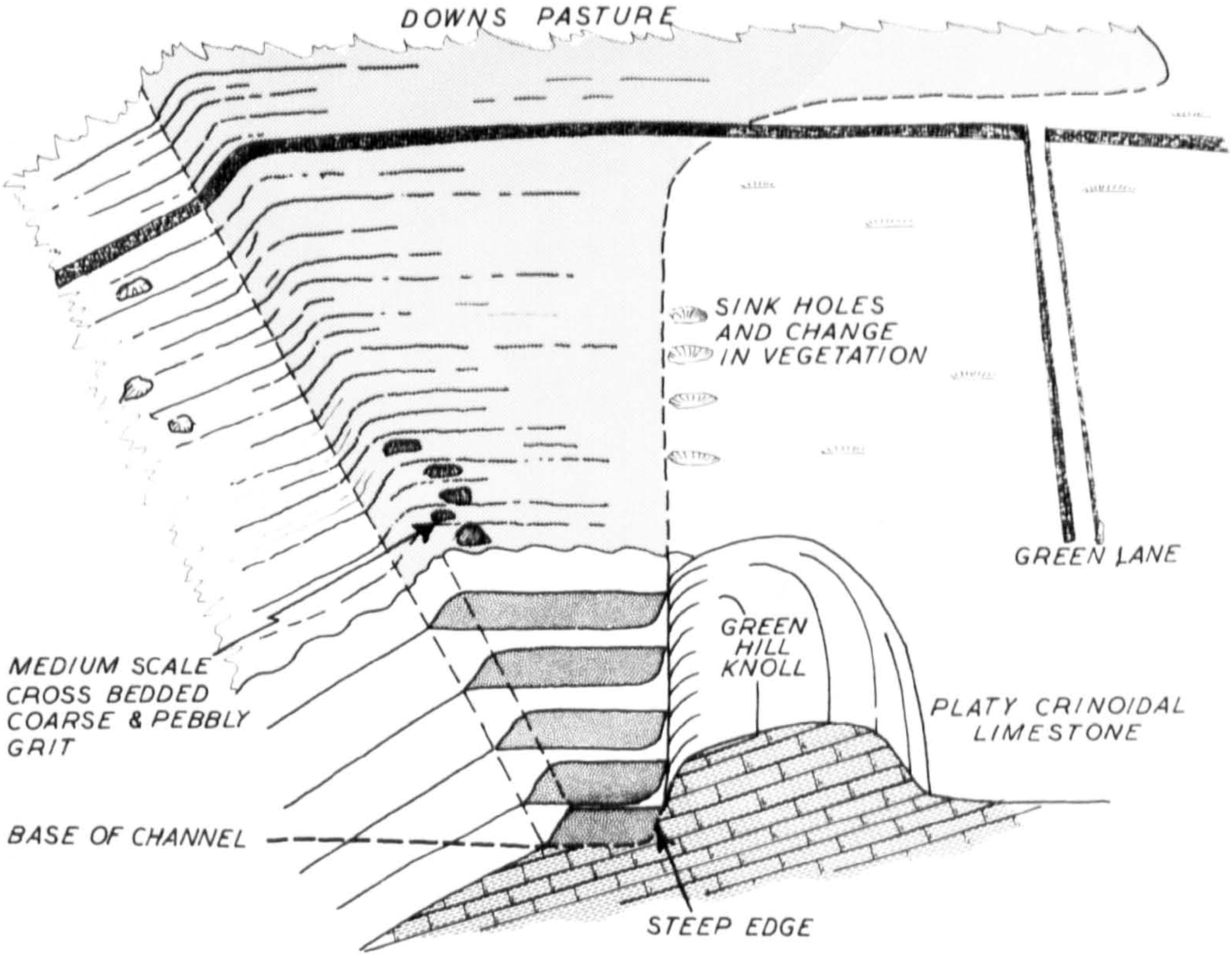


Fig. 44

Schematic oblique aerial view of Green Hill Knoll (SE00896760), north of Downs Pasture, looking almost due south. The sketch shows the Grassington Grits, represented by facies 10, Medium scale cross-bedded sandstones, in juxtaposition with Lower Carboniferous Platy Crinoidal Limestones. The field relationship suggests that the grits are in a channel at this point.

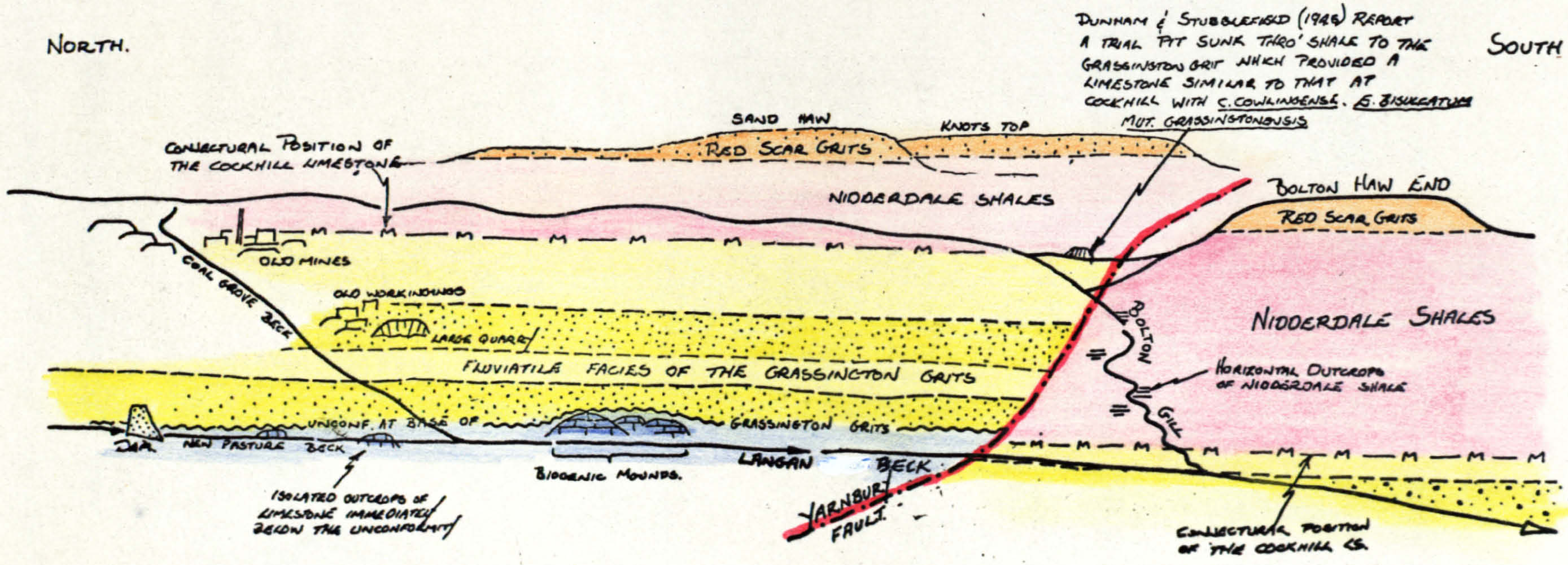


Fig. 45. Field sketch of Grassington Fell looking east across Langan Beck. The Old mines near Coal Grove Beck are at SE028667 whilst Bolton Haw End is at SE030652. The placing of the Cockhill Marine Band is very conjectural. Black Hill Moss is probably underlain by the Nidderdale Shale (see Enclosure A).

grassingtonensis which Yates (1962) regarded as a "low" E_{2a} fauna (see Chapter 2.2.2 for full discussion of implications).

5.2.3 AREA B. APPLETREEWICK MOOR & GREENHOW HILL

The Appletreewick Moor area (Enclosure B) also lies to the north of the North Craven Fault and is an eastward continuation of the stratigraphy seen on Grassington and Hebden Moors.

The Greenhow Hill area was comprehensively studied by Dunham and Stubblefield (1945) and extensive use has been made of their map during a brief reconnaissance appraisal.

The Bowland Shales, when traced eastwards from Area A are inferred to underlie the Grassington Grits in the western part of the area although they are unexposed. Their presence may be responsible for the numerous small landslips south of Toothill Ridge (SE 057639). The Grassington Grits are composed dominantly of facies 10, Medium scale cross-beds (often including logs up to 80 cm in length). Good examples can be seen near the Grimwith Reservoir Dam (SE 062641).

The thickness of the Grassington Grits varies between 53 and 61 m and is reported as being 59 m thick in the Cockhill adit (SE 11396480) in the east of the area (Dunham and Stubblefield 1945). They also report two thin coal seams (Enc. I.25) which probably correspond to the Aket coal once mined near Grimwith Reservoir (SE 06256410).

The Grassington Grits are succeeded by the thin but important Cockhill Limestone (Dunham and Stubblefield 1945). Yates (1962) considered the listed fauna as "low E_{2a}".

5.2.4 AREA C. BARDEN FELL AND POCKSTONES MOOR

This area lies immediately south of the North Craven Fault and provides a link between the block succession (e.g. areas A and B) and the expanded basinal succession (e.g. areas F and G).

The dominant structural grain of the area is a north-east - south-west fold belt. The Redlish Syncline (responsible for the Blands Beck Valley) is the tightest fold in the area (Thompson 1957), with dips of up to 40° in the Fir Beck area (SE065599).

The Skyreholme Anticline has been mapped by Anderson (1928) and Black and Bond (1952) whilst the Simonseat Anticline has been mapped by Hudson (1939). Broad use of the latter map has been made in the Pockstones Moor area.

The Bowland Shales are present on either side of the Skyreholme Anticline although they may thin considerably to the north-east. The Grassington Grits succeed them unconformably but south of the Skyreholme Anticline the distribution of stratigraphical units is complex and poorly understood. There are three reasons for this:-

(1) The whole area is poorly exposed, especially in the deep valley of Blands Beck (SE078607) and on the northern flanks of Simonseat (SE079598).

(2) The area may be more structurally complex than the map shows. For instance, the western continuation of the Nar Hill Fault (SE095611) is difficult to determine, if indeed, it is present at all.

(3) The sedimentary section expands rapidly south-wards away from the North Craven Fault, bringing in many facies associated with the progradation of the E_1 delta. In the north of this area, between High Crags (SE09056270) and Eller Edge (SE08706125) approximately 91m is present (Dunham and Stubblefield 1945), whilst south of Barden Fell, the section is estimated to be over 182m thick.

Hudson (1939) originally distinguished two sandstone horizons, the Little and Great Pockstones Grits. The generality of this subdivision is discounted here as sedimentological experience of such units suggests they are likely to be laterally impersistent.

On Simonseat (SE 079598), Lords Seat (SE 08455988) and Carncliffe Top (SE 071584) facies 11, Large scale cross-beds are exposed, (Photo 41; also Fig. 40 for cross-bedding azimuths). These may be overlain by thick sheets of facies 10, Medium scale cross-beds. Medium scale cross-beds are also exposed north of the Skyreholme Anticline, in Fancarl Crags (SE 09056270), and on the southern flanks of Barden Fell.

A thin succession of facies 5, Micro cross-bedded sandstone and facies 13, Seat earths can be seen in Great Agill Beck just above the ford (SE 08155890) (Fig. 32) (Enc. I 26). These sediments are of interdistributary origin.

The top mapping datum, the E_{2a} marine band has not been found and once again, the upper boundary of the Grassington Grits is very conjectural.

5.2.5 AREA D. EMBSAY MOOR AND RYLSTONE FELL AREA

This area has been extensively mapped since its preservation as a plateau allows a three dimensional regional study. From north to south, the succession is illustrated in a series of field sketches (Figs. 31, 46, 25 and 24).

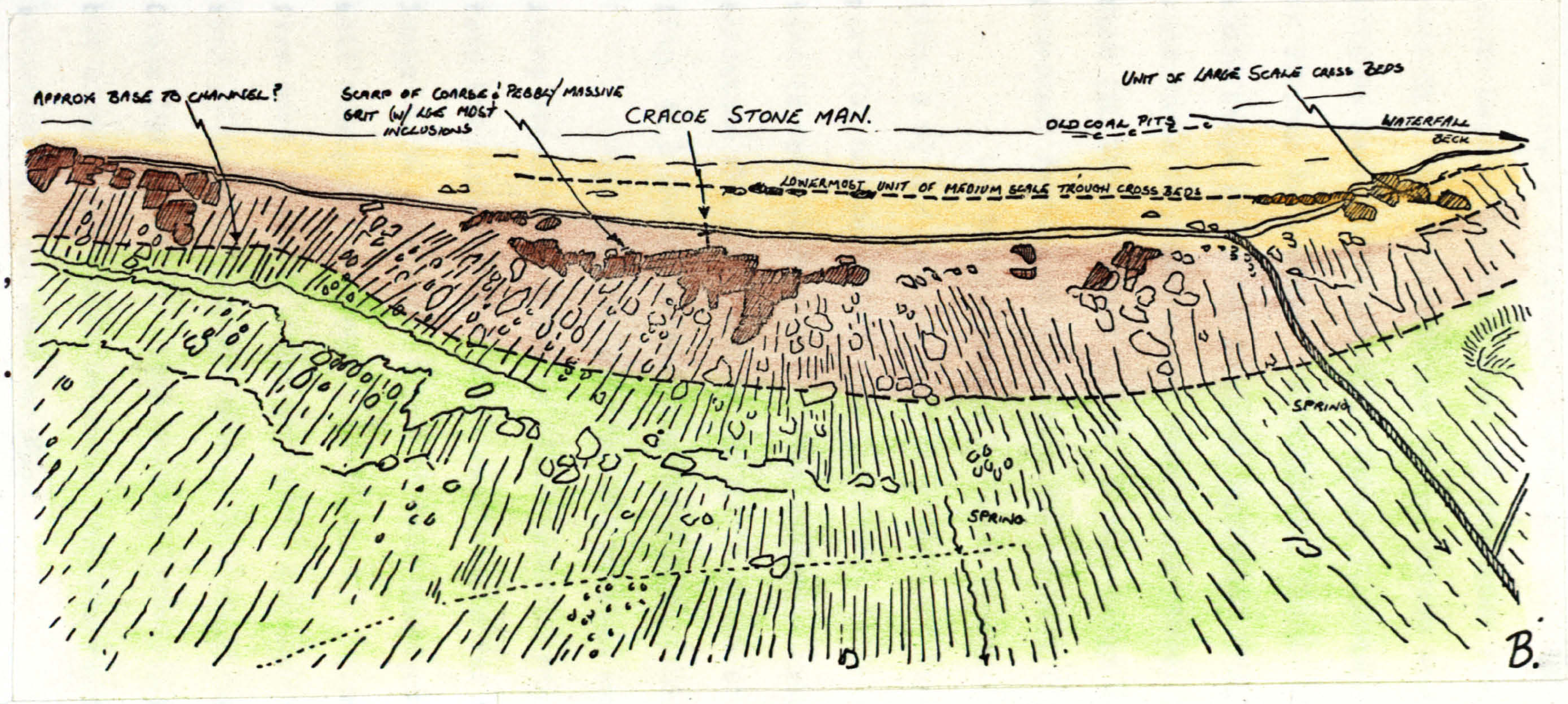
These field sketches show the fine grained facies form long featureless scree covered slopes, whilst the coarser facies usually form discreet, well defined features.

The Bowland Shales form the low, poorly drained area around the foot of the main scarp and it contrasts dramatically with the topographic featuring of the Lower Carboniferous Limestones. Good outcrops of the Upper Bowland Shales occur in Fell Gill (SD981582) south of Brownshaw (Booker and Hudson 1962) whilst other outcrops are documented from Hesker Gill (SE 01556087) and Waterspout Beck (SE 02156070) (Bond 1950, Black 1957).

The Pendle Grits are, for the most part, very poorly exposed. Their thickest development is in the south of the area where the succession is estimated to be 220 m thick (Enc. I 14; Fig. 24). They thin rapidly to the north and are not thought to be present north of Threapland Gill

COLOUR CODE.

Purple- Bowland Sh; Lt. blue- Lwr. Carb. Lst; Dk. grn.- Pendle grits; Lt. grn- Pendle Sh; Dk. brown- Facies 12, Massive sst; Lt. brown- Facies 11, L.S.X.B; Facies 10, M.S.X.B.



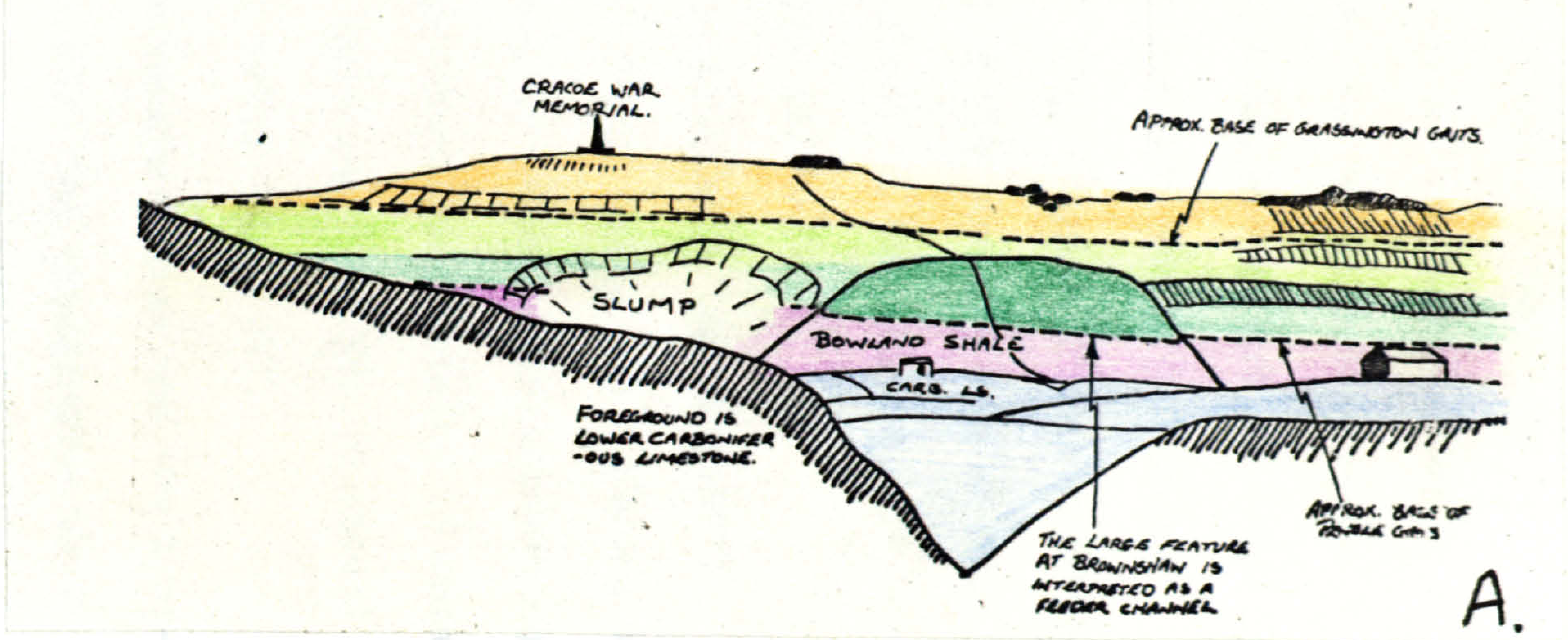


Fig. 46.

A/. Field sketch of Brownsaw (SD985588) and Cracoe Fell War Memorial (SD993588) showing stratigraphic relationships.

B/. Oblique aerial view of Cracoe Stone Man Monument (SD98255761) showing large channel at the top of the Slope Association.

(SD 99676009). Facies 1 mudstones and facies 6 thin turbidite sandstones can be seen in Ellerbeck - Waterfall Gill (SD 979566) (Enc. I 9) to the south west of Sun Moor Wood, in the upper reaches of the tributaries of Fell Gill (SD 97605765) and in the stream south west of Grouse Cottage, Witshaw Band (SE 00565467). Facies 7, Composite sandstones are well exposed in Witshaw Bank Quarry (SE 00165481) (Photo 15 and 16) and in the Broken Cabin Crags below Red Gill (SD 97955590) (Fig. 28). Facies 9 Ropy-weathering sandstones in channels are seen below Embsay Crag (SE 005550) and at High Mark (SD 990547) (Enc. I.13). A very large channel is thought to form the prominent feature at Brownshaw (SD 985588) (Fig. 46).

The Pendle Shales are well exposed in Ellerbeck (SD 98365677) (Enc. I 9) and Towburn Gill (SD 99525492) (Enc. I.12) (Fig. 33). Facies 4 parallel bedded and striped siltstones (with a good trace fossil assemblage) tend to form steep banks to the streams. Large channels of facies 12 massive sandstone are prominent on the north flank of Rylstone Fell (SD 98245764) (Fig. 46) and on Embsay Crag (SE005551) (Enc. I.14) (Fig. 27).

The angular unconformity between the Pendle Shales and the overlying Grassington Grits is illustrated in Fig. 32. The Grassington Grits form the plateau top and are responsible for the "skyline" scarps. Facies 11 large scale cross-beds (Type A) form discreet features which are especially well displayed on Cracoe Fell (Fig. 34). Facies 10, medium scale cross beds form more laterally extensive units and good examples of this facies can be seen in Dear Gallows (SD 999556) Crookrise Crag (SD 988559) and Hellifield Crags (SD 985566). Fine grained inter-channel sediments are rarely exposed but occasional "float" material includes facies 5, Micro cross-laminated sandstone with vertical burrows.

The thin, laterally persistent coal seen to the north of Deer Gallows (SE 002557), Black Sike (SD 99265720) and Burnsall and Thorpe Fell (SE 01755985) has been used as a mapping datum and is tentatively correlated with the Bradley Coal seen on Skipton Moor.

The E_{2a} marine band has not been found although silty flags seen in Rams Gill Head (SE01555545) north east of Embsay Crag may possibly be of an E_2 age. (The natural amphitheatre, with its long dip slopes, large peat whams and general poor exposure, have precluded a realistic attempt at mapping.)

The geology of the area to the east of Embsay Moor is poorly understood. However, Fig. 37 illustrates some of the major channel units seen on Eastby Fell. The area east of Burnsall and Thorpe Fell has not been mapped at all, nor has the outlier of Flasby Fell and Sharp How to the west of Embsay Moor.

5.2.6 AREA E. CALTON MOOR AND THRESHFIELD MOOR

This area lies to the north west of Burnsall and Thorpe Fell (Enclosure D). The North Craven Fault forms the northern boundary of the area.

The area has been surveyed at a reconnaissance level only, since Williamson (1960) produced an adequate map.

The Upper Bowland Shale can be recognised in Eller Beck (especially at the confluence with Hammerton Sike) (SD97056160) and in Moor Close Gill (SD932638) and Hog How Sike (SD917625) (Garwood and Goodyear 1924).

It has not been possible to ascertain whether or not the Pendle Grits are present, and it is suspected that they may be absent.

The Pendle Shales however are exposed in rare stream sections in Hammerton Hill Sike (Enc. 1.2) (SD969620) and consists of facies 4, Parallel bedded and striped siltstones. The trace fossil assemblage contained is identical to that seen in Eller Beck (SD98305676) (Enclosure D). Coarse sandstone facies form features which Williamson (1960) notes as lenticular bodies and are here interpreted as channel deposits.

The Grassington Grits form laterally continuous features on the higher parts of Threshfield Moor and Weets Top. Hudson (1944) originally termed the Weets Top succession, the Kirby Fell Grits. Facies 10, Medium scale cross-beds form a marked feature on Backstone Edge, (SD971624) and are overlain by a thin coal (known locally as the Caton Coal and formerly worked at the Threshfield Colliery, SD973628). A second coal horizon is seen on Dolmire Hill (SD967628) and Williamson (1960) suggested these two coals equate with the coals seen in the Cockhill succession (Dunham and Stubblefield 1945). It is tentatively suggested that the upper coal seam may equate with the Bradley Coal.

The E_{2a} marine band is absent through erosion.

5.2.7 AREA F. BOLTON ABBEY AND BEAMSLEY MOOR

This area was the most difficult to map on a sedimentological basis and much of the area, especially north of the Skipton Anticline, is still poorly understood.

An appreciation of the area, south of the main anticline can be gained from maps by Hudson and Versey (1935, Fig. 1), Hudson and Mitchell (1937, Plate 1), Jones (1943, Plate 1), and Stephens <u>et al</u> (1953 and Sheet 69).

Three main problems have been encountered in this area:-

(1) The area is structurally complex. The limbs of the Skipton Anticline are very steep, and incompetent sediments are much disturbed and altered (Hudson and Mitchell 1937).

(2) The facies associations of the Pendle Grits, Pendle Shales and Grassington Grits all coalesce northwards, and complex features are difficult to differentiate into the respective component parts.

(3) Marker horizons are absent and only tentative correlations can be made between measured sections.

The Bowland Shales may be seen at Skip House Wheel Scar near Bolton Abbey (SE07585408) and on the west bank of the river Wharfe, north of Eller Carr Wood (SE07105238).

The Pendle Grits are exposed in Kex Beck (Enclosure 1.30) and it is possible to delineate large channels which have eroded into intercatations of facies 1, mudstones and facies 6, thin turbidite sandstones (SE08055264) (Fig. 47).

An exposure of coarse pebbly grit at Skip House Wheel Scar near Bolton Abbey (SE07505405) is interpreted as a feeder channel deposit although Hudson and Mitchell (1937) admit that its position is ambiguous. The base of another channel can be seen at Cat Crags (SE07765441) (Fig. 21e).

A thick development of facies 7, Composite Sandstones is well displayed in the gorge at Deerstones (Enclosure 1.29) and a good example of sheet dewatering structures can be seen a few metres upstream of the packhorse Bridge (SE08925294) (Photo 17).

The junction between the Pendle Grits and the Pendle Shales is well displayed at the confluence of Howgill Sike and Kex Beck (SE09205314) (Enclosure 1.28). Whilst the lower part of the Pendle Shales is well exposed in Howgill Sike (Photo 59), the upper part of the succession is very poorly displayed. Features on the northern flank of Beamsley Beacon suggest that there may be a development of feeder channels (SE096526).

The Grassington Grits are well exposed on Langbar Moor and a series of well defined channels of facies 10, Medium scale cross-beds can be seen immediately south of Beamsley Beacon (SE098519) (Enclosure 1.28). The Grassington Grits can be traced northwards onto Beamsley Moor and Edge Top (SE092539) but north of Noska Brow (SE091573) the features become more erratic.

Lateral equivalents of the Bradley Coal, the Bradley Flags and the E_{2a} marine band are not recognised because of lack of exposure.

(NOTE: The Valley of Desolation appears to have a good succession which needs a further detailed examination).

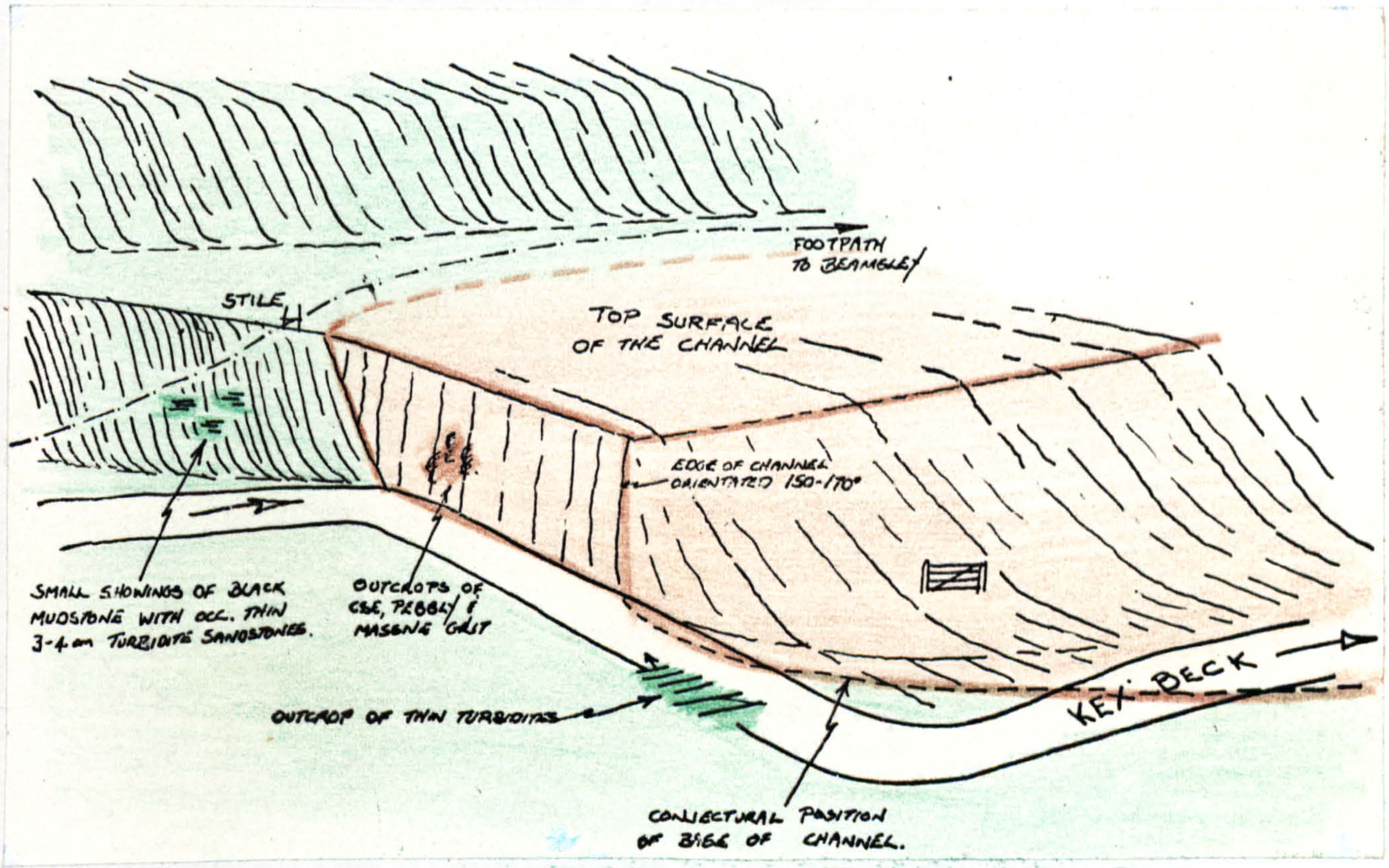


Fig. 47. Field sketch of a possible feeder channel in the Turbidite Association.
Note the lateral juxtaposition of intercalations of mudstones and thin turbidite sandstones (seen in the bank left of the stile and also in the river bed) with a more resistant mass of coarse and pebbly sandstones.
Kex Beck (SE08505264), Beamsley.

5.2.8 AREA G. SKIPTON MOOR AND FARNHILL MOOR

Skipton Moor lies to the southeast of Skipton and is bounded to the west by the Aire Valley.

The area is covered by the Geological Survey one inch Sheet 69 and Geology Survey Memoir (Stephens et al 1953).

The present detailed sedimentological investigation has lead to a complete re-appraisal of the Geological Survey map. Many of the horizons which were previously mapped as long continuous features are now seen to be short discontinuous structures related to channels (Photos 56, 57 & 58 and Fig. 20).

The Cravenoceras malhamense marine band (facies 2) in the Upper Bowland Shales forms the lowermost mapping datum (Enclosure 1.15 and 18) (see Hudson and Versey 1935, and Hudson and Mitchell 1937 for details of the fauna).

Figure 20 shows that the Pendle Grits are characterised by the presence of numerous channels of facies 9, Ropy-weathering sandstones. Details of two channel margins are illustrated in Fig. 21b and c. The feature at the base of the Pendle Grits is formed from facies 7, Composite sandstones and a well exposed section is seen in Jenny Gill Quarry (SE00355090) (Enclosure 1.18) (Photo 52). Laterally equivalent sections to the east are detailed in Fig. 9.

The interchannel sequence of facies 1, Mudstones and facies 6, Thin turbidites is usually poorly exposed. An irregular and discontinuous section can be traced up Cawder Gill (SE00015019) (Enclosure 1.19).

The boundary between the Pendle Grits and Pendle Shales is defined at the intersection of the "Gas Pipeline" with Cawder Gill (SE00525043) (see Fig. 23a). The Pendle Shales form a featureless tract of rising ground immediately below the "The Standard." (SE007504). The intensity of channeling is considerably less than in the Pendle Grits. Exposure of the Pendle Shales is poor, although at the time of mapping (1972) on incomplete succession was gained from the Gas Pipeline trench.

The section was dominantly facies 4, Parallel bedded and striped siltstones.

The Grassington Grits are well exposed in a series of laterally discontinuous scarps (see (Fig. 35). These are channels of facies 10, Medium scale cross-beds. On Farnhill Moor, Fig. 33 illustrates a development of facies 11, Large scale cross-beds (Type B) immediately below a coset of medium scale cross beds (Enclosure 1.20).

The succeeding Bradley Coal is exposed at Farnhill (SE01064632) (Stephens et al 1953) and was also temporarily exposed during the construction of the Gas Pipeline (SE01054187).

The Bradley Flags are unique to Skipton Moor and Cononley Moor (Enclosure H). For a full discussion of their stratigraphic and sedimentologic significance - see Chapter 2.2.2 and Appendix 11.

The Edge Marine Band is exposed in Eller Gill (SE00844936) due east of High Bradley, at High Edge (SE025500) and in Farnhill Moor (SE01384668) (Bisat 1924. Stephens et al 1953). Yates (1962) considered that the fauna was diagnosed of a high E_{2a} position which made its previous correlation with the Cockhill Marine Band untenable (Chapter 2.2.2).

5.2.9 AREA H. CARLETON MOOR AND CONONLEY MOOR

This area lies to the south west of Skipton. It is bounded to the east by the Aire Valley.

The area south west of Lothersdale has been mapped by Bray (1927). In the north, several stream sections of the Upper Bowland Shales and lowermost Pendle Grits are detailed by Gill (1940 and 1947). The Pendle Grits are well exposed in Catlow Gill (SD964493), Carla Beck (SD97804889) (Enclosure 1.24) and Yellison Beck (SD95034948). Facies 1, Mudstones and facies 6, Thin turbidite sandstones are out by channels of facies 9, Ropy-weathering sandstone (Fig. 23c, Photo 55) (Enclosure 1.22).

The upper part of the Pendle Shales can be seen in Peat Gill (SD97784729) (Fig. 28) (Enclosure 1.23) and consists of facies 4, Parallel bedded and striped stilstones.

The Grassington Grits have only been briefly examined but a channel base can be seen in Hengill (SD97914715) (Fig. 28).

The Bradley Flags are exposed in Tanhill Pits to the north of Cononley (SD985471) and are similar to the cross-bedded cosets seen in Bradley Quarry (SE002489).

The Edge Marine Band is well exposed in Cononley Beck (SD98554685) and correlates with the Edge Marine Band on Skipton Moor. For full details of the contained fauna, see Bisat (1924) and Stephens et al (1953).

CHAPTER 6. BASIN ANALYSIS AND SYNTHESIS.

6.1 Introduction

This final chapter is an attempt to synthesize all the relevant information concerning i) Facies Associations; ii) Palaeocurrents; iii) Ichnology and iv) Regional Palaeogeography.

The E_{1C} Skipton Moor Grit Formation delta is also compared with the R_1 Namurian Kinderscoutian delta to which it bears a close resemblance in many, but not all aspects.

6.1.1 Pre-E_{1C} Basin history

The Central Pennine Basin is one of a series of elongate basins that existed in northern Britain during Upper Devonian and Carboniferous times (Leeder 1974). Bott (1964 and 1965) provides a general hypothesis for the basin origin in his mantle flow theory. He postulates that there was a state of general tensional stress in the upper crust of northern Britain due to compensatory upper mantle flow northwards toward the isostatically rising Caledonides orogen (Bott and Johnson 1967, Fig. 6). According to Leeder (1974), basins with normal faults or hinge bound margins developed by brittle fracture in areas of crust free from late orogenic granitic plutons whilst areas with plutons tended to remain as relatively stable blocks (Fig. 48).

On a more local scale, the northern margin of the Central Pennine Basin was probably affected by two types of tectonic control (Moore 1972a):-

A) A general differential subsidence of the basin with an associated uplift of the neighbouring Askrigg Block.

B) Accidental coupling of adjacent crustal blocks resulting in a distorted subsidence and rapid re-adjustment when the coupling broke.

Moore recognises six coupling/uncoupling events from the Central Pennine Basin and the adjacent Askrigg Block, dated as B_2; P_{1C-D}; P_{2C}; E_{1C}; R_{1C} and late G_1. (As yet, Moore's hyphothesis is to be regarded with

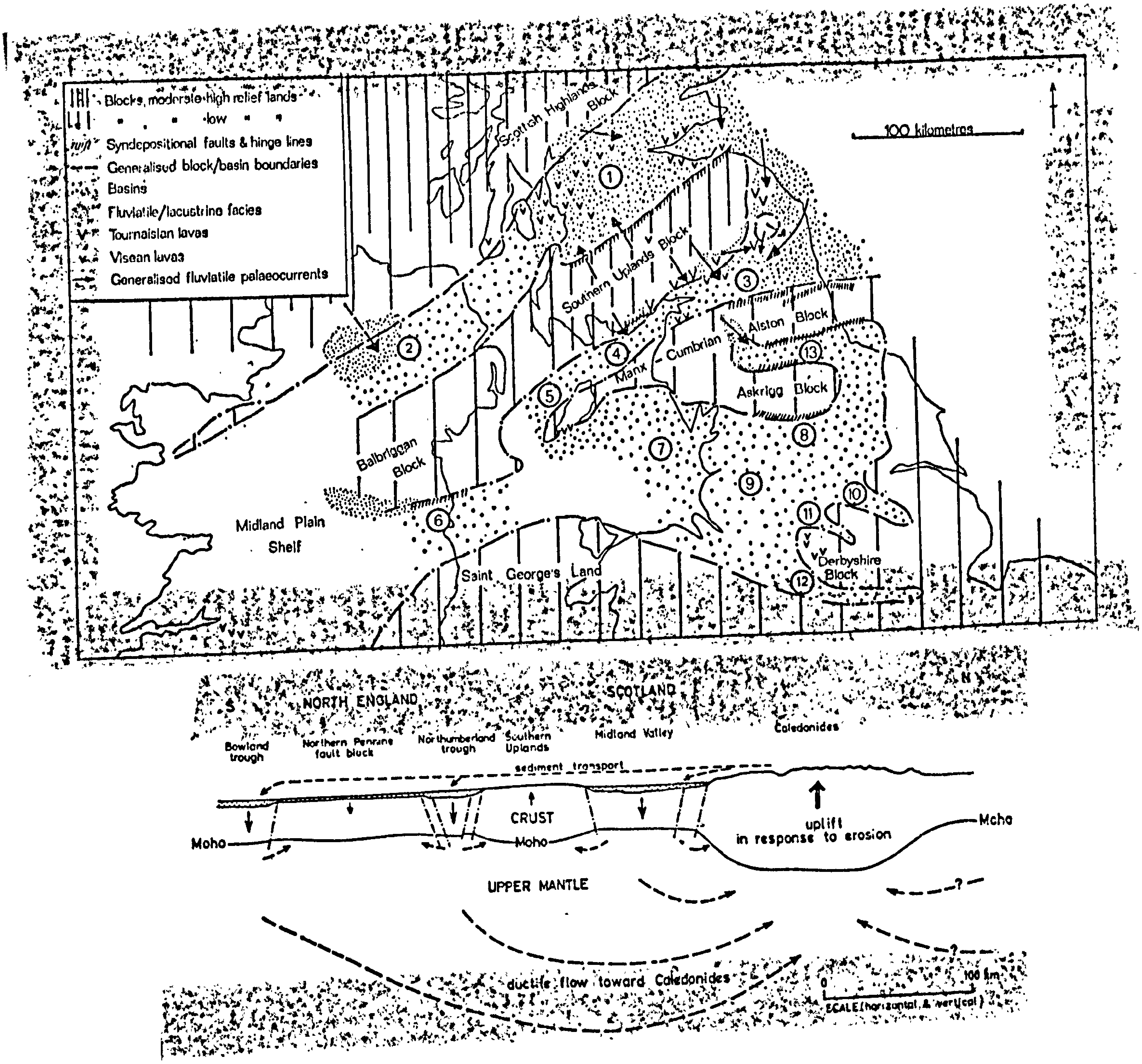


Figure 48.

A/. Map to show the location of the Central Pennine Basin in relation to the general distribution of blocks, basins, faults and hinge lines during the Lower Carboniferous. Block reliefs apply to Tournaisian times only. Basin 1 - Midland Valley of Scotland, 2 - Slieve Beagh, 3 - Northumberland, 4 - Solway, 5 - Peel, 6 - Dublin, 7 - East Irish Sea, 8 and 9 - Central Pennine Basin, 10 - Gainsborough, 11 - Edale, 12 - Widmerpool, 13 - Stainmore/Ravenstonedale. Map from Leeder (1974, Fig. 1).

B/. The formation of the Central Pennine Basin (Bowland Trough), Northumberland Trough and Midland Valley sedimentary basins, in response to uplift and denudation of the Caledonides. Cross section from Bott and Johnson (1967, Fig. 6).

caution until further research has been done). In general terms though, this coupling/uncoupling mechanism seems to have clearly operated in pre-E_{1C} times.

In the coupling process, the basin is infilled and consequently subsides, and in doing so pulls the block edge down. When the strain becomes too great the couple breaks and the block edge rises quickly. This elevated edge is subsequently eroded and the effects of the erosion decrease away from the edge. An example of this is seen in the Grassington area. Wilson (1960) demonstrates a pronounced thinning of the Yoredale cyclothems along the southern edge of the Askrigg Block. He also illustrates an unconformity below the E_{1C} Grassington Grits where the surface of the unconformity steps down to the southeast (Wilson 1960, Fig. 7; Ramsbottom 1966, pl. 4) (this thesis, Fig. 5).

6.1.2 Evolution of the E_{1C} Delta

The E_{1C} succession begins with the deposition of the Upper Bowland Shales. These shales and their lateral equivalents, e.g.:- the E_{1C} Edale Shales have a widespread distribution throughout the Central Pennine Basin. They have been noted in boreholes in the southern North Sea, in the Sawley Borehole (Thompson 1957), in the Rooscote Borehole, near Barrow-in-Furnace (Aitkenhead and Jones, in press) and in the Edale area of Derbyshire (Edwards et al 1954). The mudstones are considered to have been deposited in a comparatively quiet, deep basin.

The introduction of clastic material in the E_{1C} marked the beginning of a series of major basin infilling processes which continued until Westphalian times.

The E_{1C} clastic material was introduced into the Central Pennine Basin over a broad front, e.g.:- from Roosecote to Sawley, a minimum distance of 90 km. Figure 49 puts this broad front into perspective when compared with the present day Ganges Delta (Gresswell 1963).

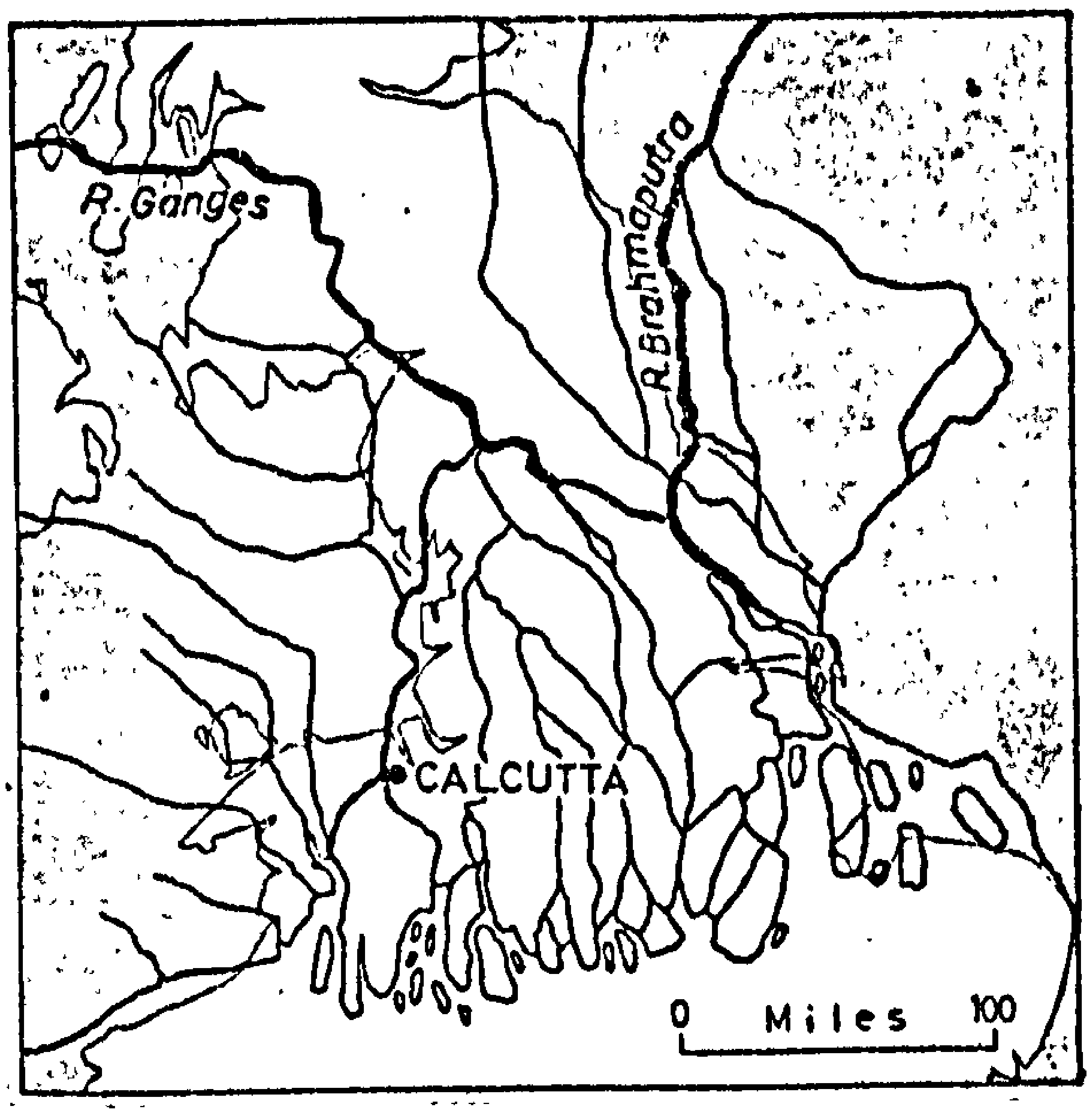


Fig. 49. Comparison of the present day Brahmaputra River with the north of England (both to the same scale), (after Gresswell 1963).

6.1.3 Palaeogeography of the E_{1C} Feeder system

According to D. Moore (personal communication) the E_{1C} material entered the Askrigg Block near the mid-point of the northern boundary of the block (Fig. 42). He also suggests that these currents may have followed the line of the Rogerely Transgression across the Alston Block (Dunham 1950) with a northern continuation of the main channel across the present day Northumberland coast in the vicinity of Alnmouth (Westoll et al 1955). D. Moore (personal communication) also regards the Mirkfell Gannister as being indicative of emergent delta plain conditions, whilst Rowell and Scanlon (1957) suggest the beds lay on the flank of the main delta which was depositing the Lower Howgate Edge and Grassington Grits. The southward passage of the E_{1C} fluviatile deposits caused widespread erosion on the Askrigg Block. Wilson (1960) illustrates some of the resultant scarp and channel topography.

The Kendal trough and Cleveland depression to west and east of the Askrigg Block respectively, probably also acted as local feed routes.

6.1.4 Major factors influencing the E_{1C} Delta evolution

Once the coarse arenaceous material had reached the northern edge of the Central Pennine Basin, it began to build a prograding deltaic wedge. What factors influenced the Delta build up?

In the case of the R_1 Kinderscoutian delta, McCabe (1975b) notes that there is no evidence of tides, beach or barrier deposits. A similar regime is thought to have existed in E_{1C} times for the same reasons. This lack of environmental modifactory elements has considerable implications. It means that the E_{1C} reservoir (reservoir being used in Fisher's (1969) context of a depositional basin) had a very low energy. The amount of reservoir energy is important in deciding the ultimate shape of the delta system (Fisher 1969, Coleman and Wright 1975). On the basis of reservoir energy, Fisher divides delta systems into two broad groups:-

A. Delta systems made from a large proportion of fluvially influenced (CONSTRUCTIVE) facies are considered HIGH CONSTRUCTIVE systems.

B. Delta systems consisting of predominantly marine influenced (DESTRUCTIVE) facies are HIGH DESTRUCTIVE systems.

On this basis, both the E_{1C} and R_1 delta systems fall into the former category, i.e.:- high constructive systems. The salient features of high constructive delta systems are listed below.

> "High constructive deltas have a high sediment input relative to the main reservoir energy, lobate and elongate birdsfoot systems result. Large delta plains develop whilst a high mud content in the system is reflected in a very thick prodelta facies"(Fisher 1969).

The next factor to be considered as having an important influence on the delta is the basin shape and in particular the margin morphology. Recently, Collinson (in Parker 1975) suggested that turbidite fans could occur in two situations here termed category A and B respectively.

Category A - at the foot of a fixed slope fed by canyons.

Category B - at the foot of a prograding delta slope.

One broad and generalised influence that might be drawn from this suggestion is that Category A models largely represent CONTINENTAL EDGE situations, whilst Category B models are more likely to be in RESTRICTED BASIN situations. Sedimentologically, the two models may be distinguished as follows (Parker 1975):-

Category A - A fan fed by a canyon has a triangular shape with the apex corresponding to the proximal part of the fan.

Category B - A prograding delta slope fan has a much wider proximal portion.

Suggested examples of each category are given in table 7.

TABLE 7

CATEGORY A	
LA JOLLA FAN	Shepard *et al* (1969)
SAN LUCAS FAN	Normak (1970)
REDONDO FAN	Haner (1971)
CATEGORY B	
NORTH SEA PALEOCENE FAN	Parker (1975)
LAC LEMAN DELTA	Houbalt and Jonker (1968)
R_1 KINDERSCOUTIAN DELTA	Walker (1966): Collinson (1968/69/70b)/McCabe (1975a)
E_{1C} SKIPTON MOOR DELTA	This thesis

It is here suggested that the Central Pennine Basin deltaic infills fall into category B.

With regards to the Central Pennine Basin examples, it is possible to further sub-divide them into three basic delta types (Collinson 1976). (Table 8).

TABLE 8

I. TURBIDITE FRONTED DEEP WATER DELTAS
  i) Up to 300m deep.
  ii) Consists of turbidite apron, delta slope siltstones, fluviatile channel sandstones.
  iii) Turbidite filled channels on the upper slope.
  iv) Evidence of slump scars on the upper slope.

con't......

2. SHALLOW WATER DELTA SHEETS
   - i) Whole sequence usually less than 100m thick.
   - ii) Turbidite deposits generally lacking.
   - iii) Composed of coarsening-up mudstone/siltstone slope deposits.
   - iv) Topped by a sheet sandstone.

3. SHALLOW WATER ELONGATE DELTAS
   - i) Display a coarsening-up slope sequence.
   - ii) Topped by a current-parallel elongate sandbody.
   - iii) Complex internal geometry related to modern bar-finger sands and preserved mouth bars.

Again it is possible to categorise the E_{1C} delta as type 1. TURBIDITE FRONTED DEEP WATER DELTA .

To recapitulate then, the E_{1C} delta can now be categorised as

1. HIGH CONSTRUCTIVE
2. RESTRICTED BASIN - CATEGORY B.
3. TURBIDITE FRONTED DEEP WATER DELTA.

6.1.5 Turbidity current genesis

It is suggested below that Britain probably experienced a seasonal monsoon-like climate and that the rivers had a high bed-load. The question is, what happened to this seasonal influx of flood-material once it reached the low energy 'reservoir'?

It is suggested that the rivers flushed straight out into the Central Pennine Basin creating "River Generated Sandstones", i.e.:- turbidites (cf. Reading 1970). Other instances of turbidity currents originating at river mouths during flood stages are suggested by Heezen et al (1964), Houbolt and Jonker (1968), Nesteroff et al (1969), van Straaten (1959), Walker (1969) and Van de Graaf (1971).

In the case of the R_1 Kinderscout delta, Collinson suggested that sediment laden traction currents might have developed auto-suspension at the top of the slope and flowed down channels cut in the slope, in the manner of turbidity currents.

In light of this proposed model of "River Generated Sandstones", examples from the E_{1C} delta are now re-examined.

In the Facies Association descriptions, concerning the Turbidite, Slope and Delta Top sediments, it was noted that there was a continuum of coarse grained sediments in a channelised form.
This continuum is arranged thus:-

TABLE 9	Facies	Photos	Strat./Facies Assoc.
LARGE SCALE CROSS-BEDS	11	44	Delta Top Association (Grassington Grits)
↓			
MASSIVE BEDS	12	49 50 51	
↓			Slope Assoc. (Pendle Sh)
ROPY WEATHERING SANDSTONES	9	23 24 25 26 27 54	Turbidite Association (Pendle Grits).
↓			
COMPOSITE SANDSTONES	7	28 16	

The inference to be drawn from this is that once the material reaches the delta edge, it debouches down the slope and the facies described above are the result of varying depositionary processes.

6.2 LARGE SCALE PALAEOGEOGRAPHIC SETTING

6.2.1. Global Palaeogeography and Palaeoclimatology

Perhaps here is a good place to consider some of the regional palaeogeographic and palaeoclimatic conditions that might have been prevalent during the E_{1C}. On several occasions in Chapter 4.4, sedimentologic comparisons have been made with the Brahmaputra River and the following section attempts to demonstrate that similar hydrologic processes and seasonal climates might have operated.

For this analysis, it is necessary to accept the existence of a Carboniferous landmass composed of continental landmasses now widely dispersed. The palaeoclimate has been deduced from an analogy with the present day climatic patterns and palaeobotanical and palaeontological considerations.

Bullard et al (1965) proposed a re-assembly of circum-Atlantic blocks into a single continent on the basis of a best fit of continental shelf edges. The disposition of this continental landmass relative to a postulated palaeoequator indicates that the North Atlantic continent, and in particular, the Caledonide Mountains may well have been in the vicinity of the equator, or at least within 10 degrees of it (Ramsbottom 1971b, Creer 1971, Smith et al 1973, Turner and Tarling 1975).

Making the assumption that global atmosphere circulation patterns were similar to those of today, then the North Atlantic continent lay in an equatorial low pressure belt (Fig. 50).

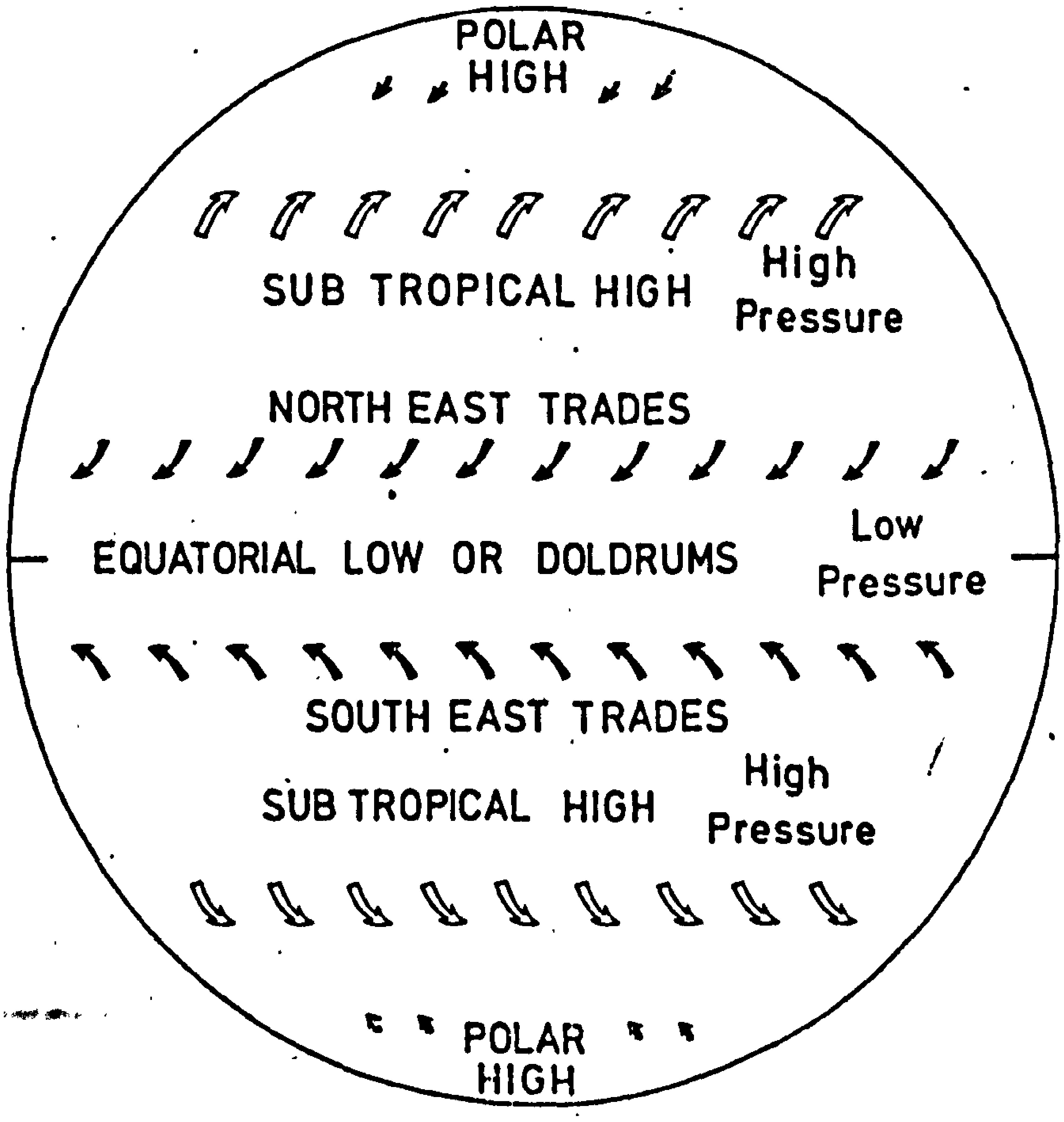


Fig. 50. Present day global atmospheric circulation patterns.

The supposition made here is that northern Britain lay in the path of southeast winds blowing from the mid-latitude high pressure belts. They would conform with the present day Trade Winds (Ramsbottom 1971b). These southeasterly Trade Winds were probably moist, especially after a passage over the (?) Mid European sea and Tethyan Ocean (Ramsbottom 1971b, Turner and Tarling 1975, Figs. 8-9). In their path lay the barrier of the Caledonian Mountains which would cause the warm moist winds to rise and consequently give intense precipitation.

An analogy can be made with the present day South East Asia Monsoons. The monsoon is seasonal and fluctuates due to the migration of pressure centres with the precession of the equinoxes.

6.2.2 Sedimentologic Considerations

The sedimentological implications of this seasonal rainfall are numerous. Schumm (1968) speculates on some of the consequences in general.

i) With grasses not in existence, barren surfaces suffered rapid episodic erosion with marked run-off. Floods were numerous, short lived and intense.

ii) Stream laid deposits were coarser as a result of rapid erosion. Sudden flooding would give sheet-like alluvial deposits.

iii) Sediments already in the river channels would be liable to flushing by major floods which would yield massive amounts of sediments moved as bed load.

Evidence for the spread of coarse arenaceous flood deposits during the Carboniferous, southwards from the Caledonian mountains is provided by the following examples:- Northern Ireland Delta - Visean (George 1958); the Calciferous Sandstone Series - Dinantian (Greensmith 1965); the Fell Sandstone of Northumberland (Rayner 1953, Robson 1956); the E_{1C} Skipton Moor Delta and the R_1 Kinderscoutian Delta (Walker 1966, Collinson 1968, 1969, 1970b, McCabe 1975a, 1975b).

6.3 COMPARISON WITH THE R_1 KINDERSCOUT DELTA

The E_{1C} Skipton Moor Grit Delta is similar in many respects with the R_1 Kinderscout Delta. A chart showing the broad comparisons is given as Enclosure J. McCabe (1975b) divides the R_1 Delta into three broad 'assemblages' and these are comparable with the three associations designated above.

However, minor differences do exist. For instance, in the E_{1C} delta, there is an apparent lack of a unit comparable with the cross-laminated and inclined beds interpreted by McCabe (1975a) as Slope Gully infills. This might be due to lack of exposure.

Second, the E_{1C} delta seems to have a preponderance of facies II, Large scale cross-beds (Type A) rather than the large scale units (Type B) which typify the Kinderscout Grit "Delta Topset." This could be explained by the close proximity of the E_{1C} examples to the basin margin with consequent increases in gradient.

Third, there is an apparent lack of an apron of "distal" turbidites in the E_{1C} which would equate with the Mam Tor Sandstones. Note how the E_{1C} succession seems to start with Composite Sandstones representing the fan complex. This may be due to the fact that the break of slope at the foot of the delta is not seen in the Skipton area.

In fact, this last point is of considerable interest. The implication is that the E_1 delta, north of Skipton, is developed on part of the original paleoslope. This makes it rather unique when compared with many other ancient deltas. The fact that the northern limit of the basin is so well defined (Craven Faults) means that the spatial relationships of the various lithostratigraphic units on the original slope can be more readily appreciated. Because the E_{1C} succession differs from the R_1 delta in the absence and presence or stacking of the genetic units, this is taken as an indication that the original slope of the R_1 delta has not as yet been defined.

I.1.1 INTRODUCTION

A detailed examination of the fine grained sediments of the E_{1C} succession revealed numerous and diverse trace fossils. In this chapter, these trace fossils are described, identified and used to aid interpretation of the depositional environments.

For descriptive purposes, the trace fossils are divided into two groups; those with formal names, and those with informal names (Table 10).

TABLE 10

A. FORMAL ICHNOGENERA	FIG. NO.	PHOTO NO.
? ARENICOLITES	54, 55	62, 63, 64
ARTHROPHYUS	-	65, 66
BERGAUERIA	-	67, 68
COCHLICHNUS	-	69, 70, 71
? CURVOLITHUS	56	72, 73
DIDYMAULICHNUS	-	74
GRYOPHYLLITES	-	75
? HELICOLITHUS	-	76
LOPHOCTENIUM	57	77, 78, 79, 80, 81
MAMMILICHNUS	-	82, 83, 84
MONOCRATERION	58, 59	85, 86, 87, 88, 89, 90, 91
MUESTERIA	-	92
PALAEOPHYCUS	-	93
PELECYPODICHNUS	-	94
PLANOLITES	60, 61	95, 96
PROTOPALAEODICTYON	62, 63	97
RHIZOCORALLIUM	64, 65	98,99,100,(101),(102),(103),104,105, 106,107,108,109
? SCALARITUBA	66, 67	110
? SPIROPHYCUS	68	111
TIGILLITES	-	72
B. INFORMAL		
BRUSH OR SCRABBLE MARKS	-	112, 113, 114
VERTICAL TUBES:		
A) CRESCENT SCOURS	69, 70	10, 115
B) BACK FILLED TUBES?	71	-

( ) Denotes specimens collected by Trewin.

I.1.2 TAXONOMIC CLASSIFICATION

There are numerous problems and difficulties involved in producing a meaningful classification and nomenclature of trace fossils. Reviews of these problems are to be found in the "Treatise on Invertebrate Palaeontology, Part W" by Hantzschel (1962) and "Proposal of a Code of Nomenclature of Trace Fossils" by Sarjeant and Kennedy (1973).

The list below illustrates some of the more important problems recognised.

(1) There has been no extensive comparison of morphology and ethology for modern animals.

(2) The remains of the animals responsible for the trace are normally absent.

(3) A single animal may show more than one behavioural pattern and can thus produce a variety of different structures.

(4) Conversely, an animal with only one behavioural pattern can produce different trace structures because of different types of sediment.

(5) There has been excessive taxonomic differentiation, based purely on appearance.

(6) There has also been excessive grouping of forms, which has effectively masked some of the more important distinctions.

(7) The International Commission of Zoological Nomenclature (I.C.Z.N.) failed to produce a set of rules with the consequence that genera and species designations are only valid before 1931. After this date, they are supposedly invalidated by the ruling of the I.C.Z.N.

NOTE: All names used herein are classified as ichnogenera and ichnospecies. This procedure designates the taxa as Trace Fossils. (Hantzschel 1975).

It is now customary to use a Binary nomenclature for trace fossils. Hantzschel (1962) conceeds that the terms "genera" and "species", when applied to trace fossils, do not have the same standing or meaning as they do in normal taxonomic usage. He recommends that the terms "ichnogenera" or ichnospecies" should be used. He also suggested that there should be the addition of the suffix "ichnus" (Greek ICHNOS = trace) to the generic name in order to render it recognisable as a trace fossil.

Sarjeant and Kennedy (1973) have made a very strong case for the retention of the two basic units "ichnogenus" and "ichnospecies". They consider the terms to be equivalent in scope to the "form genus" and "form species" of the BOTANICAL CODE. Any differences within the ichno-species which warrants recognition is termed "variety". This, they claim, has the asset of being without "formal status" under the ZOOLOGICAL CODE.

It would signify "a minor difference without implication of a specific significance for that difference."

Sarjeant and Kennedy (1973) also reviewed two other systems. The first is based on the idea that a trace fossil should be given no formal name at all, but instead, should be given a cypher, e.g. TRACE FOSSIL 12 of Smith (1970). They think that this system would rapidly become unwieldy and would have problems of priority and comprehensibility. In addition, as Frey (1973) observes, numerical designations or symbols are apt to be lost or overlooked in subsequent literature surveys.

The second system involves the use of informal names, e.g.:- cruzianid or thalassiniodid. This system, however, would only be useful for poorly preserved material. The disadvantage of using suffixes would be that familial relationships would be implied where none was intended.

To conclude, the Binomial system is popular, since the application of names such as Rhizocorallium jenense or Planolites vulgaris, instantly conjures up the correct morphological picture. It also alleviates a long and ponderous description of the morphology.

1.1.3 CLASSIFICATION BASED ON MODES OF OCCURRENCE AND PRESERVATION.

Classification needs to stress the origin, configuration and preservation of the trace fossil. So far, trace fossil groupings have been based largely upon:-

A) Position of preservation - STRATONOMY = TOPONOMY

B) Behavioural and purpose of trace making animal = ETHOLOGY

I.1.4 TOPONOMIC CLASSIFICATIONS

The most widely accepted Toponomic Classification of bioturbation structures is that by Seilacher (1964a) who formulated a series of terms (e.g.:- epirelief, semirelief and hyporelief) to describe the positional characteristics of trace fossils in sediments (Fig. 51).

An even more comprehensive guide to the ways in which semireliefs are formed, modified and preserved is illustrated by Frey (1971) (Fig. 52), based on work by Seilacher (1964a), Webby (1969) and Chamberlain (1971a)

Seilacher's basic concept was further expanded by Martinsson (1965 and 1970). Martinsson's "Stratonomic" Classification, particularly stressed the relationship between the casting medium (sediment filling) and the host matrix (Fig. 53). Chamberlain (1971a) however, thought that a stratonomic classification had its limitations since "too few categories are available". One category may apply to too many forms, and each category may indicate the work of the same animal in several environments.

I.1.5 ETHOLOGIC CLASSIFICATIONS

Since it is extremely difficult, if not impossible, to identify the producers of many traces, some authors have erected non-commital names. They have preferred to use characteristic morphologic features, based on the supposed purpose of the structures. Seilacher's (1953) "Ethologic Classification" is best known, and considered here (Table 11).

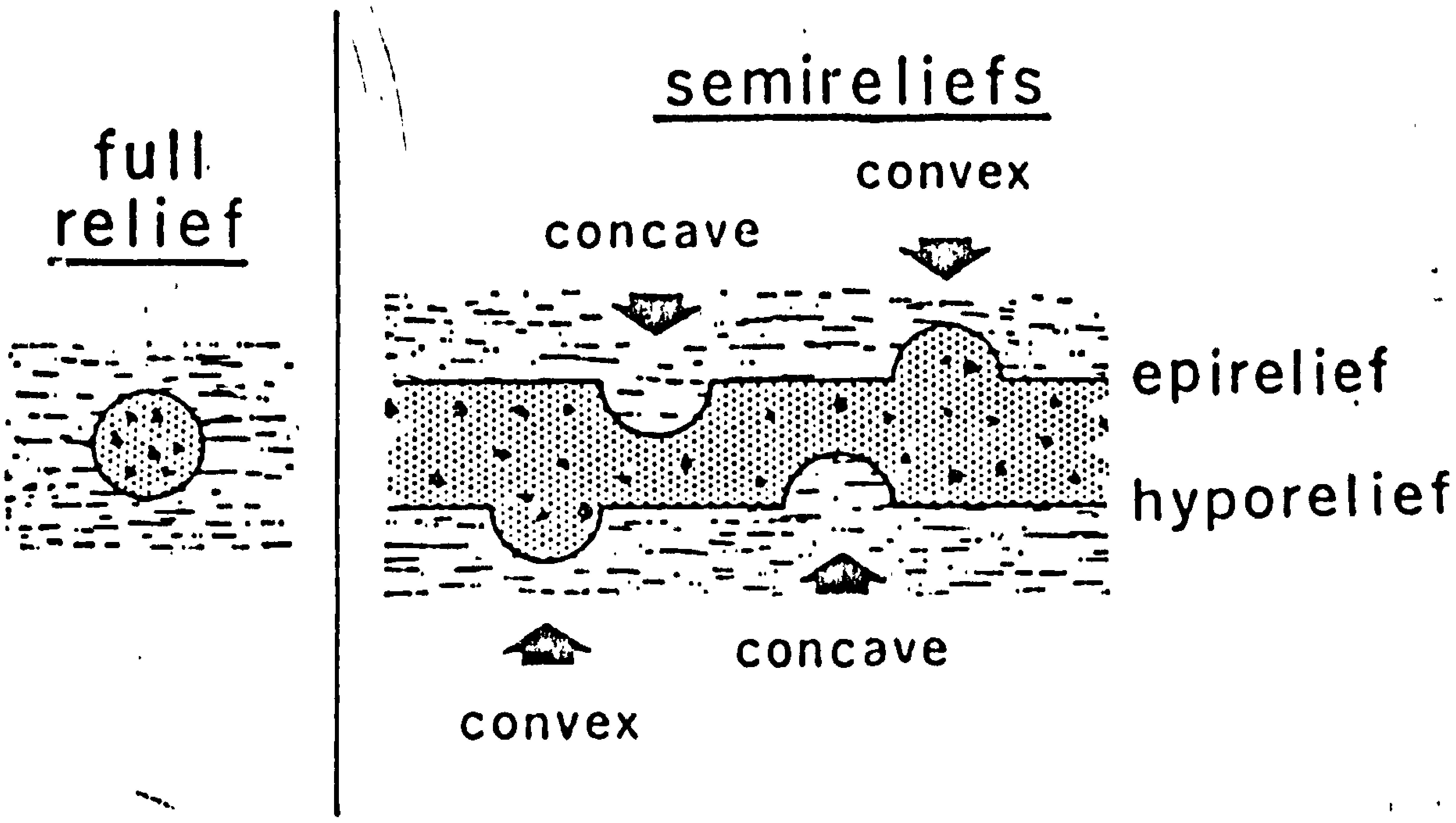


Fig. 51. Toponomic classification of bioturbation structures by A. Seilacher.

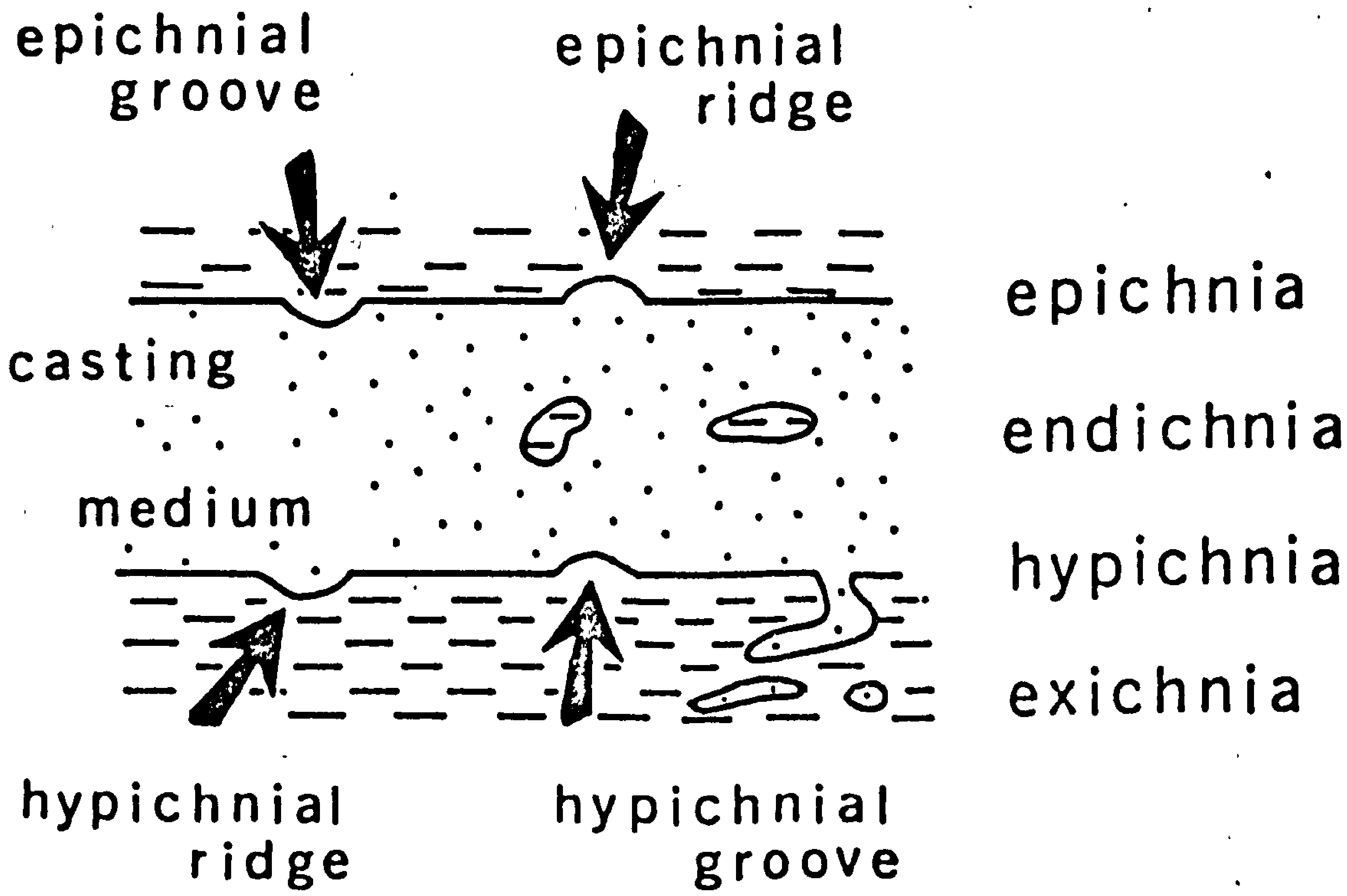


Fig. 53. Toponomic classification of bioturbation structures by A. Martinsson.

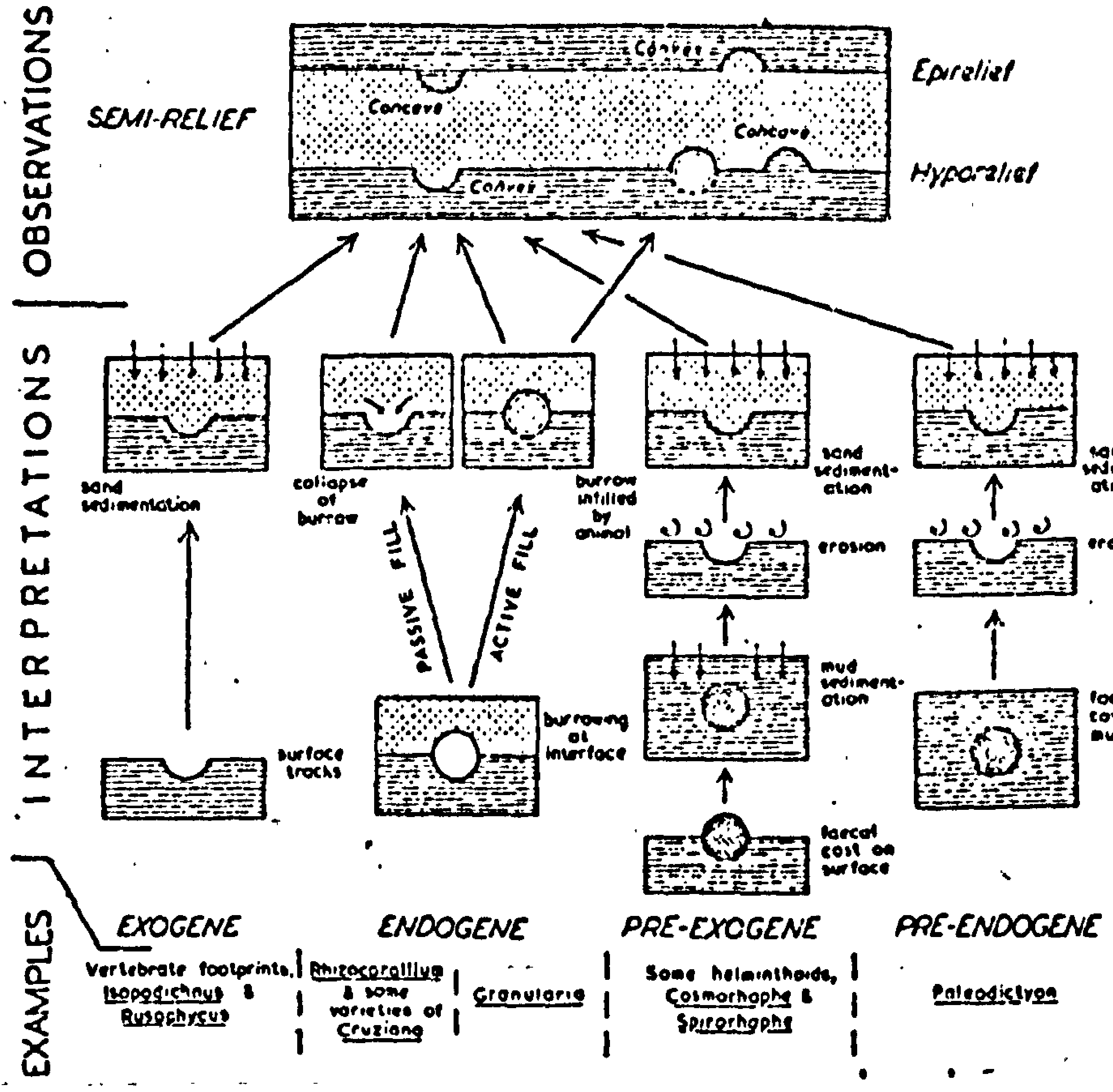


Fig. 52. Toponomic classification and Processes of preservation of bioturbation structures. Full relief and cleavage relief structures not indicated. (After Seilacher 1964a; Webby 1969; Chamberlain 1971a and Frey 1971).

TABLE 11

PASCHICHNIA	(Grazing Trail)	The winding and meandering trails & burrows of vagile mud-eating organisms.
FODINICHNIA	(Feeding structures)	Extensive burrow & tunnel systems made by hemisessile sediment eaters.
DOMICHNIA	(Dwelling structures)	Permanent domicile burrows made by vagile and hemisessile organisms, feeding without the sediment, e.g. predators and filter and suspension feeders.
REPICHNIA	(Crawling traces)	Trails, burrows and tunnels left by vagile benthos during locomotion.
CUBICHNIA	(Resting traces)	Resting marks (or body impressions) left by vagile organisms temporarily resting on the sea floor.

The main disadvantage is that it is not always possible to assign a trace to one particular activity; traces may well be multi-purpose . The problem is further aggrevated by the fact that little or nothing is known about the nature and behaviour of the animals which produced the structures. Finally, no provision was made for "escape structures" within the classification.

The above discussion briefly outlines and reviews three of the major classifications - taxonomic, toponomic and ethologic.

As noted by Sarjeant and Kennedy (1973), each classification has its own merits and there is no need to establish a classificatory hierarchy, "..... nothing would be achieved, and a great deal would be lost, if these terminologies were all abandoned or if one were adopted in preference to the others" (p. 464).

The descriptions of the ichnotaxa below, follows with minor modifications, the format used by Fursich (1974).

a) Description and Preservation

b) Facies and Stratigraphic distribution

c) Associations

d) Interpretation and discussion

The trace fossils are listed in alphabetical order (cf Hantzschel 1962 and 1975) with informally named traces listed separately.

1.2.1 ICHNOGENUS ? ARENICOLITES SALTER 1857

Fig. 54 and 55. Photos 62, 63 and 64.

a) DESCRIPTION AND PRESERVATION

A negative epirelief consisting of small elongate depressions which are approximately 21 - 23 mm long, 14 mm wide and 3 to 5 mm deep (Fig. 55). At either end of the depression are two small raised mounds or knobs, circular or elliptical in shape and varying in diameter between 4 and 6 mm. Vertical serial sectioning and X-ray photography through the depression show little or no disturbance of the sediment below the structure.

The structures show no preferred alignment or relationship to the orientation of the ripples.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Structures found on a single loose block of facies 6, Thin turbidite sandstone. Upper part of Pendle Grits.

c) ASSOCIATION

Rhizocorallium Cochlichnus Planolites Bergaueria

d) INTERPRETATION AND DISCUSSION

Domichnia of worms? Due to the lack of typical U-shaped internal structuring, the trace is only tentatively referred to as Arenicolites. The surface structures, however, show a resemblance (Photos 62 & 64) to the paired openings figured by Fursich (1974b, Fig. 5a). Fursich shows that the preservation of the raised knobs is due to a differential weathering of the burrow components.

It is suggested that there may be an association with the trace described as Rhizocorallium. The Rhizocorallid A trace described below, has similar dimensions. The organism responsible for the Rhizocorallium

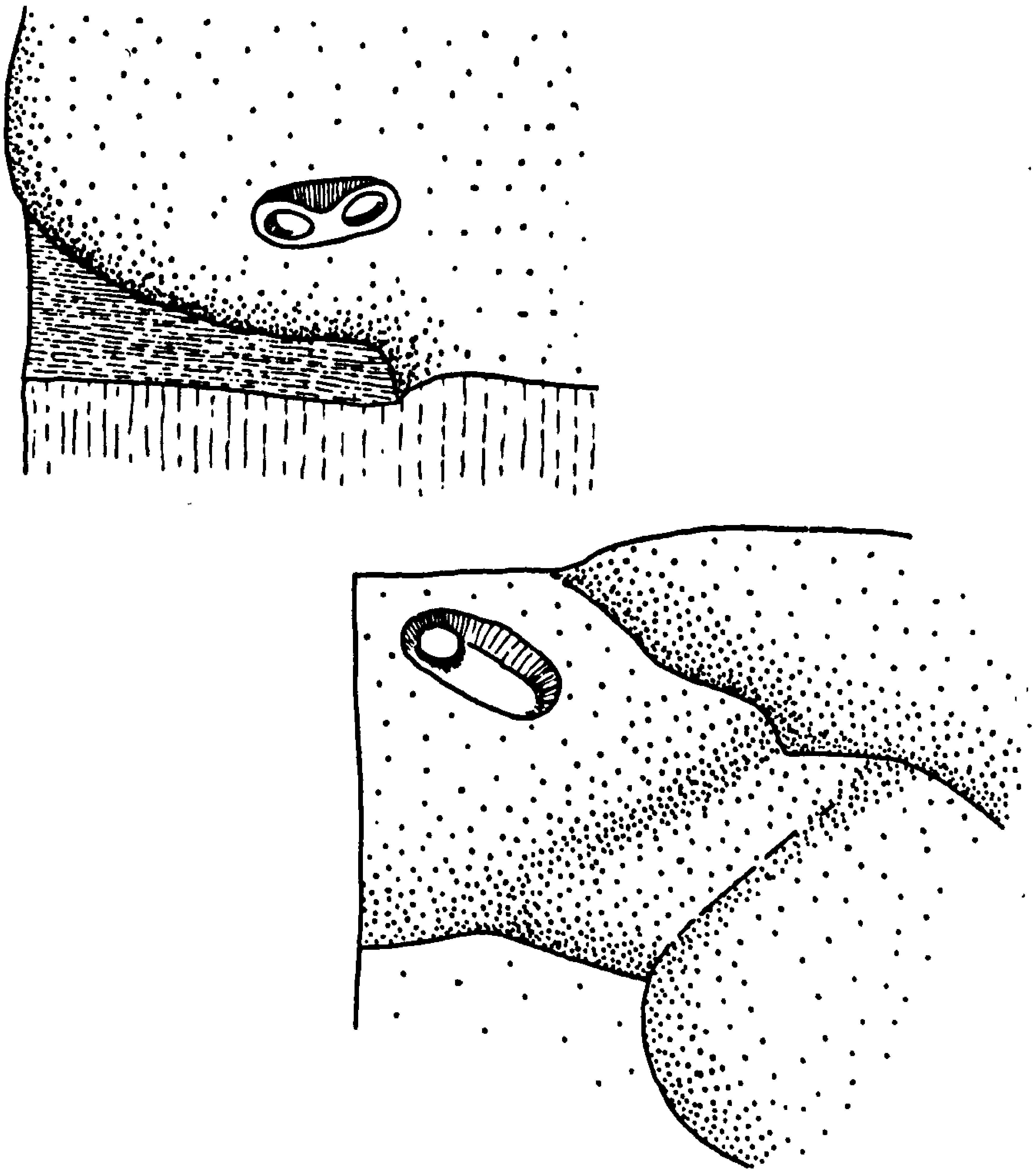


Fig. 54. Sketch of bow-shaped linguoid ripples on facies 6, Thin turbidite sandstones showing the elliptical pits identified as <u>?Arenicolites</u>.

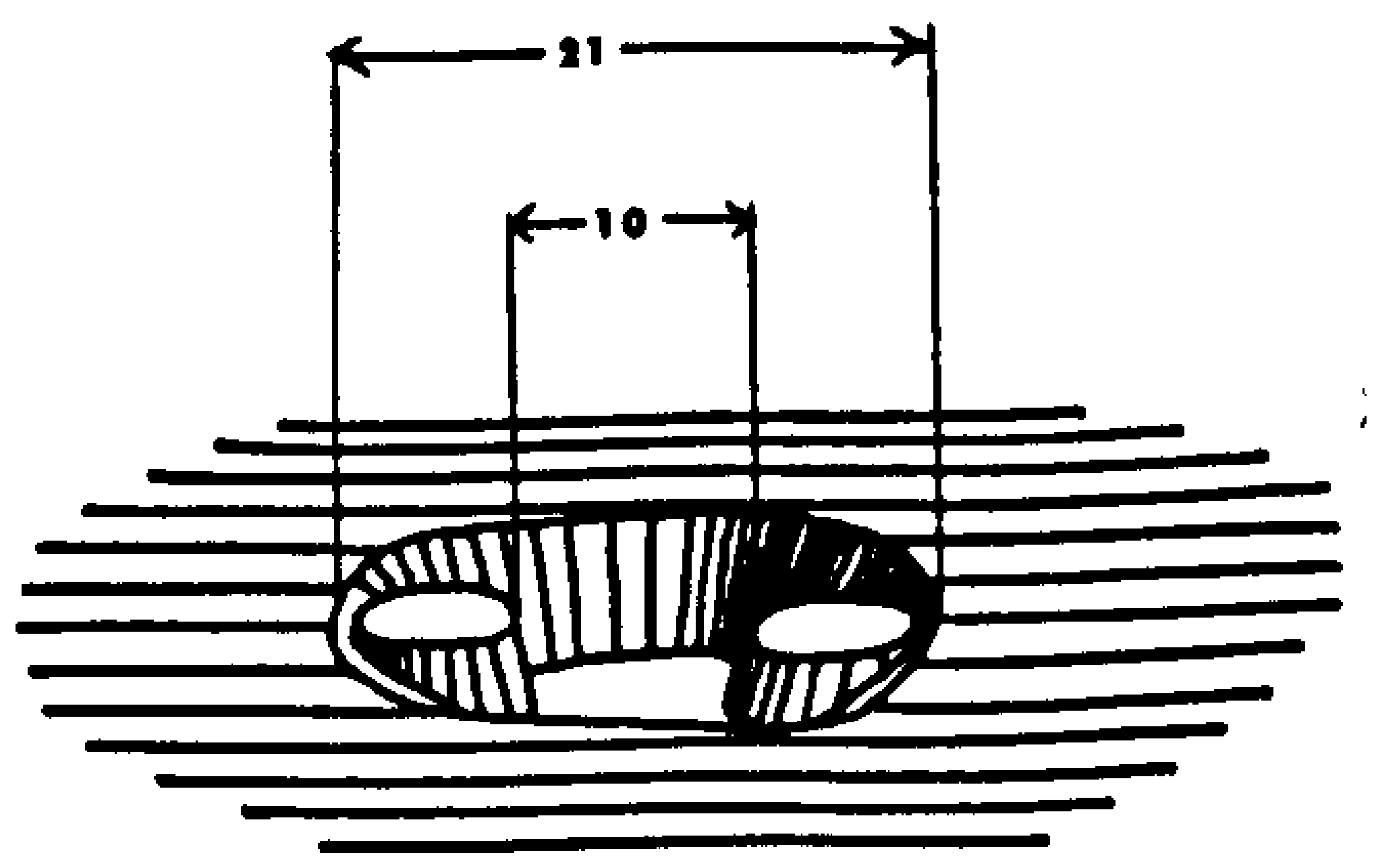


Fig. 55. Sketch of the <u>?Arenicolites</u> epirelief showing dimensions (in millimeters).

traces, instead of burrowing horizontally along the sand/mud interface, may have entered the sand in a vertical manner. Muller (1959), Chisholm (1970) and Fursich (1974a) have all made observations concerning the vertical to horizontal orientation of <u>Rhizocorallid</u> protrusive and retrusive structures.

I.2.2 ICHNOGENUS <u>ARTHROPHYCUS</u> HALL 1952

Photos 65 and 66.

a) DESCRIPTION AND PRESERVATION

Vertical to sub-horizontal tubes preserved as positive hyporeliefs. The non-branching tubes, 7 to 10 mm wide, are frequently oval shaped (due to compaction) and show close packed, irregular annulations. Tubes may be penetrative into the underlying mudstone units.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstones, Pendle Grits.

c) ASSOCIATIONS

<u>Planolites</u> <u>Palaeophycus</u>

d) INTERPRETATION AND DISCUSSION

<u>Arthrophycus</u> has been diagnosed as "horizontal, annulated, conduit-like, branched or unbranched, ... branched burrows enlarged slightly at the point of bifurcation"(Frey and Howard 1970, P. 162). <u>Arthrophycus</u> tubes may also stick to the soles of thin bedded sandstone (Ksiazkiewicz 1970).

The E_{1C} specimens show many similarities to these descriptions but there are several differences. For instance, they do not branch, nor do they have a median furrow as noted by Frey and Howard (1970). Also, they are vertical to sub-horizontally inclined, although Frey & Howard (1970, Fig. 3a, P. 147) do in fact show an inclined specimen.

I.2.3 ICHNOGENUS BERGAUERIA PRANTL 1945

Photos 67 and 68.

a) DESCRIPTION AND PRESERVATION

Small, sub-hemispherical protuberances (positive hyporeliefs) randomly distributed on the sharp bases of facies 6,Thin turbidite sandstones. They are up to 20 mm in diameter and vary between 6 and 10 mm in depth. Individual forms are circular in plan and the surface is either smooth or has a slight granular texture. The sediment infill is identical with the overlying unit. Stained thin sections and X-ray photographs show no internal organisation.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6,Thin turbidite sandstones. Very common throughout the Pendle Grits and the lower part of the Pendle Shales.

c) ASSOCIATIONS

Muesteria ? Helicolithus Mammilichnus Protopalaeodictyon

d) INTERPRETATION AND DISCUSSION

This structure closely resembles Bergaueria, Prantl, as figured by Hantzschel (1962, Fig. 112, 4a & 4b 1965), Lessertisseur (1965), Radwanski and Roniewicz (1963, Plate 9), Alpert (1973, Plate I, Fig. 5) and Hakes (1976, Plate 2, Ia). Bergaueria has been interpreted by various authors (see Alpert 1973 for review) as the casts of burrows made by sedentary organisms such as coelentarates, anthozoans or actinians, or even the infilling of decomposition hollows.

Whilst this notion may apply to forms figured in the literature, it is thought that the E_{1C} structures may have a different origin. It is suggested that the structure may be the dwelling place of a worm living at the mud/sand interface. Similarly, Bonney (1903) rejects a coelenterate cast origin and instead favours an annelid origin.

NOTE: In view of the traditional association of Bergaueria with structures interpreted as casts of anthozoans, coelenterates or actinians, the present writer was inclined to look for another taxonomic name. However, Crimes (oral communication 1976) has argued that the name *Bergaueria* is still applicable since it refers only to the morphological description.)

I.2.4 ICHNOGENUS *COCHLICHNUS* HITCHCOCK 1858

Photos 69, 70 and 71.

a) DESCRIPTION AND PRESERVATION

Winding and sinuous trails in a variety of preservational forms, e.g. positive and negative hypo- and epirelief, also full reliefs. Trails vary from 1 to 2 mm in width with a wave length of 16 mm to specimens that are 4 to 5 mm wide and have a wave length of 45 mm.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Found in facies 4, 6 and 8. (Also found on Sinuous Crested Ripples in the Bradley Flags). Pendle Grits and Pendle Shales. *Cochlichnus* is especially common in the upper part of the Turbidite Association and the lower part of the Slope Association.

c) ASSOCIATIONS

Planolites *Rhizocorallium* *Pelecypodichnus* *Lophoctenium* *Spirophycus*

d) INTERPRETATION AND DISCUSSION

Repichnia and probably fodinichnia of a small worm-like organism. For full synonymies and nomenclatural history of *Cochlichnus*, see Hantzschel (1975) and Hakes (1976). *Cochlichnus* has frequently been referred to as *Sinusites*, e.g. Seilacher (1963), Crimes (1970) and Nowak (1970).

Moussa (1970) compared recent nematode trails with Eocene sinusoidal trails and considered them morphologically similar whilst Micheau (1955) suggested that *Cochlichnus* was probably produced by small worms lacking well developed parapodia.

I.2.5 ICHNOGENUS ? CURVOLITHUS FRITSCH 1908

Fig. 56 Photos 72 and 73.

a) DESCRIPTION AND PRESERVATION

This burrow consists of simple ribbon-like trails, occurring as full reliefs. The burrows vary in width between 10 and 16 mm and have a relief of 1 - 2 mm. Individual burrows are unbranching but commonly intersect (Photo 73). The burrow is trilobate and consists of two concave furrows on either side of a slightly wider convex ridge (Fig. 56). The burrows are straight to gently curved, except where they make a turn. Here, the angle of turn is usually between 5 and 25° but occasionally it can be almost 90° (Photo 72). The burrows lack internal organisation indicating back filling.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 4, Parallel bedded and striped siltstone. Occasionally found in the upper part of the Turbidite Association (Pendle Grit), but common throughout the Slope Association (Pendle Shales).

c) ASSOCIATIONS

Cochlichnus Lophoctenium Tigilittes

d) INTERPRETATION AND DISCUSSION

Ribbon-like trails have been diagnosed as Curvolithus by Hantzschel (1962 and 1964), Heinberg (1970 and 1973), Chamberlain (1971a, Fig. 4n) and Hakes (1976). Hakes notes that there may be many minor variations in form whilst still maintaining a basic trilobate configuration and these morphological differences are probably related more to preservation than to construction of the structure. He also considers the trace as a repichnia of a mollusc, probably a gastropod. A full discussion of the locomotory behaviour of the organism responsible is given by Heinberg (1973).

I.2.6 ICHNOGENUS *DIDYMAULICHNUS* YOUNG 1972

Photo 74

a) DESCRIPTION AND PRESERVATION

An irregular curved to straight furrow preserved as a positive hyporelief. The burrow, which is 4 to 5 mm wide is smooth and trilobate with a very narrow median depression. The burrows are post depositional and cut across sole structures.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstone, Pendle Grits.

c) ASSOCIATIONS

Bergaueria

d) INTERPRETATION AND DISCUSSION

This type of doubly furrowed burrow has been commonly referred to as *Rouaulita* (de Tromelin 1878, Peneau 1946, Hantzschel 1965 and Crimes 1970), but this name was invalidated by Hantzschel (1965). Apparently, the name was applied to a gastropod genus prior to its application to a trail by de Tromelin in 1878. Young (1972) therefore erected the new ichnogeneric name, *Didymaulichnus* such that 'double' (Greek *DIDYMO*-) 'furrow' (Greek AULAX) and '-ichnus' (meaning track) are combined.

Didymaulichnus is distinguished from *Cruziana* by the former being very smooth whilst the latter has V-shaped markings. The term *Fraena* (Rouault 1850) is restricted to non-trilobate hyporeliefs (Hantzschel 1962).

Hakes (1976) considers the burrow to be a repichnia of a small mollusc, probably a gastropod whilst Young (1972) also likens the burrow to molluscan trails. Hakes also thinks that the trace is indicative of shallow water, whereas the E_{1C} material is from the Turbidite Association.

I.2.7 ICHNOGENUS *GYROPHYLLITES* GLOCKER 1841

Photo 75

a) DESCRIPTION AND PRESERVATION

A positive hyporelief consisting of a radial pattern of small petallike protuberances surrounding a central terminal projection. The structure is approximately 16 mm wide, 3 - 4 mm deep and has an average of nine petals. Vertical thin sections (stained) and X-ray photography show no discernable structures above the structure.

b) FACIES AND STRATIGRAPHICAL DISTRIBUTION

Facies 6,Thin turbidite sandstones. Upper part of Pendle Grits and lower part of the Pendle Shales.

c) ASSOCIATIONS

PLANOLITES ? SCALARITUBA Vertical tubes (Cresent Scours)

d) INTERPRETATION AND DISCUSSION

Gyrophyllites is usually diagnosed as a vertical stem from which lobate offshoots radiate at different levels; the whole structure is conical in shape (Gregory 1969, P. 14). For illustrations, see Fursich and Kennedy (1975, Fig. 3 & 4), Fursich (1974 b, Fig. 31a, 31c and Fig. 32) and Gregory (1969, Fig. 6).

The E_{1C} material however, has only one horizontal rosette of lobes at the sand/mud interface. This could be explained as the only preserved part of a three-dimensional feeding system. For instance, Fursich and Kennedy (1975) note that organisms burrowing downwards usually terminate at the clay/sand interface. The rosette lobes are due to radial feeding and the central terminal projection, where preserved, is explained as an abandoned probing shaft.

NOTE: Seilacher (pers.comm. 1971) has called the E_{1C} specimens 'stelliglyphs' and interpreted them as feeding patterns around burrows.

I.2.8 ICHNOGENUS ? HELICOLITHUS AZPEITIA 1933

Photo 76

a) DESCRIPTION AND PRESERVATION

A positive hyporelief burrow which consists of a series of offset lobes all linked in an en-echelon manner. These lobes are 10 to 12 mm long, 5 to 7 mm wide and 5 to 6 mm deep, and form a trail 10 to 12 cm long. At one end of a specimen, the pattern becomes confused and somewhat bulbous as though another burrow has been initiated in another direction.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstones, Pendle Grits.

c) ASSOCIATION

BERGAUERIA

d) INTERPRETATION AND DISCUSSION

The trail has similarities to Cochlichnus but it is larger and has bulbous projections at the apices. Hantzschel (1962) and Ksiazkiewicz (1970) described similar trails and call them Helicolithus, noting that they were screw-like, meandering and cut across turbidite fluting.

I.2.9 ICHNOGENUS LOPHOCTENIUM RICHTER 1850

Fig. 57 Photo 77, 78, 79, 80 & 81.

A/ ICHNOSPECIES LOPHOCTENIUM comosum RICHTER 1851

a) DESCRIPTION AND PRESERVATION

Endogenic full reliefs. An irregular shaped spreite field with no well defined boundary. The spreite are concentrically spaced and are formed from a series of small chevron-like marks. One specimen shows the spreite fields connected by a thin trail, preserved as a full relief (compare Fig. 57 with Photo 81).

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 4, Parallel bedded and striped siltstone. Lower part of the Pendle Shales.

c) ASSOCIATIONS

COCHLICHNUS TIGILLITES and CURVOLITHUS

d) INTERPRETATION AND DISCUSSION

Chamberlain (1971a) believes this trace to be made by a worm-like organism that systematically mined the sediment. The chevron pattern is made as the organism pushes itself forward. With successive feeding passes, the organism overlaps the previous feeding pass and eventually a

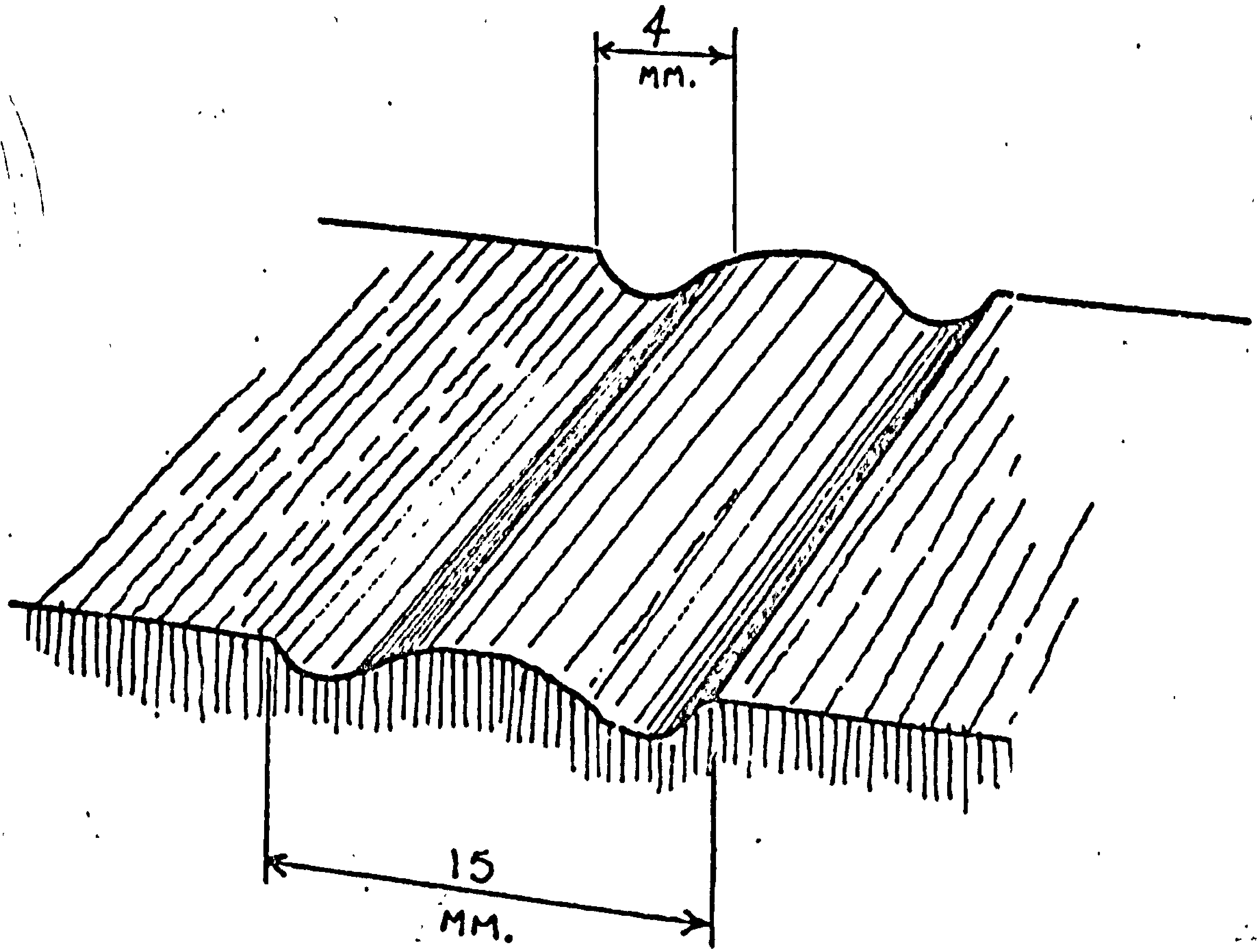


Fig. 56. Sketch of the full relief of Curvolithus showing dimensions (in millimeters).

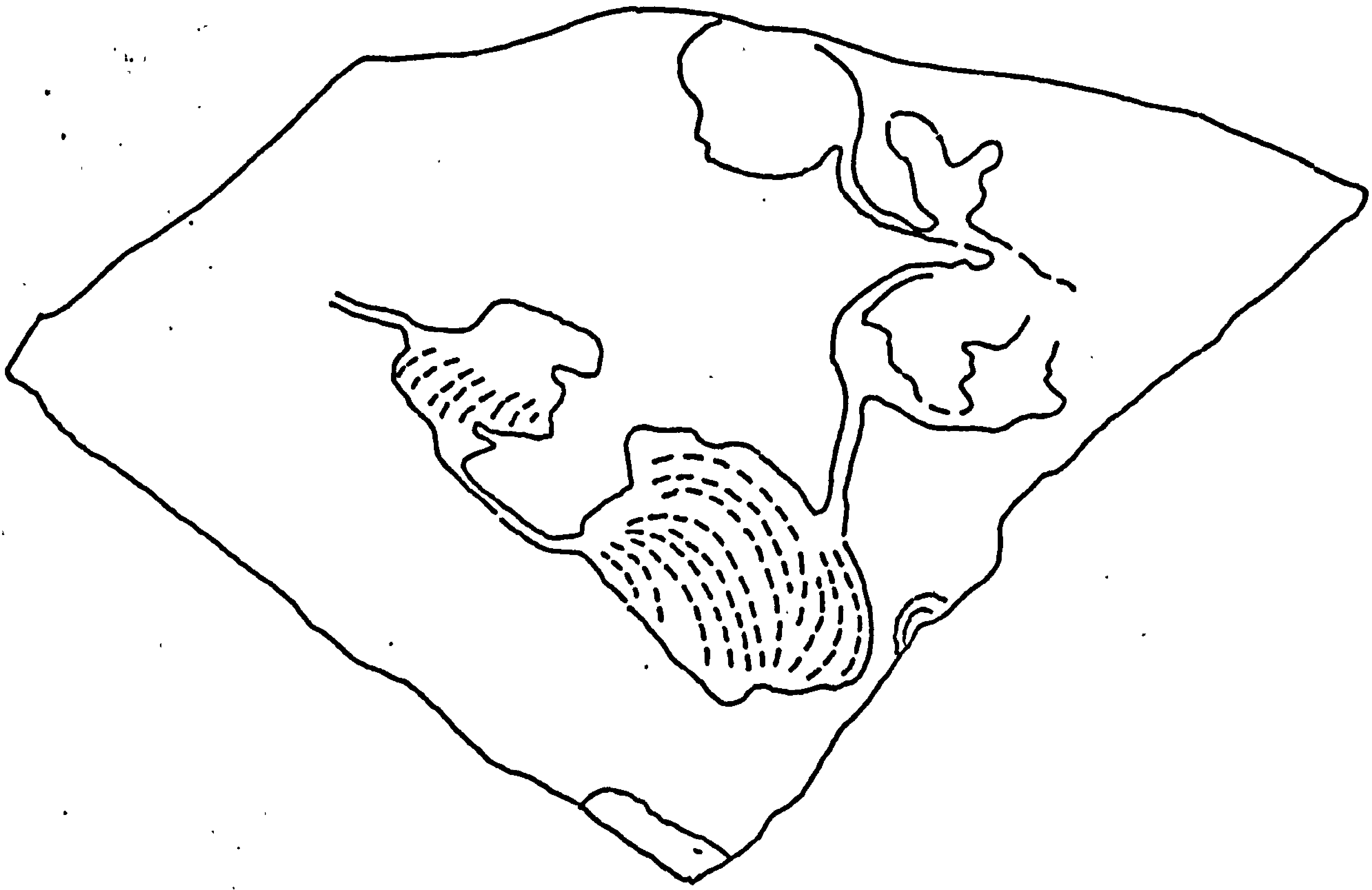


Fig. 57. Plan of the full relief Lophoctenium showing the connection of spreite fields by small burrows (compare this diagram with Photo 81).

concentric spreite field is built. The interconnecting tubes are similar to those illustrated by Chamberlain (1971a, Plate 32, Fig. 4) for Lophoctenium haudimminera.

B/ ICHNOSPECIES LOPHOCTENIUM haudimminera CHAMBERLAIN 1971a

a) DESCRIPTION AND PRESERVATION

Endogenic full reliefs. The structure consists of irregular spreite fields, occasionally up to 70 mm wide. A peripheral rim or margin to the spreite field is often preserved (Photo 80). The spreite are concavo -convex and are protrusive into the outer marginal areas.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

(As L. comosum)

c) ASSOCIATIONS

(As L. comosum)

d) INTERPRETATION AND DISCUSSION

This structure is similar to that figured by Chamberlain (1971a, Plate 32, Fig. 3 & 4). He thought that the spreite field was formed by an organism systematically mining the sediment within the confines of a peripheral tube. The specimens described by Chamberlain all occur in flysch sequences of the Ouchita Mountains.

Both Simpson (1970) and Chamberlain (1971a) note the similarity and apparent relationship between Lophoctenium and Zoophycos and the implications of this relationship are discussed more fully after the systematic descriptions (Chapter 1.3.3).

I.2.10 ICHNOGENUS MAMMILICHNUS CHAMBERLAIN 1971a

Photo 82, 83 and 84

a) DESCRIPTION AND PRESERVATION

A positive hyporelief consisting of smooth sub-hemispherical protuberances with circular or elliptical terminal projections. The structure varies between 9 and 12 mm in diameter and is 7 mm deep. The terminal projection varies in width between 3 and 5 mm. Vertical thin sections (stained) and X-ray photography reveal no disturbance of the sediment immediately above the structure.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, thin Turbidite sandstones. Pendle Grits and the lower part of the Pendle Shales.

c) ASSOCIATION

PLANOLITES COCHLICHNUS TIGILLITES? BERGAUERIA

d) INTERPRETATION AND DISCUSSION

The structure bears a close resemblance with Mammilichnus aggeris described by Chamberlain (1971a, see Plate 30, Fig. 6 - 7 text Fig. 7G-J). He derives the name from its teat-like appearance. He acknowledges that the exact nature of the form is difficult to ascertain but thinks that it was made by an organism resting or hiding in the sediment.

In all probability, Mammilichnus and Bergaueria may be related and represent preservational and modificational end members.

I.2.11 ICHNOGENUS MONOCRATERION TORELL 1870

Fig. 58 & 59 Photos 85, 86, 87, 88, 89, 90 & 91.

a) DESCRIPTION AND PRESERVATION

Straight, cylindrical, isolate tubes pass vertically upward into circular and steep sided funnels. The tubes have diameters ranging from 2 mm to 8 mm and can be up to 13 cm long. The funnel dimensions also vary, with diameters averaging 15 mm at the upper widest part and tapering to the dimensions of the tube beneath. They vary in height between 15 mm and 30 mm.

Several specimens show funnels with a raised rim (Fig. 58). The rim appears to be a continuation of a lining to the funnel. Within this lining, the central portion is organised into light and dark laminae. These laminae are gently convex downward. There may be a diffuse zone outside the lining just before the host sediment laminae are seen

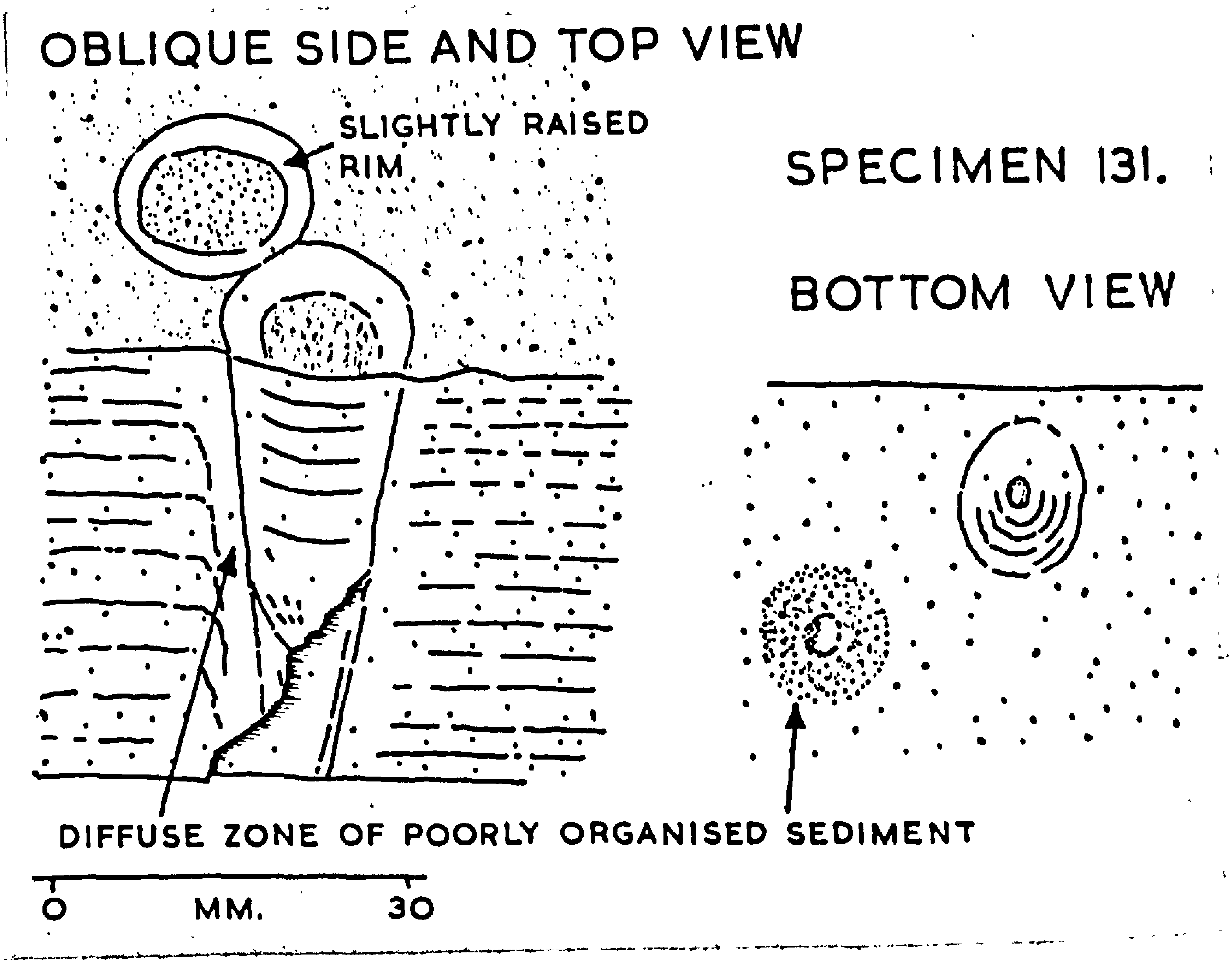


Fig. 58. Sketch of Monocraterion funnels. Note how differential weathering has left a raised rim around the periphery of the funnel.

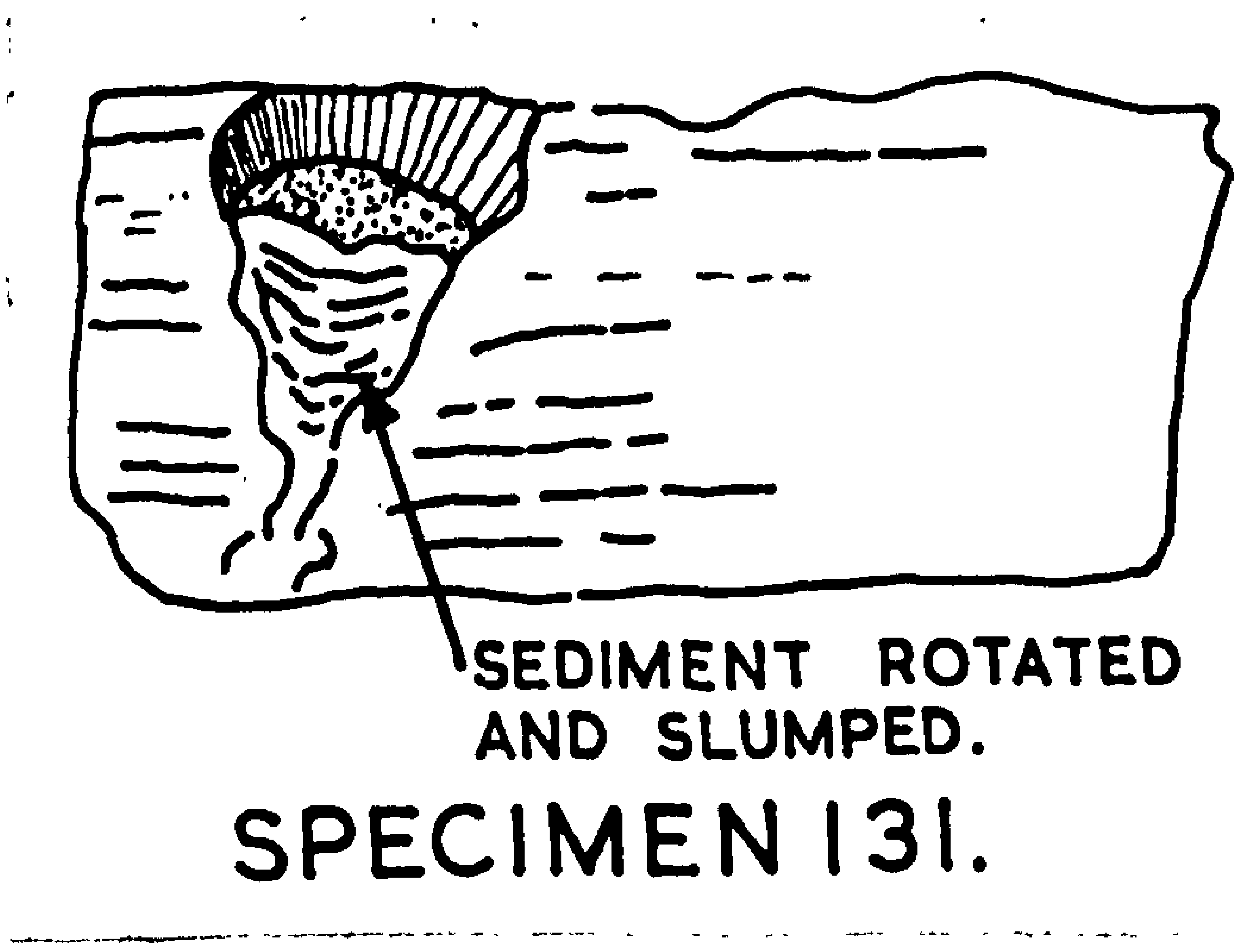


Fig. 59. Sketch of a Monocraterion funnel showing the preservation of slumped and rotated sediment in the funnel.

deflected downwards. This diffuse zone appears to maintain a constant diameter down through the sediment, whereas the funnel diameter decreases. The raised rim and diffuse zone are clearly seen in Fig. 58 (specimen 131).

The host sediment laminae adjacent to the vertical tubes can also show a downward deflection although some examples appear to be unaffected (compare Photo 88 with Photo 91).

Some tubes may also show a thin lining, usually of very fine light coloured sediment which contrasts markedly with the darker infilling material. (No mineralogical determination has been made on these specimens).

Occasionally associated with this type of lined burrow is an unusual development of randomly orientated dark carbonaceous(?) flecks. These occur around the tubes on the parting planes (Photo 89).

Rare examples have been found of crescent scour developments associated with the vertical tubes (Photo 87). Here the tubes pass upwards from silty mudstone facies into medium grained sandstone beds and immediately below the funnel, there is a marked scour around the tube preserved as a hyporelief. These scour structures are all orientated parallel to each other and indicate a current direction consistent with the regional pattern.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 4, Parallel bedded and striped siltstones and Facies 5, Cross laminated sandstones. Base of Grassington Grits and top of Pendle Shales.

c) ASSOCIATIONS

PELECYPODICHNUS COCHLICHNUS and CURVOLITHUS

d) INTERPRETATION AND DISCUSSION

As Frey and Chowns (1972), Hantzschel (1975) and Hakes (1976) point out, there is some question as to whether Tigillites and Monocraterion should be included under the name Skolithus especially as there are no well defined dividing lines between the three ichnogenera. Fursich (1974b) states, "The taxonomy of simple vertical burrows is in urgent need of revision. Morphological features such as funnel-shaped apertures in Monocraterion, Torell (1870) or less crowding of the tubes as in Tigillites Ronault (1850) do not justify separation at the ichno-specific and certainly not at the ichnogeneric level (sic)."

Whilst these objections are noted, it is felt that the E_{1C} specimens justify differentiation into two forms. Monocraterion is here defined as a vertical tube which always possesses a funnel, and Tigillites (described below) is defined as a vertical tube, not closely packed and lacking a funnel. Furthermore, Tigillites is differentiated from Skolithus by burrow diameter (Fursich 1974b).

Monocraterion is considered to be domichnia of small work-like organisms. Cerianthus lloydi, as described by Schafer (1962) was considered a modern analogue of the organism responsible (Hallam and Swett 1966). Schafer (1962) notes that Cerianthus normally lives in a burrow lined with a mucilaginous sheath. It is suggested that a similar organism is responsible for the E_{1C} vertical tubes and funnels. For instance, those specimens with hyporelief crescent scours suggest that the tube was able to resist local scouring or sediment creep. Also, the raised rim of the funnels implies that the animal lined the funnel sides. Similar resistant rims to funnels are figured by Bruun-Petersen (1973, Fig. 2) and Horne and Gardiner (1973, Plates 1 to 4). Bruun-Petersen (1973) suggests the funnel was formed and kept open by tentacles and that steep walled funnels were due to the relative shortness of the tentacles. However, Hallam and Swett (1966) consider that the size and shape of the funnel is a reflection of the physical stability of the sediment combined with the speed and extent of upward migration of the animal.

Palaeoenvironmentally, Skolithus and Monocraterion are associated with shallow littoral conditions. Seilacher (1967) established a Skolithus facies which was the shallowest marine assemblage in his bathymetric zonation of trace fossils.

I.2.12 ICHNOGENUS MUENSTERIA STERNBERG 1833

Photo 92

a) DESCRIPTION AND PRESERVATION

A horizontal burrow preserved as a positive hyporelief. The burrow, which varies in width between 3 and 4 mm is characterised by a series of transverse annulations spaced at 3 mm intervals.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin urbidite sandstone. Pendle Grits.

c) ASSOCIATIONS

BERGAUERIA

d) INTERPRETATION AND DISCUSSION

Trace fossils with back fill structures have been called Planolites, Richter (1937) (Webby 1970, Fig. 15), Taenidium Heer 1877 (Hakes 1976), Keckia Glocher 1841, 1843 orMuensteria Sternberg 1833. Fursich (1974b) states that since there is no basic difference between these ichnogenera, Muensteria, should be used since it has priority.

Hakes (1976) reports that back-filled burrows are considered facies independent since they have been reported from flysch facies (Heer 1877) to non-marine sediments (Seilacher 1963 and Stanley and Fagerstrom 1974).

I.2.13 ICHNOGENUS PALAEOPHYCUS HALL 1847

Photo 93

a) DESCRIPTION AND PRESERVATION

A positive hyporelief burrow. The burrow, 2 to 4 mm wide, is smooth, cylindrical and sinuous with occasional Y-branches.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstone. Pendle Grit.

c) ASSOCIATIONS

PLANOLITES

d) INTERPRETATION AND DISCUSSION

Fodinichnia of a small worm. The branched cylindrical burrow corresponds to Hall's description of Palaeophycus from the Ordovician of New York State (Hall 1947, P.7, P.12, Figs. 1, 2, 4 and 5). Also noted by Ksiazkiewicz (1970) in the Eocene flysch and in the Jurassic of Southern England (Hallam 1970).

The fact that Palaeophycus branches distinguishes it from Planolites. It may also have affinities with Protopalaeodictyon which it partly resembles.

I.2.14 ICHNOGENUS PELECYPODICHNUS SEILACHER 1953

Photo 94

a) DESCRIPTION AND PRESERVATION

This trace is identified in two forms, either as small almond-shaped positive hyporeliefs or as endogenic disturbances within siltstones.

The positive hyporeliefs can also be divided into two types. One type is very small and smooth and is found on facies 6, Thin turbidite sandstones. It ranges in size from 2 - 3 mm in width and is 1 - 2 mm deep. The structure shows a random orientation relative to the sole marking azimuths.

The second type is much larger and occurs in shallow water sediments. This type is up to 15 mm long and 12 mm deep. It frequently shows a continuation of the structure into the overlying bed.

The endogenic disturbances are also oval-shaped in plan. They vary in width from 7 - 15 mm and length from 10 - 20 mm. The endogenic disturbances are difficult to collect due to the weathered nature of the material.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstones, Pendle Grits; Facies 4, Parallel bedded and striped siltstones, Pendle Shales; and Symmetrical rippled (Type B) sandstones, Bradley Flags.

c) ASSOCIATIONS

<u>PLANOLITES</u> <u>COCHLICHNUS</u> <u>MONOCRATERION</u>

d) INTERPRETATION AND DISCUSSION

Commonly interpreted as cubichnia of bivalves (Seilacher 1953. Osgood 1970. Eager 1974). <u>Carbonicola</u> (Harding 1970b and Eager 1974) and <u>Anthraconia</u> (Eager 1974 and McCabe 1975b) have been found associated with the endogenic disturbances and these disturbances are interpreted as escape shafts. Hardy (1970b) has reported finding bivalves in the death position at the top of the shaft. Seilacher (1953) interpreted the hyporelief as having been made by the pelecypods pressing sand into the soft underlying sediment.

There is still a controversy as to whether the structure should be called <u>Lockeia</u> (James) or <u>Pelecypodichnus</u> (Seilacher).

<u>Lockeia</u> was first reported by James in 1879 from the Ordovician of Ohio and several authors, e.g. - Osgood (1970), Chamberlain (1971a) and Hakes (1976) consider that under the Law of Priority, this name should be maintained. However, the name <u>Pelecypodichnus</u> as erected by Seilacher (1953) is well established in Europe, e.g.:- Lessertisseur (1955) Hantzschel (1962) and especially in the Carboniferous Central Pennine Basin literature, e.g. McCabe (1975a & b), Collinson and Banks (1975), Hardy (1970b) and Eager (1974).

Eager (1974) rejected the term <u>Lockeia</u> because "James did not supply a figure with his original description." However, as Hakes (1976) points out, according to the International Code of Zoological Nomenclature (Article 12), type species established prior to 1931 need only to "have been accompanied by a description, definition or indication." Hakes considers that James (1879 P.17) did supply an adequate description of <u>Lockeia</u> in his original publication.

This argument is acknowledged but as the term <u>Pelecypodichnus</u> is widely used and understood in the Carboniferous literature, it is retained here.

I.2.15 ICHNOGENUS PLANOLITES NICHOLSON 1873

Fig. 60 and 61 Photos 95 and 96

a) DESCRIPTION AND PRESERVATION

Horizontal interface trails, preserved as both positive and negative epireliefs and hyporeliefs, inter-connect with vertical and oblique burrows. They are simple and unbranched and have straight to highly sinuous courses. Tube diameters range from 0.2 mm to 10 mm. Tube walls are generally smooth, especially in very small forms. Large burrows tend to be elliptical due to compaction (Fig. 61).

The epirelief trails are almost always negative and the trail often ends at a small depression (Fig. 60). The depressions vary in size; some are only as wide as the smallest trail whilst others have diameters ranging up to 12 mm. The depressions are either simple or they may show a small stalk or projection in the middle. The hyporelief trails may be negative or positive. The shape and arrangement of the hyporelief trails is similar to that of the epireliefs. Some specimens clearly show the trails post-dating the tool moulds.

The vertical and oblique tubes are often difficult to distinguish because of their general lack of colour or grain size contrast. However, those penetrating the underlying mudstone facies show immediate contrasts (Fig. 61a and b).

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstones. Pendle Grits and lower part of Pendle Shales.

c) ASSOCIATIONS

PALAEOPHYCUS COCHLICHNUS TIGILLITES ARTHROPHCUS
GYROPHYLLITES DIDYMAULICHNUS BERGAUERIA RHIZOCORALLIUM A & B

d) INTERPRETATION AND DISCUSSION

Fodinichnia of infaunal worms. Osgood (1970) has discussed the relationship of Planolites with the somewhat similar burrow Palaeophycus.

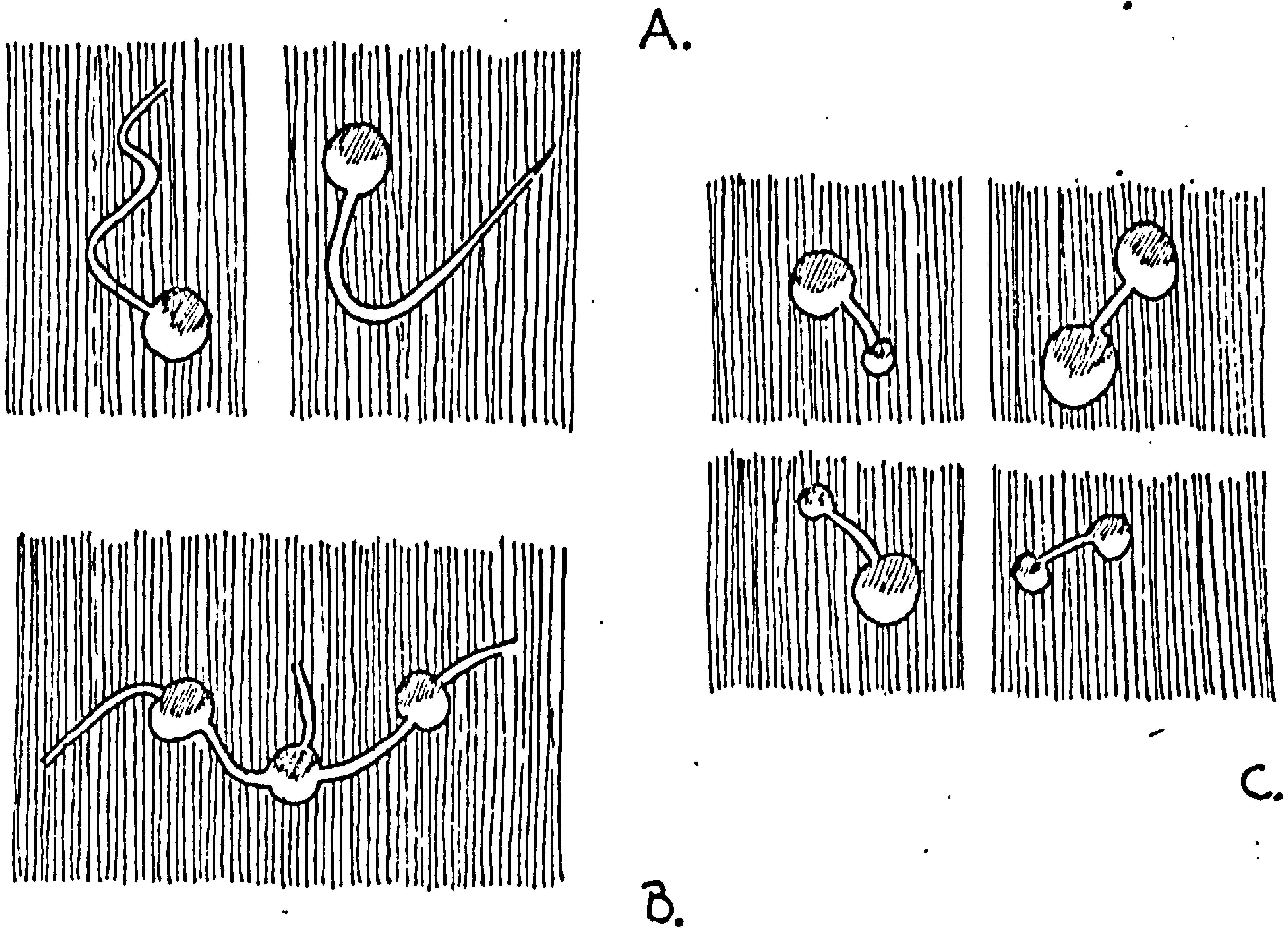


Fig. 60. Three sketches of the negative epirelief Planolites. Sketches made from rubbings on facies 6, Thin turbidite sandstone, Natural scale.

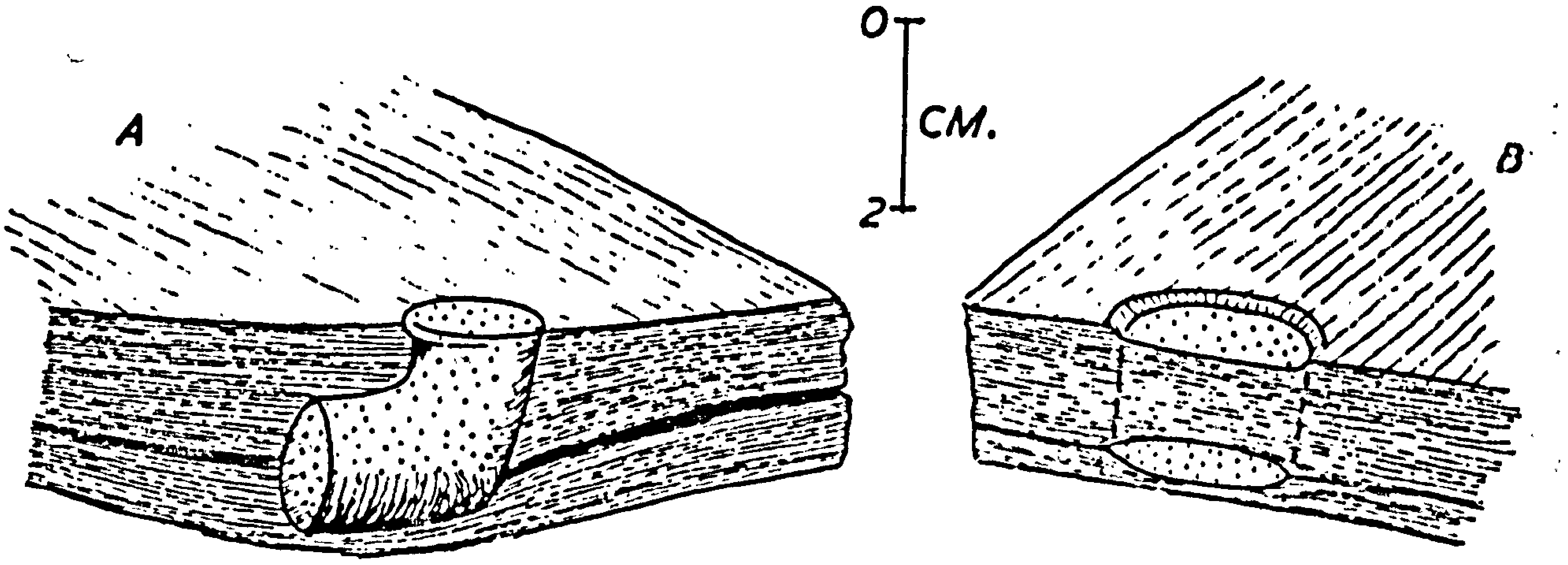


Fig. 61. Planolites preserved as sub-vertical burrows. The elliptical shape is caused by compaction.

However, Planolites is diagnosed as a simple cylindrical unbranched burrow while Palaeophycus is branched (Hakes 1976).

I.2.16 ICHNOGENUS PROTOPALAEODICTYON KSIAZKIEWICZ 1970

Fig. 62 and 63. Photo 97.

a) DESCRIPTION AND PRESERVATION

Meandering horizontal burrow system preserved as positive hyporeliefs. The burrows vary in size and complexity. The tubes are straight to slightly curved for 20 - 30 mm and then they branch, the result being an irregular and incomplete hexagonal pattern (Fig. 62a).

The largest trail is over 26 cm long. The tubes themselves vary considerably in size, some are quite stout with diameters of 17 - 18 mm whilst others are thin and narrow, only 3 or 4 mm wide.

Several specimens also show a central area where the tube geometry is concealed beneath a comparatively smooth 'skin' of mudstone adhering to the sandstone. Further work is necessary to determine the exact relationship of this area to the burrow system.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstones. Top of Pendle Grit.

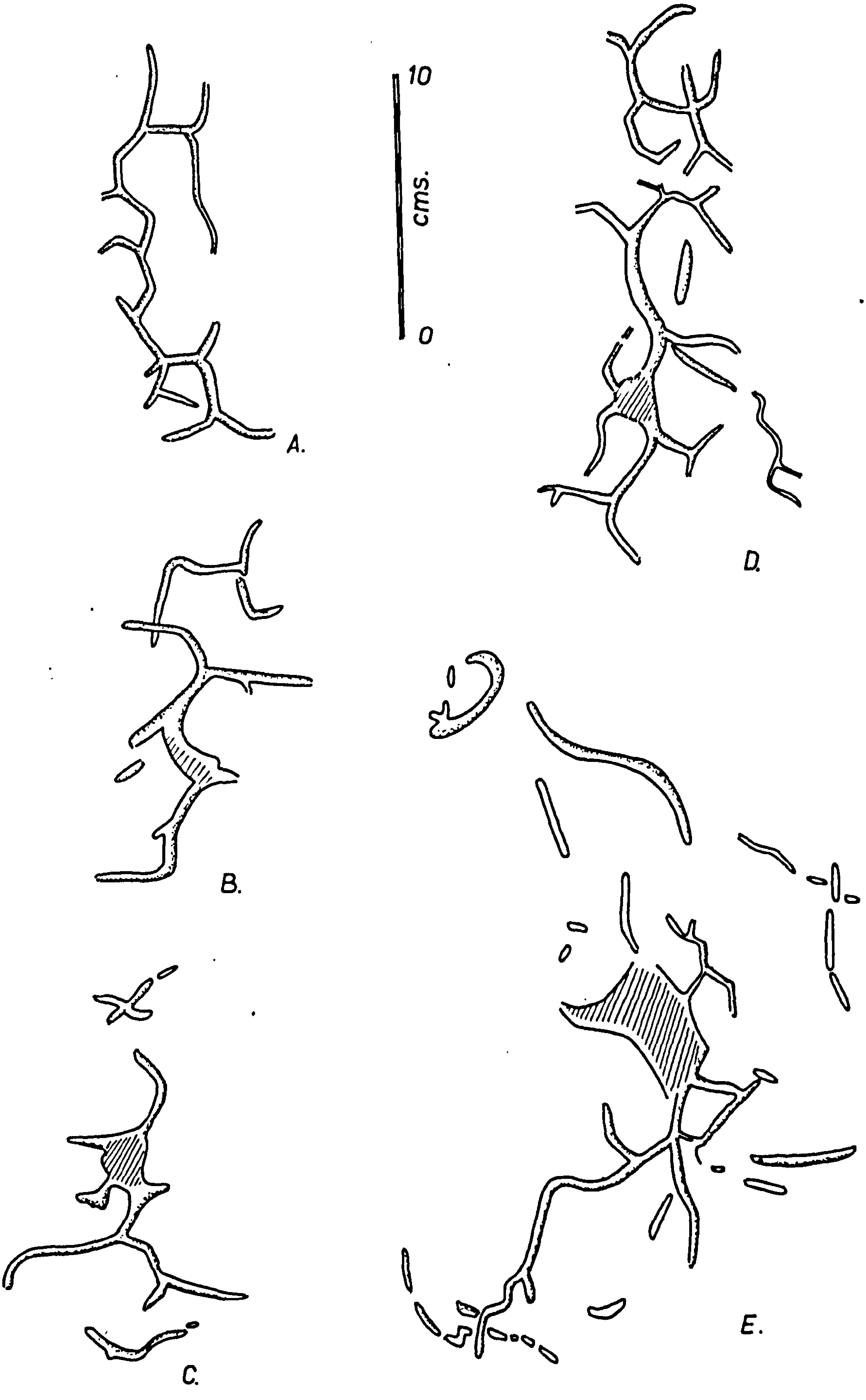
c) ASSOCIATIONS

BERGAUERIA PLANOLITES

d) INTERPRETATION AND DISCUSSION

In many ways, this network trail resembles Palaeodictyon Meneghine in which there is a "honeycomb tube network, most regularly 6-sided, but also 5- to 8- sided meshes which are commonly open on one side; size variable; in relief on lower surface of beds" (Hantzschel 1962). However, since the shape of the network is more irregular than that figured by Hantzschel, it seems more appropriate to include it in the form erected by Ksiazkiewicz as Protopalaeodictyon incompositum (Ksiazkiewicz 1970). He diagnoses Protopalaeodictyon as "a meandering sole trail with ramifications on the apices of the meanders." Similar structures are also figured by

Fig. 62. Five sketches of possible Protopalaeodictyon positive hyporeliefs. All drawn from the sole of a facies 6, Thin turbidite sandstone (specimen 167, Photo 8, Bareshaw Beck, SD981484, Carleton).



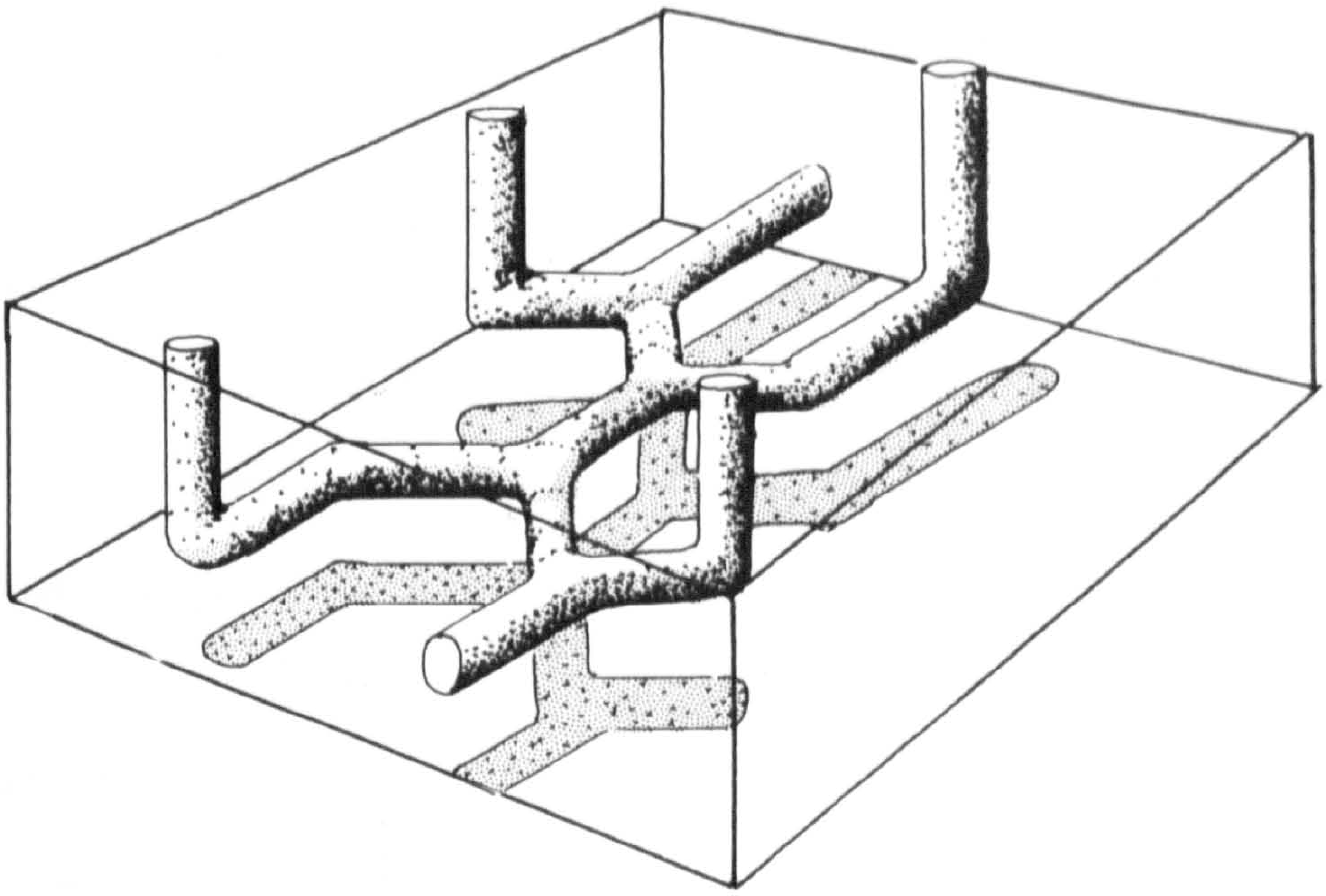


Fig. 63. Highly schematic sketch of what a "feather stitch" Palaeodictyon burrow system may look like (see Seilacher 1974, Fig. 4).

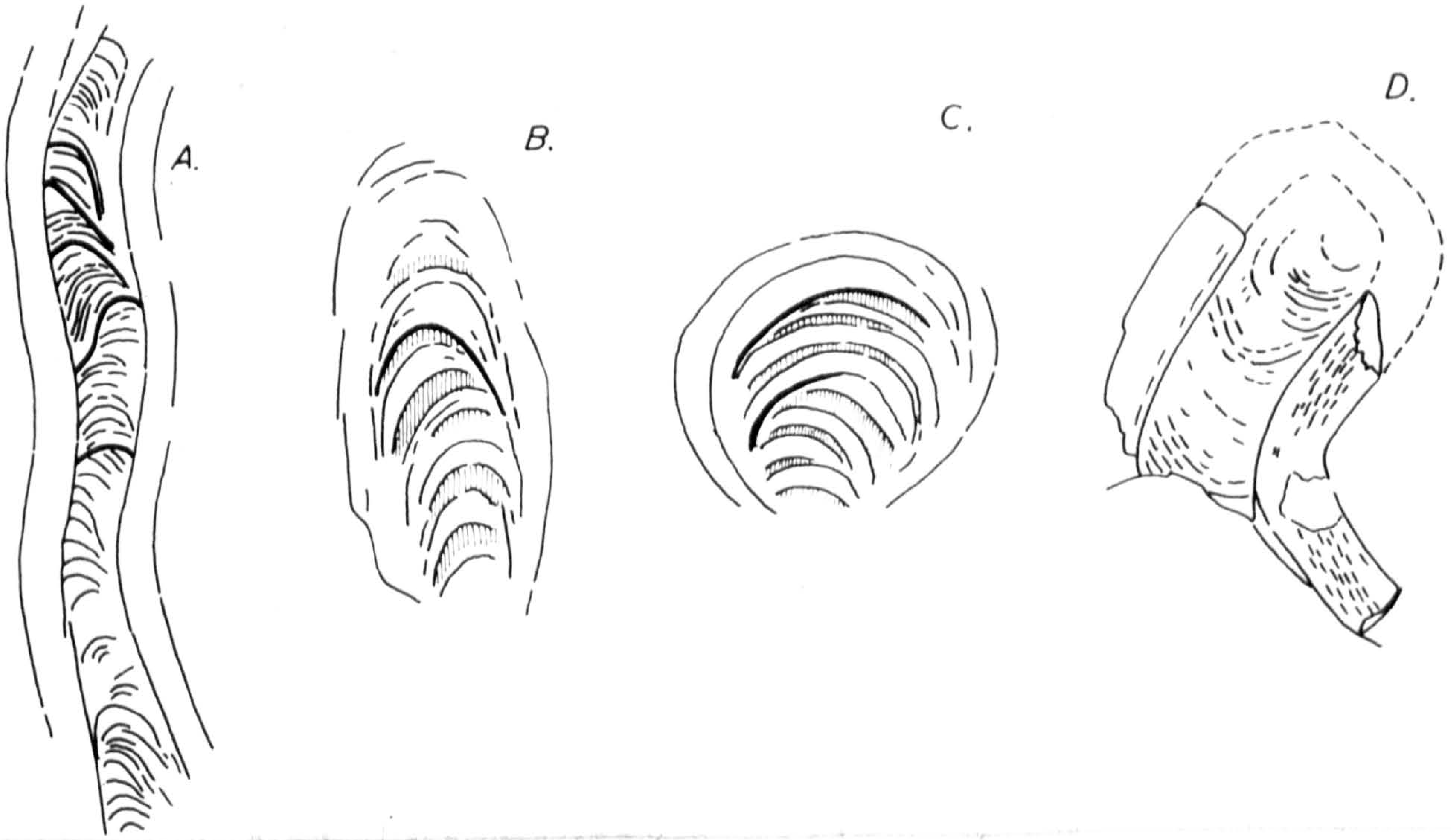


Fig. 64. Four sketches of Rhizocorallium positive epireliefs (see Photos 101, 105, 107 and 103 respectively). Note how the sense of movement of the organism responsible for the trail can be gained from studying the truncation of spreite between the lateral tubes.

Crimes et al (1974, Fig. 2). Seilacher (pers.comm. 1971) examined Photo 97 and thought that the trail was reminiscent of an "initial Palaeodictyon" whilst also bearing a resemblance to a 'feather stitch' trail. Recently, Seilacher (1974, Fig. 4, P. 242) has figured some varieties of feather stitch systems. In particular, Fig. 4e of Seilacher's text illustrates one possible behavioural pattern which may be applicable to the types illustrated above (Fig. 63).

I.2.17 ICHNOGENUS RHIZOCORALLIUM ZENKER 1836

Fig. 64 and 65 Photos 98, 99, 100, 101, 102, 103, 104, 105
106, 107, 108, 109.

a) DESCRIPTION AND PRESERVATION

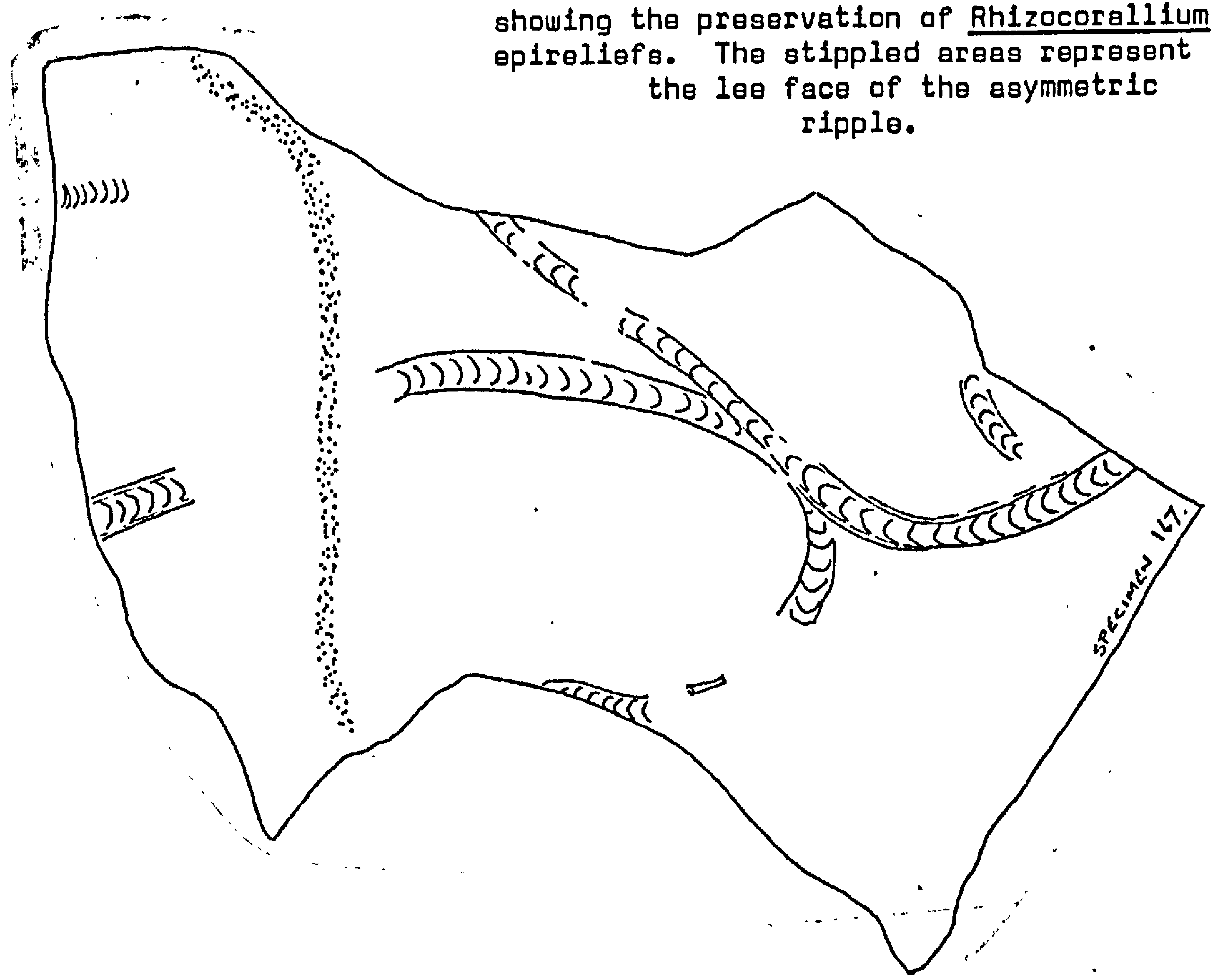
Two varieties of Rhizocorallium have been recognised, Type A and Type B. Material collected by N. Trewin from the E_{1C} of Staffordshire is also figured as an aid to interpretation.

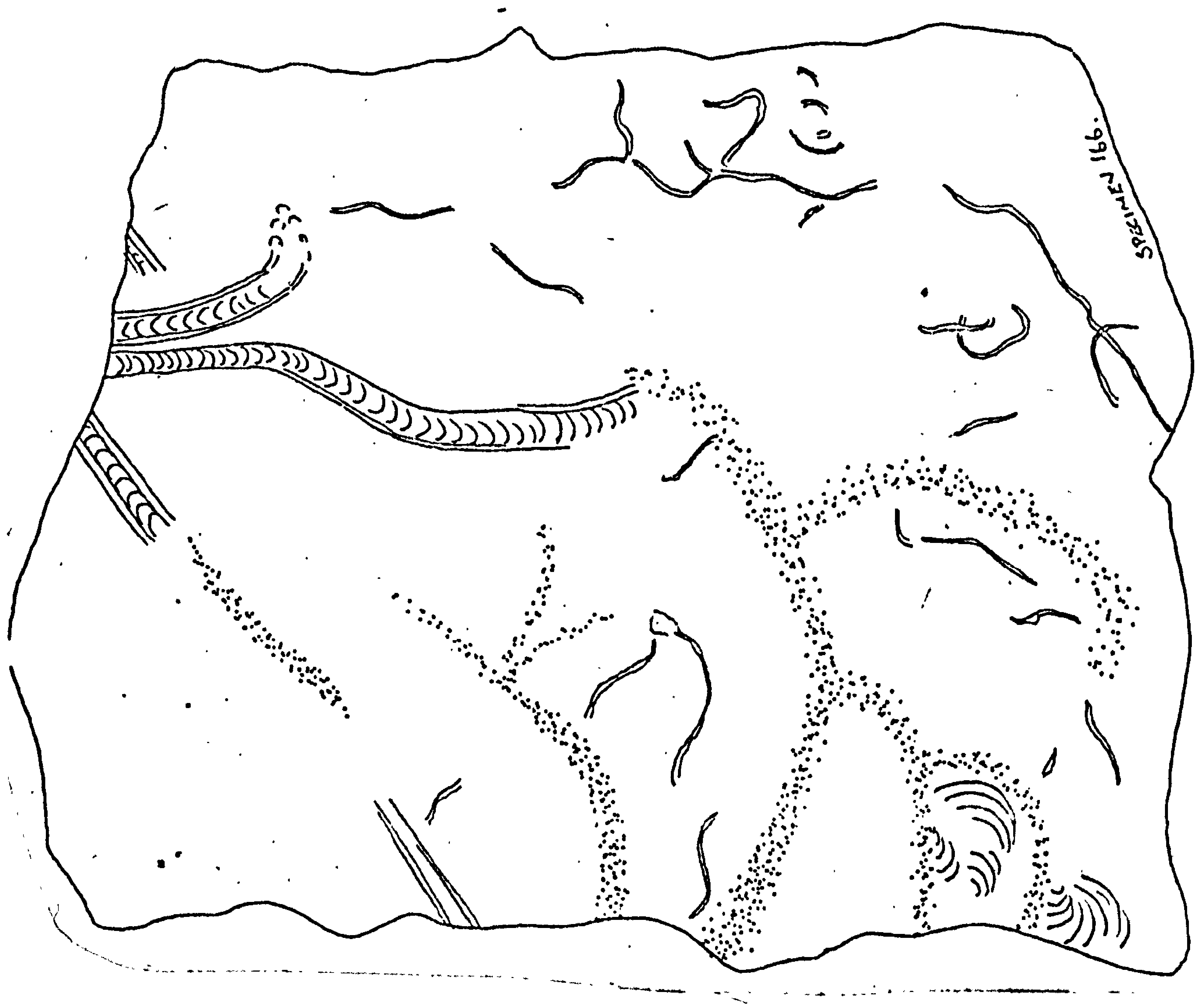
TYPE A RHIZOCORALLIUM

This form is a long positive epirelief trail, either straight or slightly sinuous. The trace consists of two parallel tubes separated by a small furrow in which can be seen numerous closely spaced spreite (Photos 98 and 99). The tubes are oval-shaped and have a maximum diameter of 6 mm whilst the furrow separating them varies between 5 and 10 mm. The maximum length of trail observed in over 150 cm.

A close comparison of this material can be made with material collected by N. Trewin from the E_{1C} sequence of North Staffordshire (Photos 101, 102 and 103). The dimensions of the structures collected by Trewin are the same as those from the Skipton area. However, Trewin's specimens show a better development of the spreite. They also show a U-shaped termination and the development of thin sub-parallel striations on one of the flanking tubes (Photo 103). These striae are on the top of the tube and are parallel to the sides.

Fig. 65. Two sketches of rippled tops of facies 6, Thin turbidite sandstone showing the preservation of Rhizocorallium epireliefs. The stippled areas represent the lee face of the asymmetric ripple.





Preservation of the traces is very variable. In good specimens, the flanking tubes and spreite are clearly defined, but other specimens show only a shallow depression where the tubes may have been. The inference is that the tube has been plucked away during specimen collection. Yet other specimens show only the preservation of the spreite.

TYPE B RHIZOCORALLIUM

These forms are short positive epirelief trails. They are either sub-rectangular or globular in shape (Photos 104, 105, 106 and 107). The former type have an abrupt square end with the spreite convex away from it. The opposite end is rounded and has a tube around the periphery which in some examples, extends back along the length of the trace.

b) FACIES AND STRATIGRAPHICAL DISTRIBUTION

Facies 6, Thin turbidite sandstones. Pendle Grits and lower part of Pendle Shales.

c) ASSOCIATIONS

PLANOLITES ARTHROPYCUS COCHLICHNUS BRUSH AND SCRABBLE MARKS

d) INTERPRETATION AND DISCUSSION

Type A specimen closely resemble Rhizocorallium jenense (Zenker 1936). These are described as ".... U-shaped spreites burrows, parallel and distinct, tube diameter: diameter of spreite usually >1:5 ....." Fursich (1974a, Page 18).

Both Type A & B Rhizocorallium have spreite which are convex forward, ie protrusive. As the animal advanced and changed direction so earlier spreite became truncated (Fig. 59). This observation is complimented by illustrations in Veevers (1962, Fig. 2 & 3), Sellwood (1970, Fig. 3a), Chisholm (1970, Fig. 7) and Seilacher (1967, Fig. 4). Fig. 64d shows the probable starting point of one of the animal traces. The outer tube periphery must have been completed before the animal moved off.

Seilacher (pers.comm.) thought that the animals descended through the overlying mud to the sand/mud interface before commencing burrowing in a "horizontal" direction. This may account for the better development of the traces on the crests of the linguoid ripples (Photo 98). Additional evidence for this theory is seen in Photo 103. Here faint parallel marks are seen on the <u>upper</u> surface of one of the flanking tubes. These are interpreted as scratch marks, probably made by an animal which clawed at the over lying sediment as it propelled itself along. Similar scratches are figured by Hantzschel (1962, Fig. 129, P. W207), Veevers (1962, Plate 1), Farrow (1966, Fig. 6, P. 113), Durkin (1968, Plate 4) and Chisholm (1970, Plate VI, Fig. 5). Chisholm (1970) and Fursich (1974) both suggest that the excavation had to be into consolidated or partly consolidated mud for the scratch features to have a chance of being preserved.

Veevers (1962, P. 10) interprets the trace as being formed by a "worm shaped animal.... which advanced through the sediment by making a succession of U-tubes that overlap to form a compound U in U structure." Similarly, Hantzschel (1962) and Farrow (1966) regard the structure as being a burrow, probably made by a crustacean, the scratch marks being reminiscent to those seen on modern crustacean burrows (Farrow 1971).

I.2.18 ICHNOGENUS ? <u>SCALARITUBA</u> WELLER 1899

Fig. 66 and 67 Photo 110

a) DESCRIPTION AND PRESERVATION

A horizontally meandering burrow system preserved as an endogenic 'full relief'. Specimens show a Y-branching with the limbs opening through angles of up to 120^0. The burrow is 7 - 8 mm wide. In certain lighting conditions, it is possible to see a series of concavo-convex spreite on several specimens (compare Fig. 66 with Photo 110).

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 4, Parallel bedded and striped siltstones. Pendle Shales.

c) ASSOCIATIONS

<u>COCHLICHNUS</u> <u>CURVOLITHUS</u> <u>LOPHOCTENIUM</u>

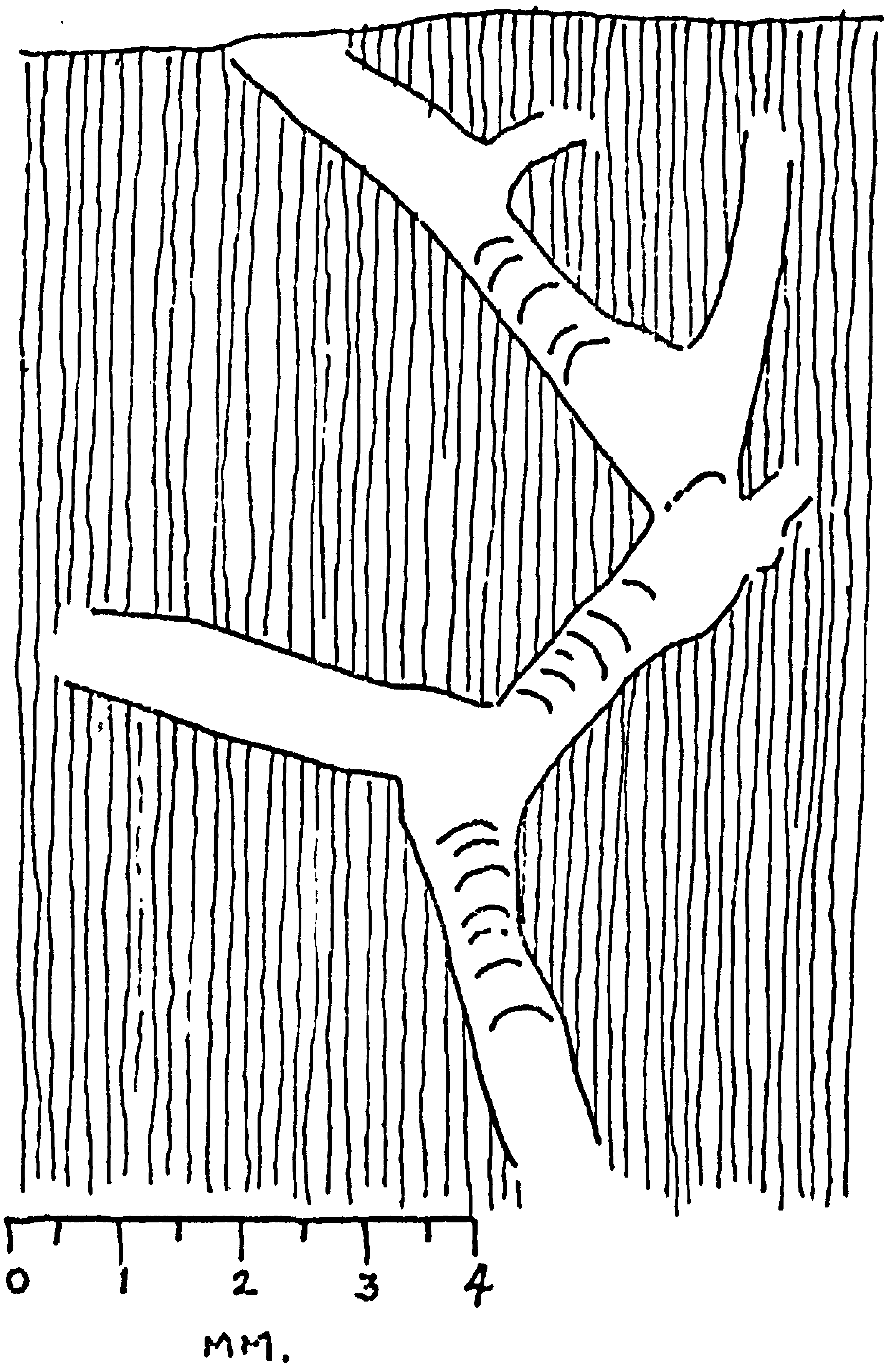


Fig. 66. ?Scalarituba. Note internal organisation and compare with Photo 110.

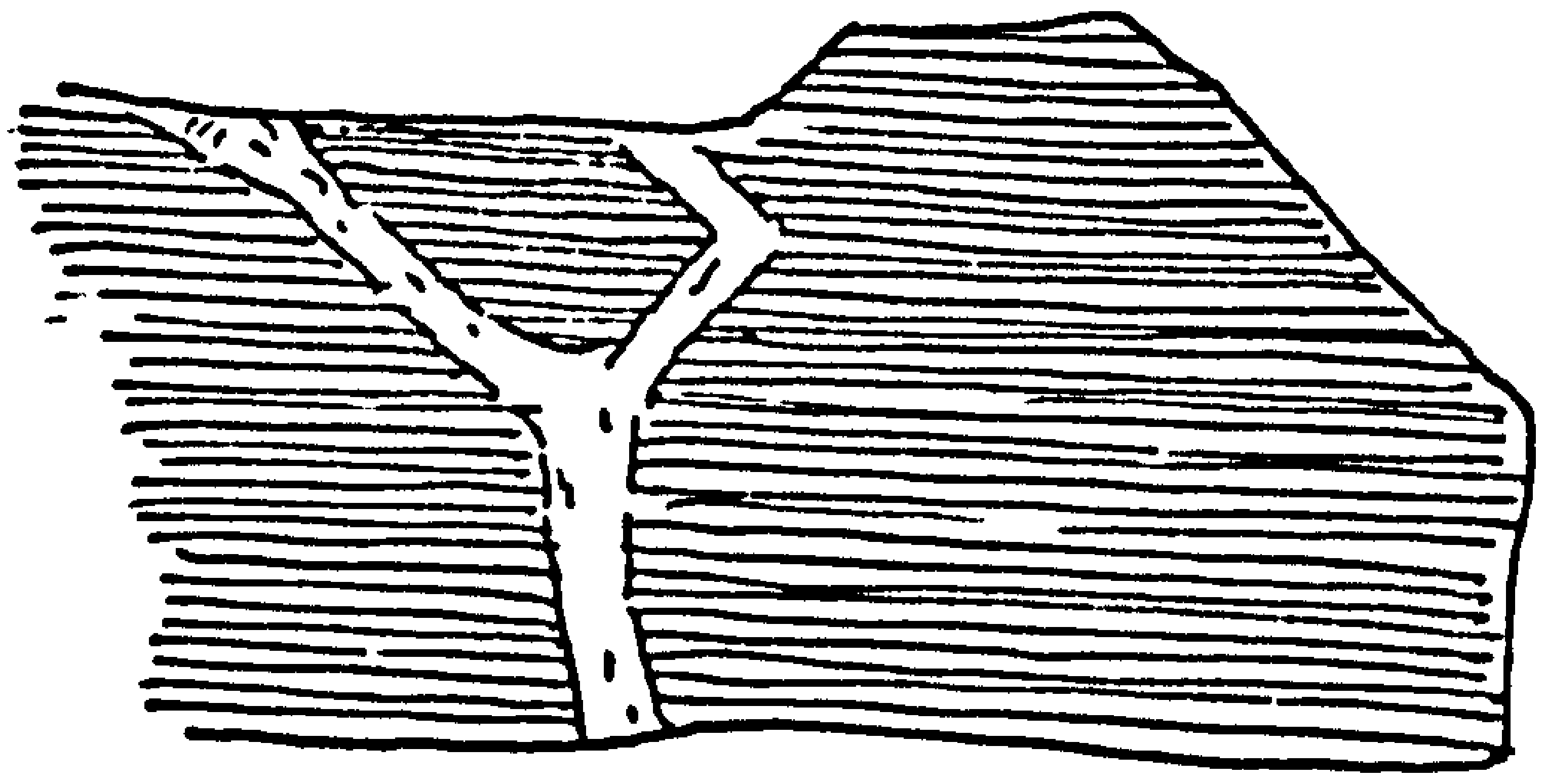
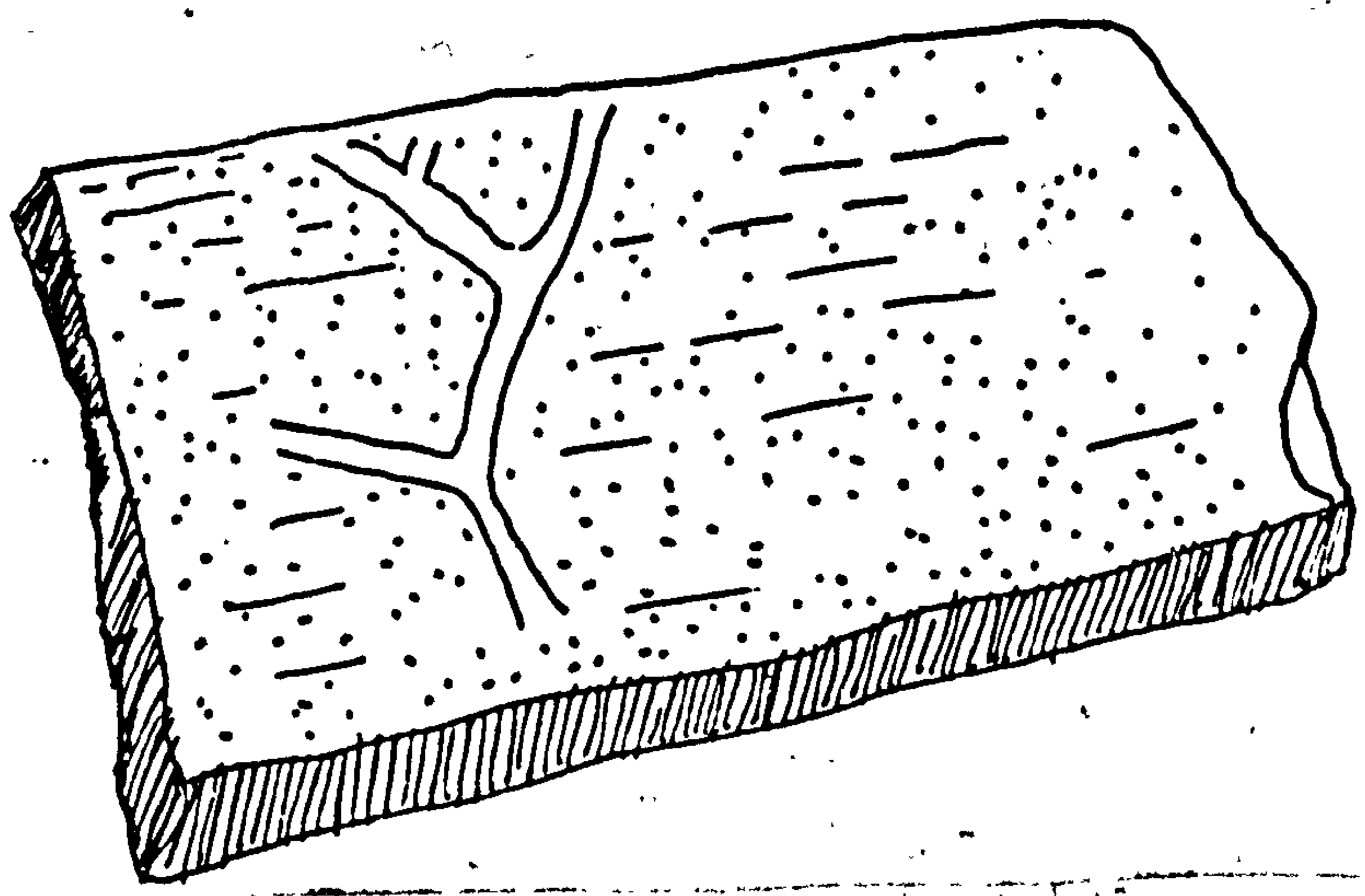


Fig. 67. Two field sketches of ?Scalarituba (¾ scale).



d) INTERPRETATION AND DISCUSSION

This trace fossil is difficult to name. Although it bears a superficial resemblance with the Y-branching burrow systems described as Thalassinoides, according to Chamberlain and Clark (1973), Thalassinoides burrows are not known before the Triassic. Also decapods (normally attributed as making this type of burrow) are not known before the Permian.

However, the E_{1C} Y-branching specimens are diagnosed as Scalarituba on the basis of Hayward's (1976) description. He describes Scalarituba as occasionally branching with a series of arched transverse laminae.

These transverse partitions are interpreted to be the result of a worm burrowing within the sediment and episodically back-filling the burrow. Seilacher and Meischner 1964, Conkin and Conkin 1968. Hayward 1976 and Hakes 1976.

Hayward (1976) described Scalarituba from deep water (Bathyal) sediments of the Lower Miocene of New Zealand. Seilacher and Meischer (1965) and Chamberlain (1971) have described it from moderately deep Zoophycus facies whilst Conkin & Conkin (1968) consider Scalarituba to be indicative of tidal-flat environments.

I.2.19 ICHNOGENUS ? SPIROPHYCUS HANTZSCHEL 1962

Fig. 68 Photo 111

a) DESCRIPTION AND PRESERVATION

A partially formed spiral structure preserved as a negative epirelief. The trace is 2 mm wide.

b) FACIES AND STRATIGRAPHICAL DISTRIBUTION

Facies 11, Large scale cross-bed foreset ? (Type B). Grassington Grits (One specimen - left in situ).

c) ASSOCIATIONS

COCHLICHNUS

d) INTERPRETATION AND DISCUSSION

Most likely the pasichnia of a small worm or gastropod. Spirophycus has been described by Chamberlain and Clark (1974), Hantzschel (1962) and Ksiazkiewicz (1970) amongst others.

The E_{1C} specimen occurs on a bedding plane of what is thought to be a large scale cross-bed foreset (Type B). The preservation of such a trace fossil in this environment seems completely anomalous. (Further research is required in this locality to gain a better appreciation of the sedimentary regime and the bed form configurations).

I.2.20 ICHNOGENUS TIGILLITES RONAULT 1850

Photo 72

a) DESCRIPTION AND PRESERVATION

Large vertical tubes between 20 and 25 mm in diameter preserved as epi-hypo- and full reliefs. The matrix of the burrow is identical to the host sediment. The tubes are widely and randomly spaced.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 4, Parallel bedded and striped siltstones. Facies 6, Thin turbidite sandstones. Pendle Grits and Pendle Shales.

c) ASSOCIATIONS

CURVOLITHUS COCHLICHNUS and LOPHOCTENIUM

d) INTERPRETATION AND DISCUSSION

Domichnia of worms. These vertical burrows are similar to Skolithus Haldemann 1840. However, they are much larger in diameter and are not as closely packed as Skolithus(Westergard 1931. Howell 1943. Holland and Swett 1966). As noted in the discussion concerning Monocraterion there is some question as to whether Tigillites and Monocraterion should be included under Skolithus. Frey and Chowns (1972, P 26) have distinguished between Tigillites and Skolithus by burrow diameter. Tigillites was interpreted to be the larger and they were less densely packed than Skolithus. However, Alpert (1974) argues that the degree of crowding and spacing of the burrows is incorrectly used as a taxonomic character and that burrow density is a palaeocological variable, dependent on sedimentation rates. Alpert also considers that large vertical burrows over 15 mm in diameter should be placed in a new genus rather than be classed as *Skolithus*. He recommends *Pilichnia*, Chamberlain 1971a. However *Pilichnia* was originally defined as a large sub-cylindrical gallery with an oval or elliptical profile (c.f. *Pilichnia elliptica* of Chamberlain 1971a) although later variations were diagnosed as being circular in transverse section (Chamberlain and Clark 1973).

I.2.21 BRUSH OR SCRABBLE MARKS

Photo 112, 113 and 114.

a) DESCRIPTION AND PRESERVATION

These traces occur as shallow negative epireliefs on the top of facies 6, Thin turbidite sandstones. They vary in width from 12 mm to 40 mm. The trace consists as a series of concavo-convex depressions and ridges scribing the top of the ripples.

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstones. Pendle Grits and lower part of Pendle Shales.

c) ASSOCIATIONS

PLANOLITES *RHIZOCORALLIUM A*

d) INTERPRETATION AND DISCUSSION

This trace is interpreted as being made by an organism that gently but systematically swept the top of the rippled sandstone in a side-to-side motion. This trace may be related either to *Rhizocorallium* or *Lophoctenium*.

I.2.22 VERTICAL BURROWS

INTRODUCTION

Vertical burrows are common throughout the E_{1C} succession. Whilst many can be assigned to either *Monocraterion* or *Tigillites* there are others which are more obscure. Perhaps the commonest of these latter forms are the tubes associated with Crescent Scours.

A) CRESCENT SCOURS

Fig. 69 and 70. Photos 10 and 115.

a) DESCRIPTION AND PRESERVATION

Crescent scours are preserved on the soles of facies 6, Thin turbidite sandstones as positive and negative hyporeliefs. Each structure consists of a small depression surrounded by a crescentic ridge. The depression or pit can either be circular or elliptical in shape and may occasionally show a small stalk-like projection in the centre. Around the periphery of the pit is a raised lip or ridge. This ridge is always well developed on one side of the depression and extending from this ridge are horns. These are streamlined parallel to tool or scour markings which are also found on the sole of turbidites.

Occasionally, a small knob or projection (positive hyporelief) occurs on a few millimetres in front of the pronounced raised ridge. This knob always occurs on the upcurrent side of the structure, as determined from the sole markings (Fig. 69).

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6, Thin turbidite sandstones. Pendle Grits and Pendle Shales.

c) ASSOCIATIONS

<u>COCHLICHNUS</u> <u>DIDYMAULICHNUS</u> <u>GYROPHYLLITES</u> <u>PLANOLITES</u> <u>BERGAUERIA</u>

d) DISCUSSION AND INTERPRETATION

Crescent scour structures have been figured by several authors including Peabody (1947), Allen and Friend (1968) and Osgood (1970). They all agree that the crescentic shape is due to the infilling on an erosion scour that has developed around the leading edge of a resistant projection, possibly a vertical burrow. This type of structure is always found preserved on the bases of facies 6, Thin turbidite sandstones. It is thought that the tubes were formed by organisms living in the mud and that they formed tubes which were either flush with the mud surface or projected above it. When a

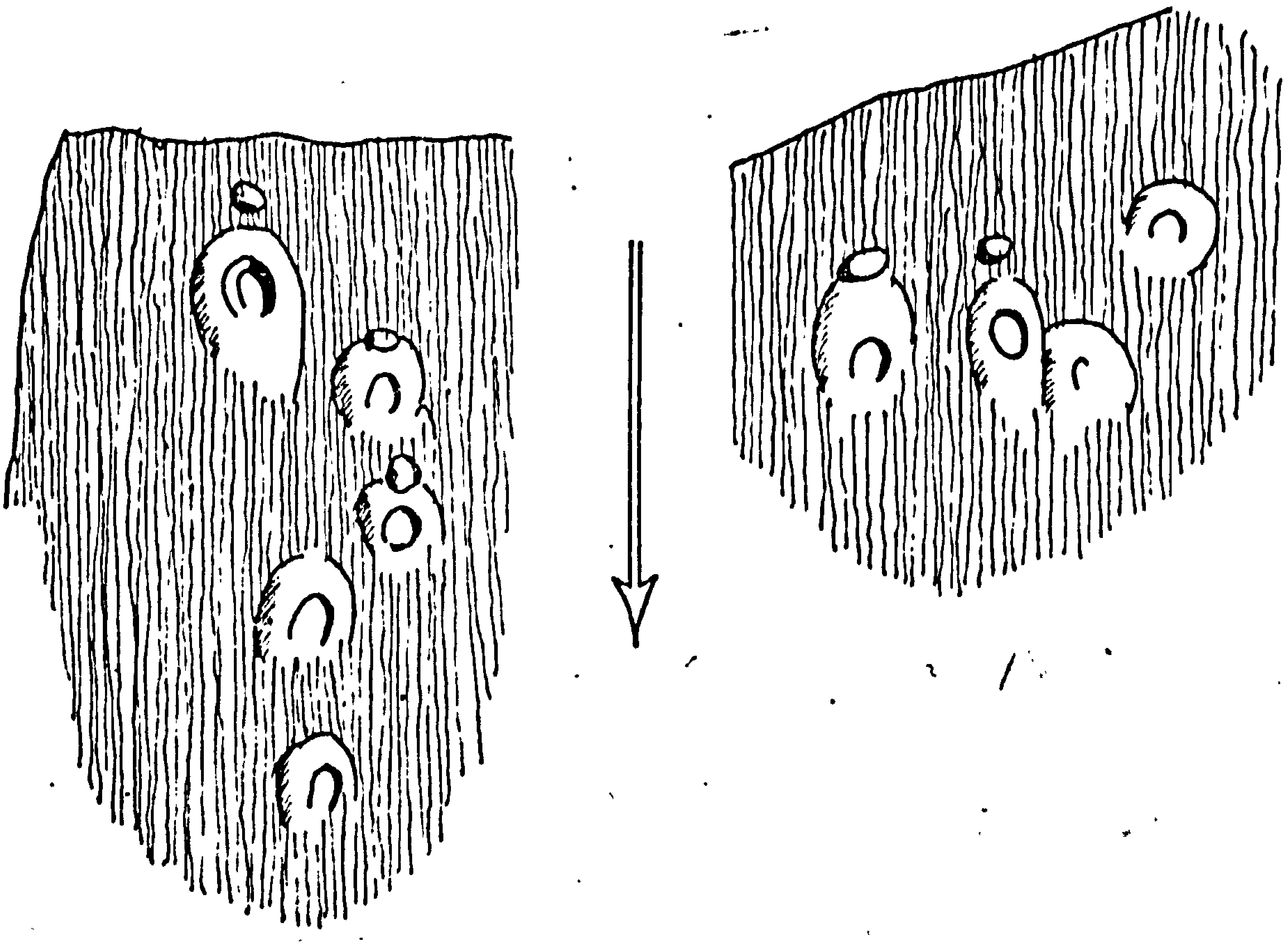


Fig. 69. Two sketches of the sole of a facies 6, Thin turbidite sandstone showing 'crescent scours'. Current direction indicated by arrow. Note the preservation of a 'Knob' at the upstream end.

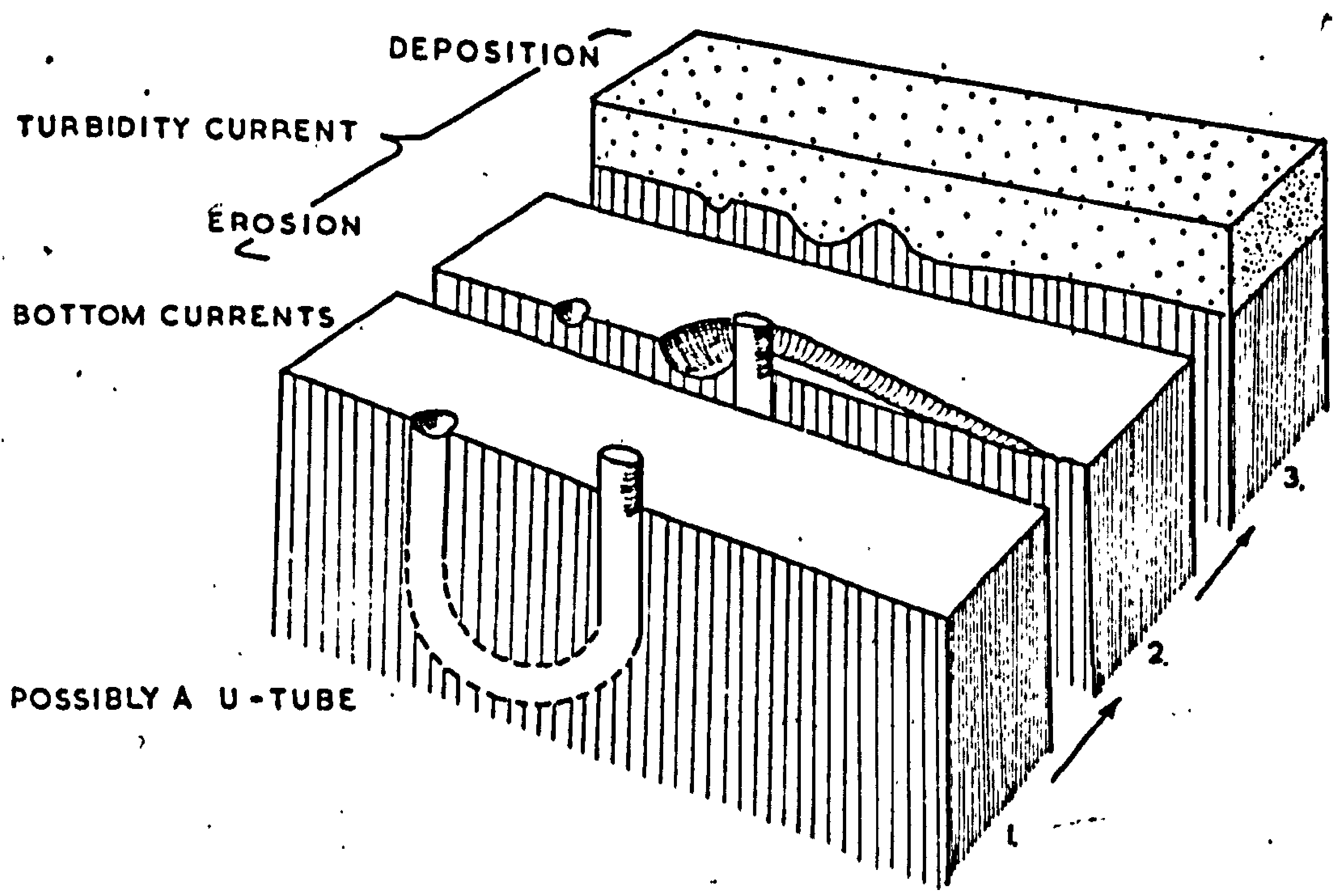


Fig. 70. A block diagram which illustrates a possible explanation of the alignment of the knob and crescent scour.

turbidity current passed across the top of the mud, the tube impinged on the turbulent current causing local vortices and scouring. The hollows which developed with local scouring were subsequently filled with sand during the depositional phase of the turbidity current.

Some specimens are however more difficult to interpret. These are the ones which have a raised 'knob' or projection upcurrent of the crescent scour (Fig. 69). The projection was originally a hollow, and the question is, when was the hollow formed? If the hollow was connected to a burrow system with the other end terminating as the cemented tube, then why does the hollow and tube always aligned parallel to the direction of the subsequent turbidity current?

Two possible causal mechanisms are considered, but both in turn raise further problems.

(1) It is suggested that the hollow was formed after deposition by the turbidity current. But if this is the case, why did the organism always burrow up in front of the crescent scour, why not in a more random manner?

(2) The second suggestion is that the organism responsible anticipated the turbidity current and aligned the tube and hollow parallel to the turbidity current. This alignment may indicate that more permanent down slope currents were operative. In fact, Collinson, Jones and McCabe (Collinson pers.comm. 1976) think that permanent under-flow and density currents were operative in the R_{1C} Slope Associations.

I.2.23 B. VERTICAL BACKFILLED TUBES?

Fig. 71

a) DESCRIPTION AND PRESERVATION

Small, vertical tubes? 20 mm high and 5 to 6 mm wide are preserved as exichnial burrow casts.

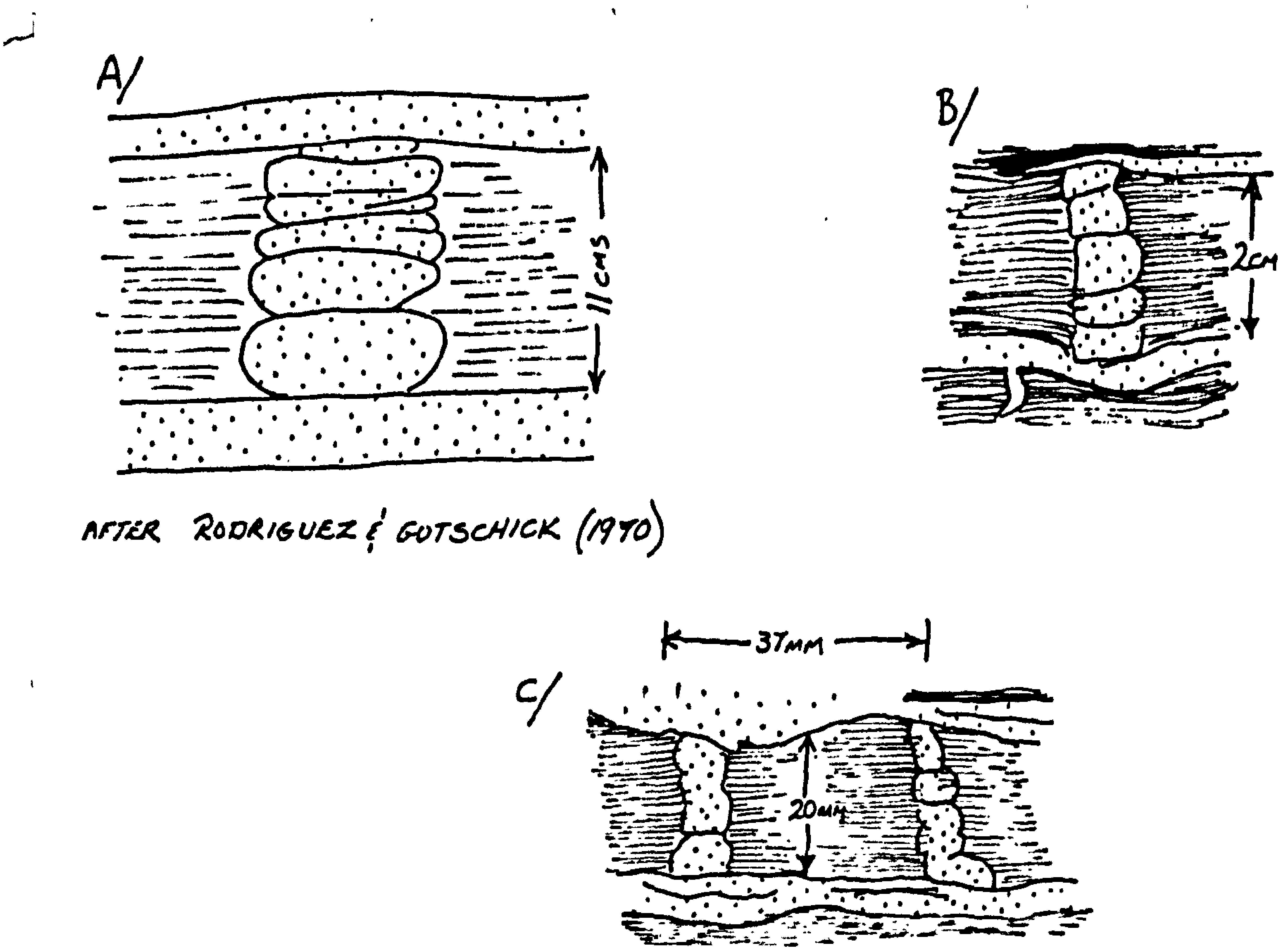


Fig. 71. Sketch of two vertical sand structures (b and c) which bear a resemblance to vertical burrows illustrated by Rodriguez and Gutschick (1970). Note however, the disparity in scale.

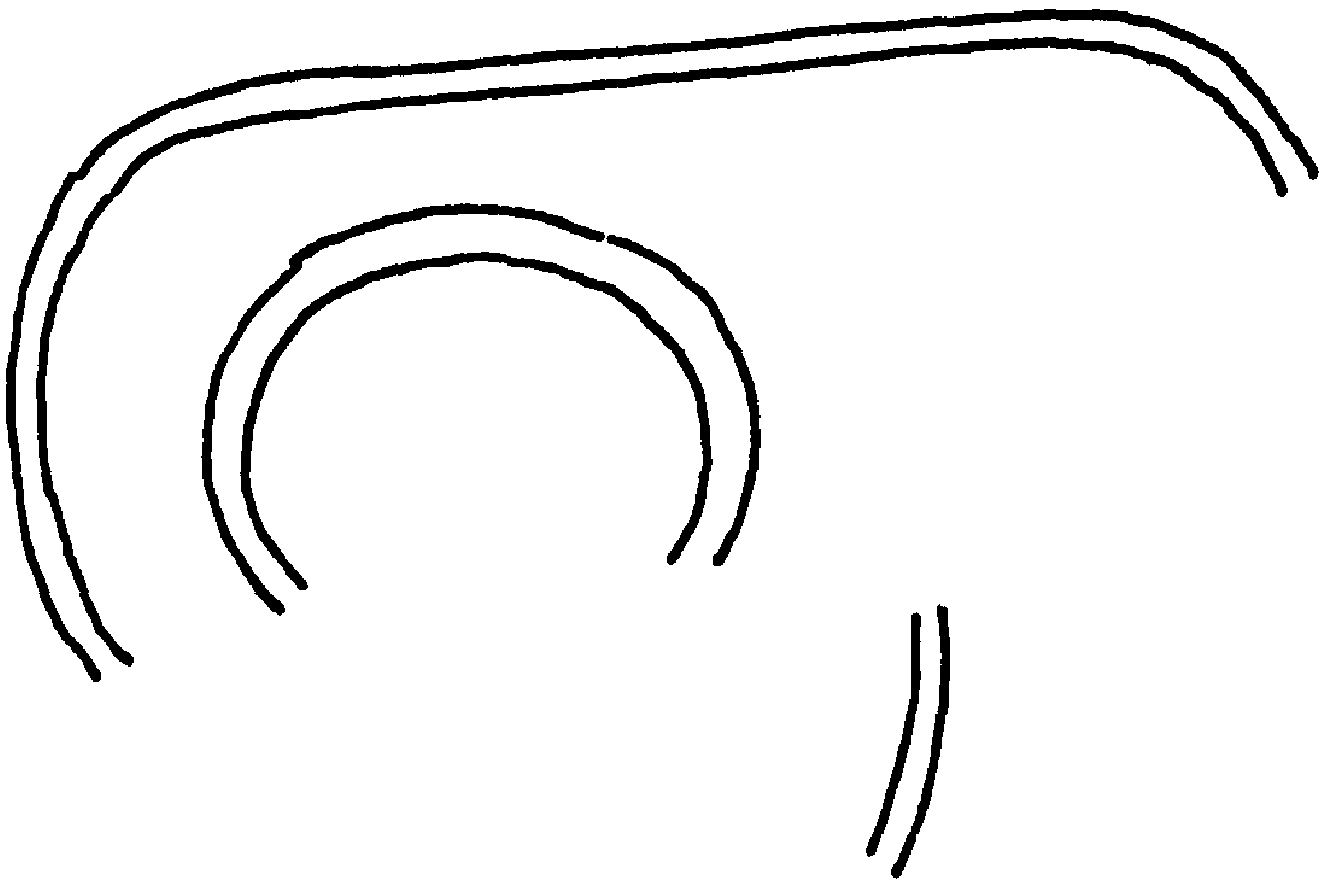


Fig. 68. Rubbing of the negative epirelief shows in Photo 111. Tentatively identified as <u>Spirophycus</u>. (Natural scale).

b) FACIES AND STRATIGRAPHIC DISTRIBUTION

Facies 6. Thin turbidite sandstones. Lower part of Pendle Grits.

c) ASSOCIATIONS

PLANOLITES

d) INTERPRETATION AND DISCUSSION

There is some doubt as to whether this structure is really a trace fossil. Whilst they bear similarities to structures figured by Rodriguez and Galschuck (1970) (compare Fig. 71 with their Fig. 5d), they may also have affinities with the vertical, annular, Arthrophycus burrows. Finally, they could even be small penetrative sandstone dykes since they occur low at a locality where indisputable sandstone dykes are common (Jenny Gill Quarry (SE00345092), Skipton Moor.

1.3 TRACE FOSSIL DISTRIBUTION AND ENVIRONMENTAL SIGNIFICANCE

So far, individual trace fossils have been identified, described and interpreted. These trace fossils and their relationship with the host sediment are now examined as potential palaeoenvironmental and palaeobathymetric indicators.

1.3.1 BATHYMETRY OF TRACE FOSSILS

Since Seilacher (1955, 1963, 1946b and 1967) divided trace fossil assemblages into bathymetric zones or ichno-facies (see table 12), other authors have recognised trace fossils in depth controlled communities (Farrow 1966; Ager and Wallace 1970; Chamberlain 1971a and b and Crimes 1973).

However, Osgood (1970), Frey (1971), Chamberlain (1971b) and Chamberlain and Clark (1973), caution that the trace fossil distribution is not strictly controlled by bathymetry, but by the zonation of oceanic conditions, e.g. aeration, sedimentation rates, currents, substrate type and nutrient availability. Also, it would appear that the ichno-facies do not possess sharply delineated boundaries (Osgood 1970). For instance,

Scoyenia facies	Non marine	Contains *Isopodichnus* and certain ichnospecies of *Planolites* and limulid trace fossils.
Skolithos facies	Littoral marine	Rapid sedimentation and erosion, shifting substrate. Contains *Skolithos* and *Monocraterion*, vertical protrusive and retrusive spreite structures.
Glossofungites facies	Littoral	Omission surfaces, stable substrates. Contains *Glossofungites*, well developed protrusive spreite resulting from growth of the producer.
Cruziana facies	Infra-littoral to circa-littoral	Well sorted sediments. Contains *Cruziana* and similar repichnia, plus inclined protrusive U-shaped spreite such as *Rhizocorallium*.
Zoophycos facies	Circa-littoral to bathyal	Impure silts and sands, no turbidite deposition. Contains tubular *Zoophycos* plus simple and efficient grazing trails.
Nereites facies	Bathyal to abyssal	Pelagic sedimentation. Trace fossils preserved mostly on bedding planes of turbidites. Contains *Nereites* and other efficient grazing trails.

TABLE 12

After Seilacher 1967, Frey 1971 and Hakes 1976.

Kern and Warne (1974) note that *Thalassinoides*, commonly used in the recognition of ancient shorelines, is now also found in deep water sediments in association with *Nereites*, *Zoophycos* and *Spirophycos*.

Hakes (1976) however, contends that even though forms may cross ichno-facies boundaries, they are still useful in palaeoecologic investigations. He advocates that the entire trace fossil assemblage must be taken into account and not just one member.

Bearing these qualifications in mind, this study attempts to demonstrate that Seilacher's original scheme can still be used as a working hypothesis. The scheme depends on the assumption that turbulent environments (i.e. shallow water) will exhibit vertical burrows of suspension feeders, whilst quiet (deep) water environments will exhibit dominantly horizontal trails of deposit feeders (Seilacher, 1967; Rhoads, 1967; Frey and Howard, 1970; Ager and Wallace, 1970 and Frey, 1971).

1.3.2 DISTRIBUTION OF TRACE FOSSILS IN THE SKIPTON MOOR GRITS

Figure 72 illustrates the vertical distribution of ichnogenera in the Skipton Moor Grits.

Pendle Grits. In the Pendle Grits, the preservation of trace fossils is almost always restricted to facies 6, Thin turbidite sandstones. Trace fossils in the interbedded argillaceous facies are extremely scarce and in the Bowland Shales, no trace fossils have been found at all.

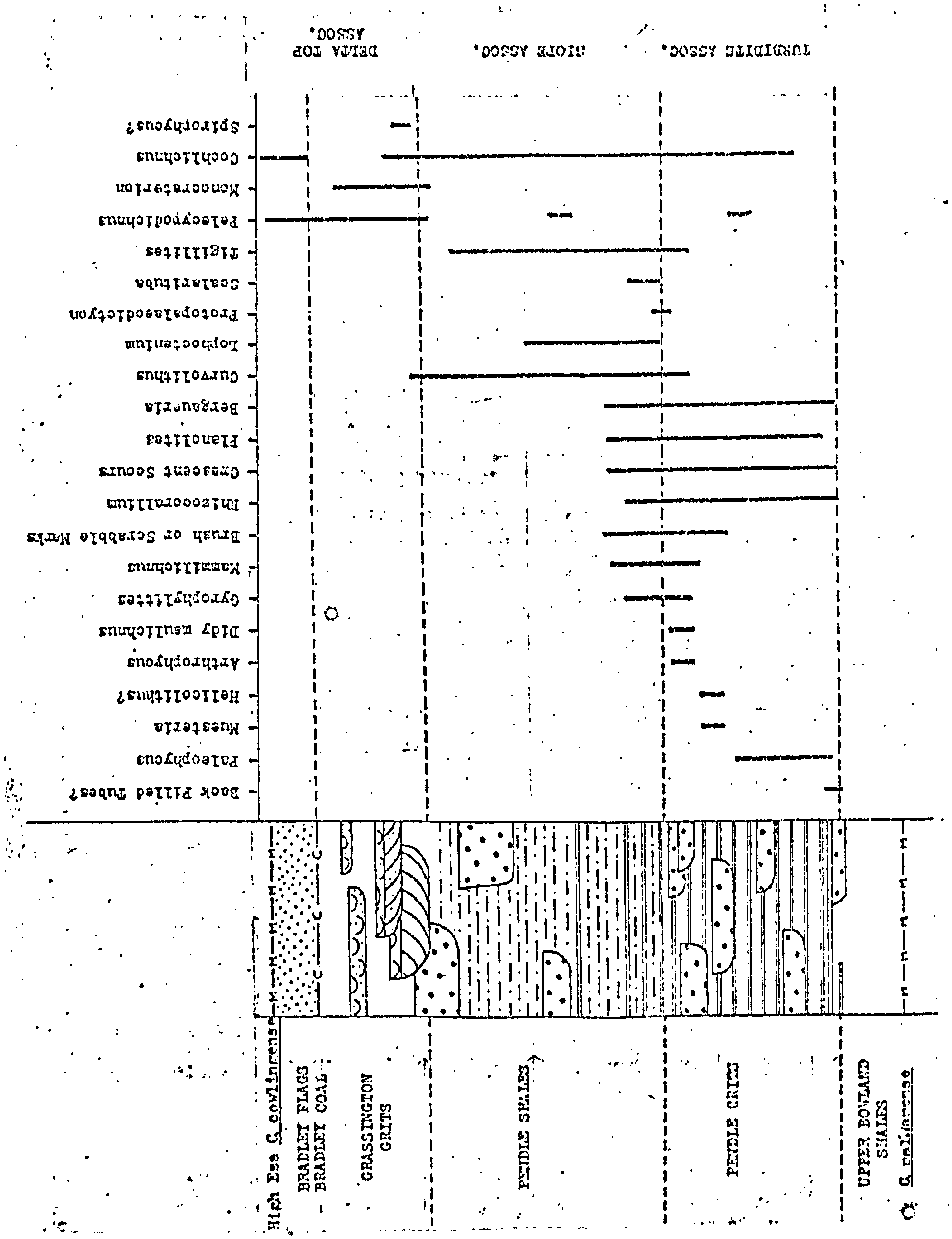
The commonest trace fossil found in the thin turbidite sandstones is Planolites; in fact, in several cases the linguoid ripples are almost obliterated by them. The preservation of Planolites as a hyporelief burrow depends on the thickness of the turbidite. It is generally absent on the bases of turbidites over 10 cm. thick. This limitation also applies to Cochlichnus, another extremely common trace fossil.

There are several other ichnogenera that are occasionally found on the thicker turbidites, e.g.Bergaueria, Didymaulichnus, ?Helicolithus and Protopalaeodictyon but these forms, with the exception of Bergaueria tend to be rare. Bergaueria can be found as extensive nests, with a density of up to 200 burrows per square metre.

Two ichnogenera of Rhizocorallium are present on the rippled tops of the turbidites. The short, globose and rectilinear Type B Rhizocorallium is found towards the base of the Pendle Grits, whilst the long meandering Type A Rhizocorallium is vertically more extensive and is also found in the lower part of the Pendle Shales.

In general, the organisms responsible for the above traces lived within or on the turbidite sandstone. However, the existence of 'Crescent Scours' as hyporeliefs on the turbidite sandstones indicate that there were

Fig. 72. Vertical distribution of trace fossils through the E_{1C} Skipton Moor Grits and the Bradley Flags.



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organisms living in the mudstones. Examination of the mudstones in direct juxtaposition with the soles of the turbidites fails to reveal the causal element of the Crescent Scour. (The debate on whether a form is pre- or post-depositional is extremely complex (cf. Ksiazkiewicz 1970) and is considered beyond the scope of this discussion).

Pendle Shales. Most of the trace fossils which occur in and on the facies 6, Thin turbidites of the Pendle Grits can also be found in turbidites of the lower part of the Pendle Shales. In addition new forms appear, e.g. Gyrophylittes and Tigillites.

However, with the introduction of progressively thicker developments of facies 4, Parallel bedded and striped siltstones, "full-relief" preservations become apparent and contrast with the semi-relief preservations associated with the facies 6, Thin turbidite sandstones. The full-reliefs occur on the splitting planes of the siltstones and are extremely numerous. Lophoctenium, Cochlichnus and Curvolithus are all common.

In those parts of the succession where thin turbidites and siltstones are interbedded, an extremely diverse assemblage can be collected (Fig. 27).

At the top of the Pendle Shales, immediately below coarse pebbly sandstones of fluviatile origin, Monocraterion and Pelecypodichnus are found in parallel bedded siltstones and facies 5, Cross-laminated sandstones. Monocraterion is found in a variety of preservational modes, often in association with Curvolithus and the ubiquitous Cochlichnus (Fig. 73).

Grassington Grits. Poor exposure of the finer grained facies of the Delta Top Association has prevented detailed examination and collection of trace fossils. Most information has come from loose scree or "float" material. In fact, only Pelecypodichnus and Monocraterion are thought to be present in any number.

(The preservation of a single Spirophycus-like epirelief, on what is interpreted as a facies 10, Large scale cross-bed foreset, is seemingly anomalous and is not yet understood.)

Fig. 73. Two measured sections through the top of the Slope Association.

Bradley Flags. Trace fossils in the Bradley Flags are described and interpreted in Appendix II.

1.3.3 INTERPRETATION

In the Pendle Grits, lithology has played an important role in determining the final distribution of the trace fossils. For instance, the complete lack of trace fossils in the mudstone facies is probably related to the non-recognition of structures because of their lack of colour and texture contrasts. Cullen (1973) has also suggested that in lithologies with a slow rate of deposition, any potential trace would be destroyed by interstitial meiobenthos (small scale biogenic activity). Similarly, trace fossils are absent in the facies 7, Composite sandstones and facies 9, Ropy weathering sandstones. Preservational factors concerning trace fossils in turbidites, such as grain size, bed thickness and flow regime have been fully discussed by Crimes (1970). He concludes that preservation potential increases in turbidites with a more distal aspect.

Seilacher (1962) has claimed that the lack of burrowing in the lower part of the very thick turbidites was evidence that the bed had been deposited from a "single-event" mechanism, i.e. a turbidity current. This has been substantiated by Piper (1973) who noted that in the case of recent thick turbidites, there was only a rare penetration of the bed which contrasted with the extensive bioturbation at the surface.

In the Pendle Shales, Lophoctenium is common and it has been suggested that it may be related to a flat spiral form of Zoophycos as figured by Kern and Warme (1974, Simpson (1970) and Chamberlain (1971a). Seilacher (1964 and 1967) believed that Zoophycos was characteristic of rocks deposited at intermediate depths (sic), i.e. between deep water Nereites facies and shallow marginal Skolithos facies. It is here suggested that both the Pendle Grits and the lower and middle parts of the Pendle Shales, correspond to Seilacher's Zoophycos facies. Although the original concept was for all turbidites and their associated traces to be designated as belonging to the *Nereites* facies, it is now apparent that the turbidites (and associated traces) in the Central Pennine Basin do not have the depth connotation as implied by Seilacher (bathyal to abyssal). (A full discussion is given in Chapter 6 of the suggestion that there are two major environments of turbidite accumulation, namely A/ at the foot of a fixed (continental) slope, and B/ at the foot of a prograding delta slope (restricted basin)).

With progradation of the Skipton Moor Delta, water depth decreased and in consequence, the general feeding style of associated organisms also changed. Instead of grazing (e.g. *Lophoctenium*, *Rhizocorallium* and *Curvolithus*), the organisms became suspension feeders (e.g. *Monocraterion* and *Pelecypodichnus*).

Pelecypodichnus burrows record the upward movement of bivalves whilst sedimentation proceeded (Eagar 1974). Both Hardy (1970b) and Eagar (1974) attributed the trace to *Carbonicola*, a fresh water bivalve which may well have had a fairly high tolerance to salinity. In the Central Pennine Basin, *Pelecypodichnus* traces have often been taken to indicate an environment associated with fresh to brackish water (Collinson and Banks 1975; McCabe 1975a & b; Guion 1973 and Eagar 1974).

The vertical extent of some *Monocraterion* burrows suggests either that sedimentation was rapid and the animal had to move quickly upwards to survive, or that the animal was forced to burrow deeply, in order to avoid ecologic stress, such as salinity changes, temperature fluctations and strong currents.

II.1 INTRODUCTION

In Chapter 2, it was decided that because of difficulties in stratigraphic and palaeontologic correlation, a full sedimentologic description of the Bradley Flags was necessary. The aim of this appendix is to compare and contrast the Bradley Flags with the E_{1C} Skipton Moor Grit Formation described above.

II.2 FACIES DESCRIPTION AND INTERPRETATION

II.2.1 FACIES A. MUDSTONES

Dark grey to black, homogeneous or laminated mudstone, the latter with abundant mica and macerated carbonaceous debris on the splitting planes.

These mudstones were deposited slowly from fall-out of suspended material in quiet water.

II.2.2 FACIES B. SILTSTONES

Light to very dark grey siltstones, ranging from well laminated to massive. Often gradational with the mudstones.

These were also deposited in quiet water, but in a more proximal environment than facies A.

II.2.3 FACIES C. RIPPLE CROSS-LAMINATED SANDSTONE

Fine to medium grained, buff sandstones with unidirectional cross-lamination. A trough form which develops a rib and furrow pattern on bedding planes.

These are the product of small ripples produced by currents in the lower part of the lower flow regime (Simons et al, 1965).

II.2.4 FACIES D. SINUOUS CRESTED SYMMETRICALLY RIPPLED SANDSTONES

Fine to medium grained sandstones which weather, either into "thin platy undulating sheets" (Type A), (Photo 116), or as thick (up to

30cm) resistant ribs (Type B), (Photo 117).

TYPE A. These rippled sandstones form sheets separated by thin veneers of argillaceous sediment which impart a dark sheen to many of the splitting surfaces. Each sheet duplicates the plan of the ripple below with the crest and trough of each layer directly above the one below. Pelecypodichnus and Cochlichnus (Photo 118) are both common (Fig. 74).

TYPE B. These ripples form units with a more massive appearance; the fine sediment drapes are absent. The ripple crests appear to be vertically offset giving a slight climbing effect. Photo 117 shows the ripples have an 'out-of-phase' plan with the occasional preservation of secondary crests (arrowed). Note also the elliptical pits of Pelecypodichnus escape shafts.

The sinuous crested symmetrically rippled sandstones are thought to have been formed by an oscillatory wave motion in comparatively shallow water. Harms (1969) has observed that oscillatory motion produces ripples that are both symmetrical sharp crested and which are comparatively continuous in ripple height and spacing. Since "falling stage" features such as "truncated or smooth tops and terraces" (Tanner 1962) are not found, this shallow water sand surface did not become emergent.

II.2.5 FACIES E. TABULAR CROSS-BEDDED SANDSTONES

Fine to medium grained, hard, light grey, well sorted sandstone. The cross-bedding occurs either as isolated sets, or as cosets; set thickness varying between 10 and 65 cm. The foresets are tangential to the lower bounding surface. The upper surface of solitary sets is sharp and often shows symmetrical round crested current ripples with average wave lengths and heights of 6.3 cm and 1.2 cm respectively.

This lithofacies represents deposition from migrating bedforms with currents in the upper part of the lower flow regime (Simons et al 1965). The upper surface is sometimes subject to wave modification, giving the current ripples on the upper surface.

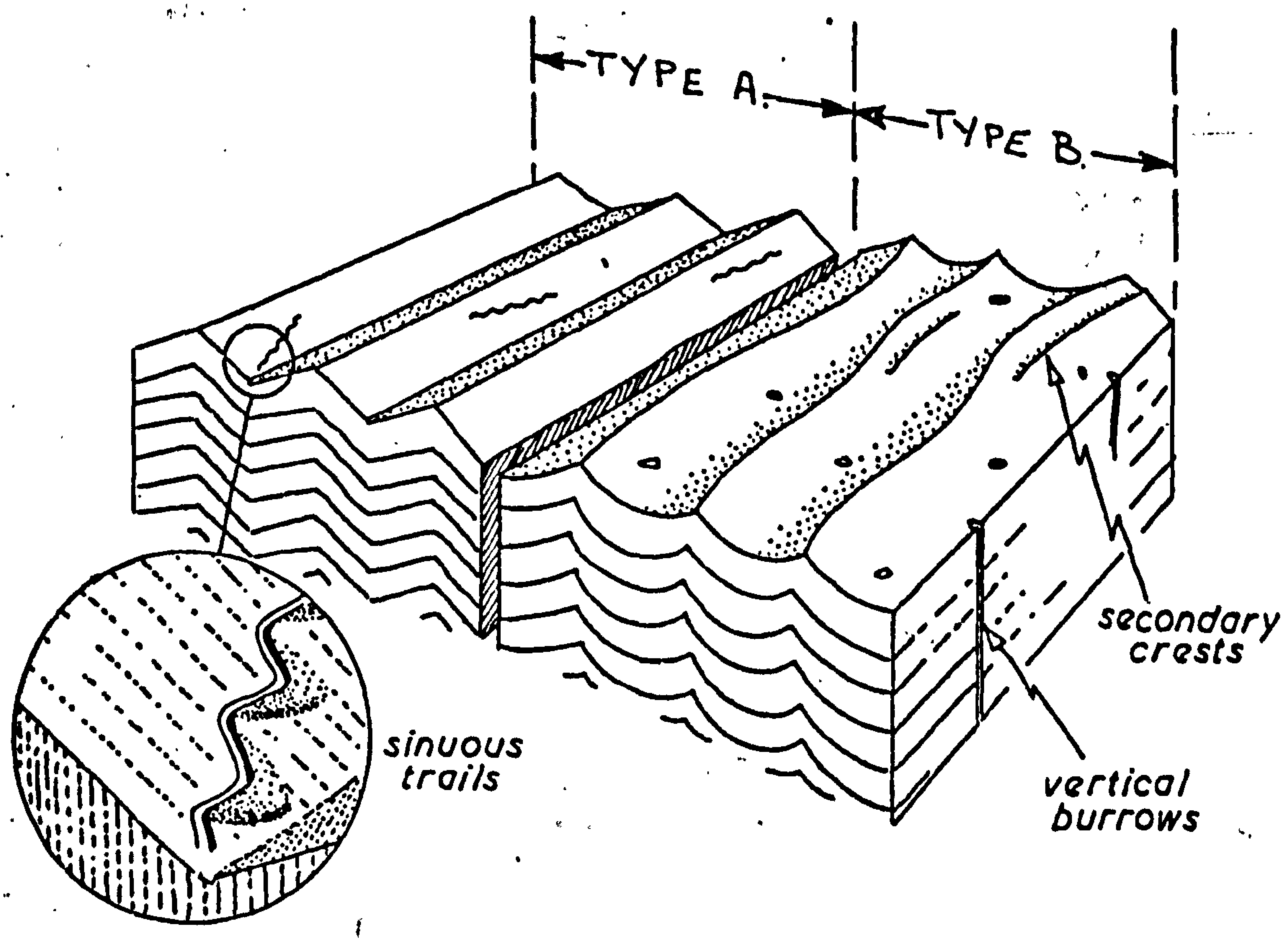


Fig. 74. Sketch of facies D, Sinuous crested symmetrically rippled sandstones (Bradley Flags) showing the two main varieties of rippling. The Type A (left) splits easily into "thin platy undulating sheets." (See Photo 116.) The preservation of a Cochlichnus trail is highlighted (Photo 118). Note that the movement of the organism down the slope caused minor avalanches at each turning point. Type B forms more resistant ribs (Photo 117). They also have occasional preservation of secondary ripple crests. Pelecypodichnus vertical escape shafts are also common. Specimens taken from High Edge Beck (SE025500), Skipton Moor.

II.2.6 FACIES F. MEDIUM TO LARGE SCALE ?KAPPA CROSS-BEDDED SANDSTONES

Fine to coarse sandstones (but not pebbly) are arranged in a series of cosets of cross-bedding. Average set thickness is 1m. Each set shows well developed bottom, fore and topset laminae, which show primary current lineation. In cross section, the sets pinch and swell to form a pattern of interlocking lenses which resemble bedforms categorised as Kappa cross-stratification (Allen 1963b), (Photo 119).

These cross-beds were probably deposited from fast migrating dunes. The flow is tentatively interpreted as being transitional between the upper part of the lower flow regime and the upper flow regime plane beds.

II.2.7 FACIES G. PARALLEL LAMINATED SANDSTONES

Fine to coarse grained sandstone with planar to slightly undulating horizontal lamination. Splitting planes show primary current lineation. One-metre units are typical (Photo 119).

Deposited as plane beds from a traction current. The primary current lineation indicates upper flow regime conditions (Allen 1964b & Simons et al 1965).

II.3 LITHOFACIES RELATIONSHIPS AND PALAEOCURRENTS

The Bradley Flags have a very limited distribution and in the present study they are only found on Skipton and Farnhill Moor (Enclosure G) and Cononley Moor (Enclosure H). Their thickest development is in the High Bradley area (approximately 52m). On Skipton Moor, three main exposures are described. From east to west these are:

II.3.1 High Edge (SE025500). In a stream section, immediately behind High Edge Farm, the following poorly exposed succession is seen. Downstream of the small bridge, facies A black, papery and 'fossiliferous' shales are seen in a small scarp on the west bank. This 'Edge Marine Band' contains a fauna regarded as High E_{2A} by Yates (1962). The shales are underlain by 5 to 6m of interbedded (facies A) black shales and (facies D) thin symmetrically rippled sandstones (Type B). These sandstones are very hard and form ledges across the stream.

This interbedded sequence is underlain by 3 to 4m of (facies D) symmetrically rippled sandstones (Type A). They are well exposed in a bluff on the west bank. The strike of the ripples is 090·270°. Pelecypodichnus and Cochlichnus burrows are common.

The underlying succession is poorly exposed and a 6 to 8m thick sequence of (facies A) mudstones is thought to be present. These mudstones rest on coarse pebbly grits, tentatively correlated with the top of the Grassington Grits.

II.3.2 Un-named tributary to Lister Gill (SE00924947) High Bradley.

The Edge Marine Band outcrops along the foot of a scarp of black 'paper' weathering shales in Lister Gill.

Immediately below the marine band, 4 to 5m of (facies E) tabular cross-bedded sandstones dip southwards at 20°. These sandstones are inter-bedded with thin developments of (facies A) mudstones and (facies B) siltstones. The section up the stream has been folded and faulted in places, and Fig. 75 shows the deformation of incompetent argillaceous facies with more competent arenaceous facies. The (facies E) sandstones show cross-bedding directed due south and occasionally show the crawling trace Nereis diversicolor (cf. Hantzschel 1940), (Photo 120 and 121).

II.3.3 Bradley Quarry (SE002489) Low Bradley.

This small, deep, water filled quarry shows a basal section of (facies F) ?Kappa cross-bedded sandstone estimated to be 18m thick. Field mapping suggests that these cross-beds are erosive into the underlying Grassington Grits, and the Bradley Coal is locally absent. These cross-bedded sandstones are overlain by (facies G) parallel laminated sandstones (Photo 119). The currents responsible for these bedforms flowed in an east-south-easterly direction (132° from 14 readings).

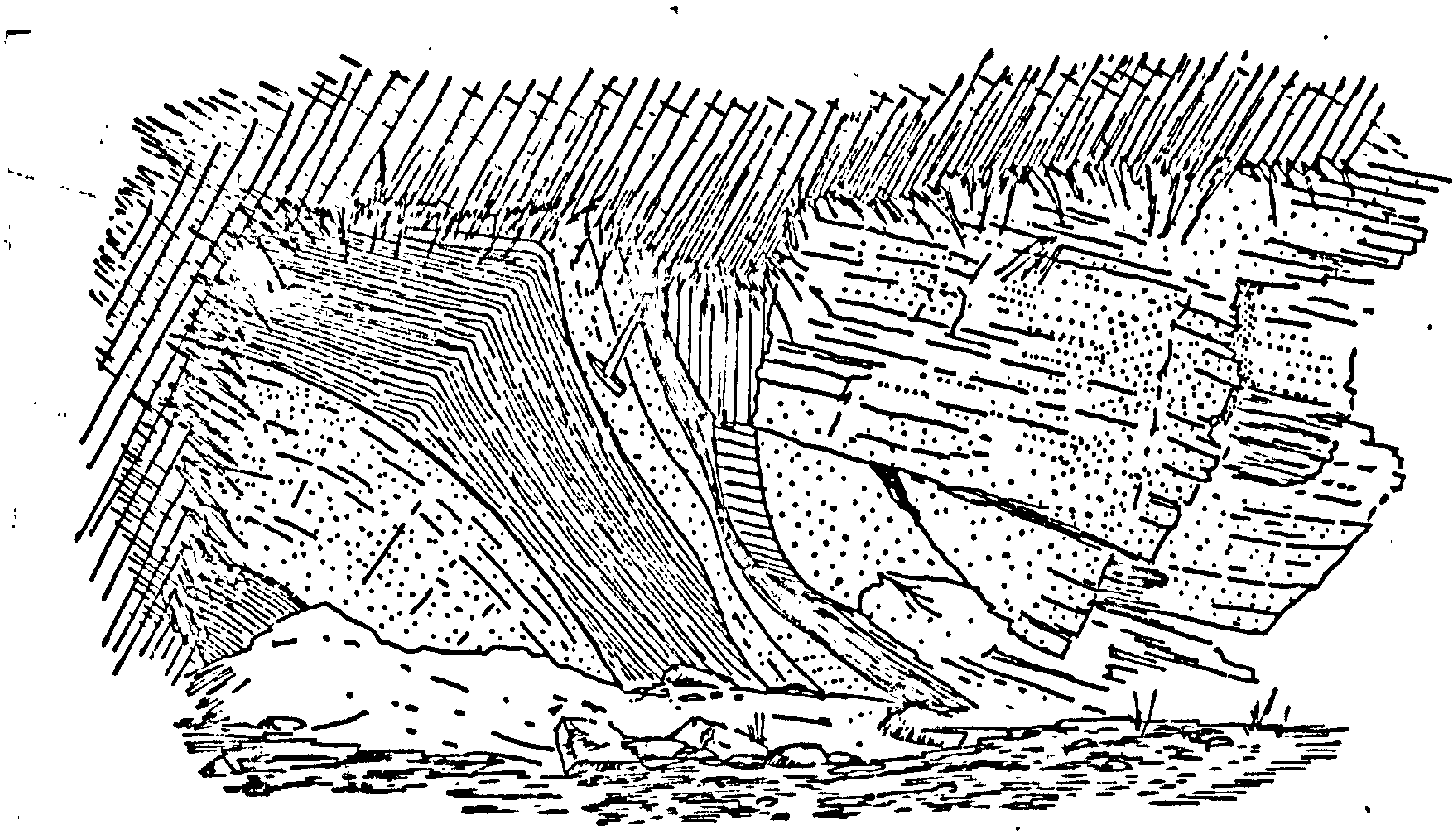
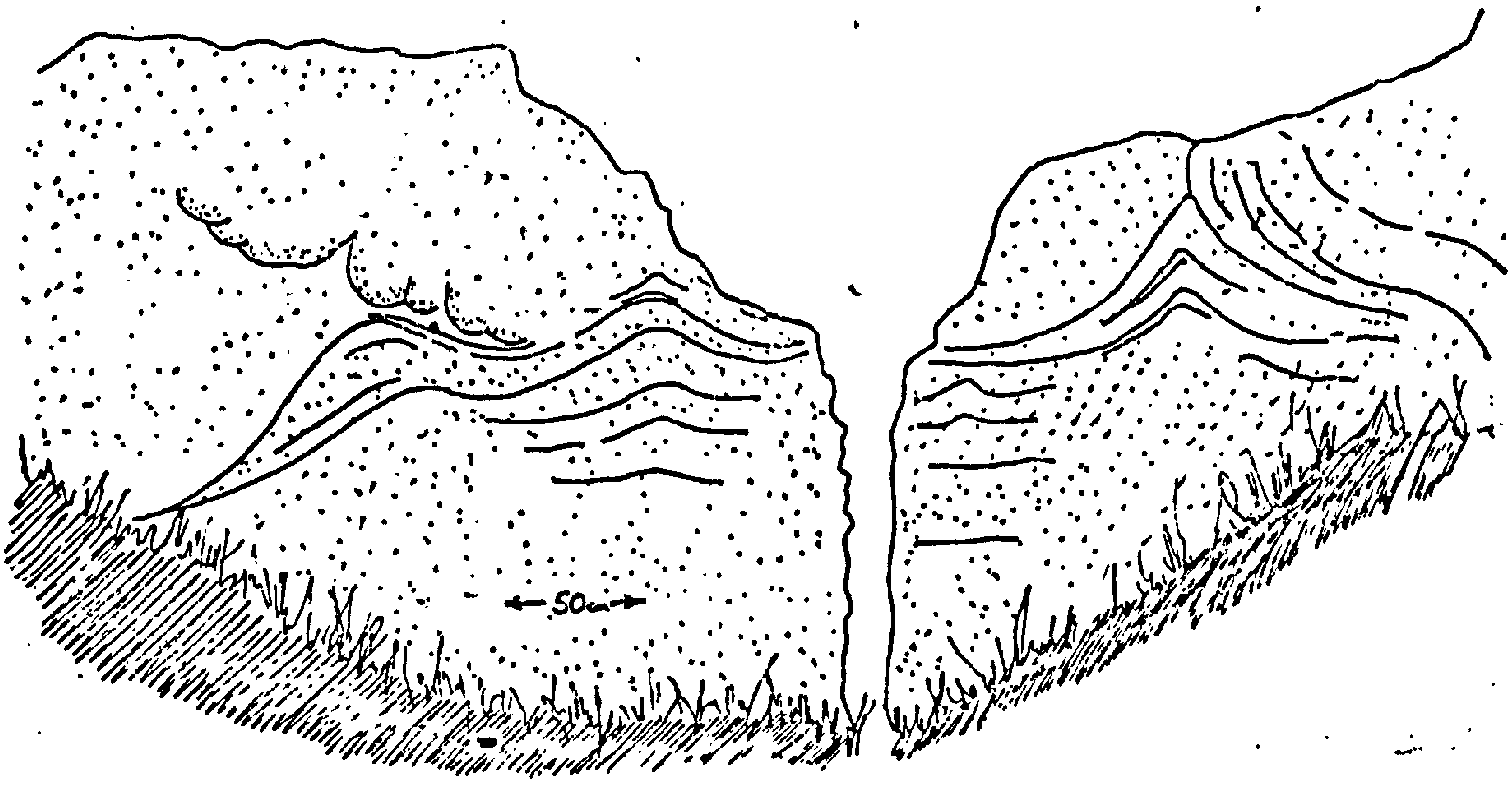


Fig. 75. Field sketch of a possible channel edge ? complicated by compaction. (Un-named tributary to Lister Gill (SE00884955), (Hammer, centre left, for scale). Bradley Flags.

Fig. 76. Field Sketch of dewatering structures in facies F, Medium scale ?Kappa cross-bedded sandstones. High Bradley Farm (SE00484956), Bradley Flags.



Minor outcrops of Bradley Flags occur in the fields to the north of High Bradley Farm and Back Lane (SE00484956). Here, cross-bedded sandstones (facies F7) were formerly worked as roadstones. Fig. 76 shows a detail of a dewatering structure at this locality.

Similar cross-bedded sandstones are seen on Cononley Moor in Oakhead Quarry (SW986470), and on Kildwick Moor (SE01254737), south of Bradley. On Kildwick Moor, the base of the Bradley Flags is believed to be erosive into the Grassington Grits, as the Bradley Coal equivalent is again absent.

II.4 INTERPRETATION AND DISCUSSION

The Bradley Flag sandstones are predominantly fine grained and this grain size contrasts markedly with the coarse, pebbly facies seen in the underlying Skipton Moor Formation.

A study of the (facies D) symmetrically rippled sandstones and (facies F) ?Kappa cross-beds also shows major contrasts. As has been noted, the only type of rippling seen in the Skipton Moor Grits is current rippling, even in the interdistributary sediments. However, the (facies D) ripples in the Bradley Flags are due to wave rippling.

In the case of the (facies F) ?Kappa cross-beds, the preservation of top-set beds and primary current lineation indicates unusually fast flow conditions. The exact origin of these bedforms is not understood. What is important though, is that these cross-beds are composed of a much finer material than the medium scale cross-beds seen in the Skipton Moor Grits.

The question is, where did the sediments come from? If they are due to reworking of the Skipton Moor Grits, what has happened to the coarser fraction? At the moment, this problem is unresolved, although it is tentatively suggested that they may be supplied from a more westerly source area. In this context, it is interesting to compare the Bradley Flags with the Namurian G_1 Haslingden Flags (Collinson and Banks 1975) which were also supplied from the west. The Haslingden Flags also differ from the typical Millstone Grit, in being finer grained, better sorted and having an unusual and a typical sand body geometry. Collinson and Banks leave the question of source open to discussion and conclude that only further regional and petrographic investigation will resolve the problem.

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