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Frontispiece

Durham Cathedral and Castle, standing above the incised meander of the River Wear. The peninsula is capped by the "Low Main Post" sandstone, which also forms the building material for the Cathedral.

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SEDIMENTOLOGY AND STRATIGRAPHY OF THE DURHAM COAL MEASURES, AND COMPARISONS WITH OTHER BRITISH COALFIELDS

by

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A thesis submitted to the University of Durham
for the degree of Doctor of Philosophy

Department of Geological Sciences October 1982

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ABSTRACT

A Westphalian (Coal Measures) sequence 900 m thick is preserved in the Durham coalfield of N.E. England, and includes the Westphalian A, B and C stages. This succession is condensed with respect to those of the central Pennine coalfields further south.

The Durham Coal Measures were deposited on a coastal, deltaic plain, characterized by having little or no relief. This plain was crossed by bifurcating distributary channels, which were separated by shallow water lakes and bays.

Trunk distributaries, probably of low-moderate sinuosity and perhaps 5 kms wide, fed sinuous major distributaries of up to 3 kms width. These in turn supplied minor distributaries, often sinuous in form, which were up to 100 m wide and fed shallow water deltas.

Interdistributary lakes and bays were generally less than 10 m deep, up to 20+ kms wide, unstratified and often anoxic. These shallow basins were infilled by crevasse splay and minor delta sedimentation.

Infilled lake and bay surfaces and abandoned channels were rapidly colonized by vegetation, and thick (perhaps up to 40 m) seams of peat were able to accumulate, often diachronously, over wide areas (100s of sq. kms).

During Namurian and Lower Westphalian times, lower delta plain conditions prevailed, in which interdistributary bays were open to marine influence so that deltaic sands could be reworked to form quartz arenitic shoreline sandstone bodies. As a result of southward deltaic progradation, this environment evolved into an upper delta plain which persisted through much of the Westphalian A and B, although during Upper Westphalian A times, the plain developed characteristics transitional to those of a fluvial plain. Occasional marine incursions caused only temporary drowning of the upper delta plain surface to 10-15 m depth.

Sedimentation was controlled on the large scale (100s of sq. kms) by patterns of deltaic sediment distribution, on the medium scale (10s of sq. kms) by a combination of structurally- and compaction-induced subsidence, and on the small scale by local sedimentary processes.

A comparison with other areas of Westphalian outcrop in Britain shows strong similarities to the depositional environment found in Durham.

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PREFACE

The research which forms the basis of this thesis was stimulated by the interest in the Coal Measures of my supervisors, Drs. A.P. Heward and G.A.L. Johnson. Initial aims were to provide a detailed three-dimensional, sedimentological study of the Durham Coal Measure sequence, using the excellent exposure provided by opencast coal workings.

With this in mind, systematic surveys were made of a number of opencast sites between October 1979 and October 1981, and supplemented by visits to other quarries and natural exposures. To obtain continuous coverage of opencast workings, it was necessary to work through two successive winters, but this was achieved with the help of comparatively mild weather.

At the same time, it was decided that a comparison with other British coalfields, particularly those of the northern Pennines, would serve to place the Durham area in its' regional Westphalian context and perhaps contribute towards a greater understanding of the British Westphalian environment. With this in mind, fieldwork was also undertaken on various areas of Westphalian outcrop in England and Wales.

It became apparent during the period of fieldwork that while detailed sedimentological conclusions could be made from the well-exposed opencasts, insufficient outcrop information was available for each stratigraphical interval to resolve the regional setting. It was thus decided to incorporate subsurface records, to facilitate the construction of palaeogeographical maps.

The thesis is divided into three parts; Part A provides an introduction and review of the topics relevant to a study of Coal Measure sediments, Part B is concerned with detailed description and interpretation of examined exposures in the Durham Coal Measures, and Part C comprises a comparison with other areas of Westphalian outcrop in Great Britain.

Part B is subdivided into Chapters and sections on the basis of stratigraphy, each interval considered separately to develop the theme of environmental evolution. Individual exposures are described and interpreted in as much detail as field data permits or justifies, while at the same time, a good deal of detailed description has been transferred to Text-Figures, Enclosures and Appendices to reduce the verbosity of Chapters 6-8. Sedimentary environments are summarized in Chapter 9, following the systematic treatment of exposures, and conclusions presented in Chapter 10.

Time has not permitted a detailed descriptive comparison between Durham and other areas, and so Part C of the thesis is necessarily short, and concerned with what I consider to be the most significant aspects of such a comparison.

With the aid of a good deal of field data, supported by subsurface information, the aims of research have been accomplished.

C.R. FIELDING
Durham
October 1982

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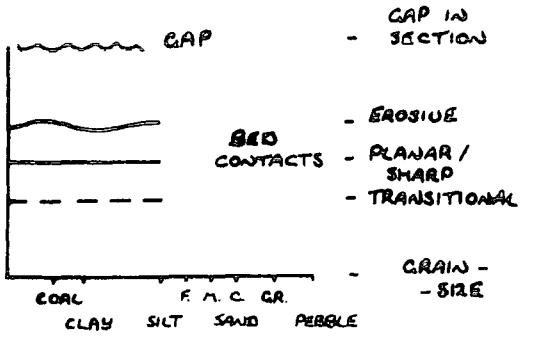
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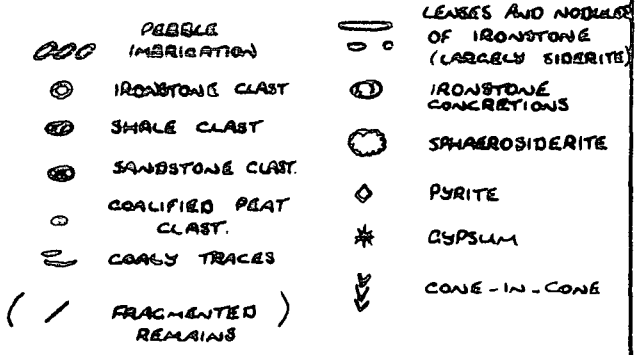
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APPENDICES

1. Graphic sedimentary logs
2. Petrographic data

KEY TO SYMBOLS USED IN GRAPHIC SEDIMENTARY LOGS






MASSIVE / UNLAMINATED


POORLY LAMINATED


LAMINATED


WELL - LAMINATED


IRREGULARLY LAMINATED


DISTURBED LAMINATION


"CRUMBLY" LAMINATION



FAULT



TECTONIC DISTURBANCE



DRIFT DISTURBANCE


MINERAL VEIN

CANNEL - CANNEL COAL

FUS. - FUSAIN

K.C. } - KAOLINITIC
F.C.R. } CLAYSTONES


TROUGH CROSS - BEDDING


TABULAR CROSS - BEDDING

EROSION SURFACE

RIPPLE CROSS - LAMINATION


CLIMBING RIPPLES.

BACKFLOW RIPPLES

RIPPLE FORM SETS

SILT FORM SETS

WAVE RIPPLES


"RIB - AND - FURROW"


INTERFERENCE RIPPLES


LADDER RIPPLES

P.C.L. PRIMARY CURRENT LINEATION

P.L. PARTING LINEATION


SINUSOIDAL RIPPLES


LOAD - CASTING


DRAG FOLDING


CONVOLUTE LAMINATION


DEWATERING STRUCTURES



SYNAERESIS CRACKS



DESICCATION CRACKS


NON - MARINE BIVALVES


" - IN LIFE POSITION


FISH REMAINS


LINGULA


MARINE FOSSILS


SPIRORBIS


OSTRACODS


ALGAE


TRACE FOSSILS


VERTICAL BURROWS

HORIZONTAL BURROWS


TRACKS AND TRAILS

PELECYPODICHNUS


STIGMARIA ROOTS


ROOTLETS


IN SITU CALAMITES


IN SITU LYCOPOD


DRIFTED FOLIAGE


DRIFTED PLANT STEMS


DRIFTED CALAMITES STEMS


VERTICAL CRACKS


MICROFAULT

DECLARATION

The content of this thesis is the original work of the author (other people's work, where included, is acknowledged by reference). It has not been previously submitted for a degree at this or any other university.

C.R.FIELDING

Durham

October I982

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PART A

INTRODUCTION AND REVIEW

CHAPTER I - INTRODUCTION

1:1 THE AIMS OF THE THESIS

The principal aim of this thesis is to describe and interpret the sequence of sedimentary rocks comprising the Coal Measures (Westphalian, Upper Carboniferous) of the Durham coalfield between Tyne and Tees. To this end, data has been collected from numerous natural exposures, quarries and opencast coal operations throughout the period from October 1979 to October 1981.

It is also intended to describe Westphalian sequences in adjacent areas, notably Northumberland, Midgeholme, Stainmore and Cumbria, to aid a more general understanding of the Westphalian environment in northern England.

Finally, it is proposed to consider coal-bearing sequences of similar age in other parts of Great Britain, hopefully to provide a comparison of preserved successions and depositional settings.

N.B. "Coal Measures" and "Westphalian" are taken as being synonymous for the purpose of this thesis.

1:2 THE AREAS OF STUDY

1.2.1 Durham

The Durham coalfield, the principal area of study, lies in the north-east part of England, between the counties of Northumberland to the north, Cumbria to the west and Cleveland and North Yorkshire to the south (Figs. 1.1, 1.2).

The area of Westphalian outcrop, governed principally by an eastward tectonic dip, is restricted to a broad, north-south-trending

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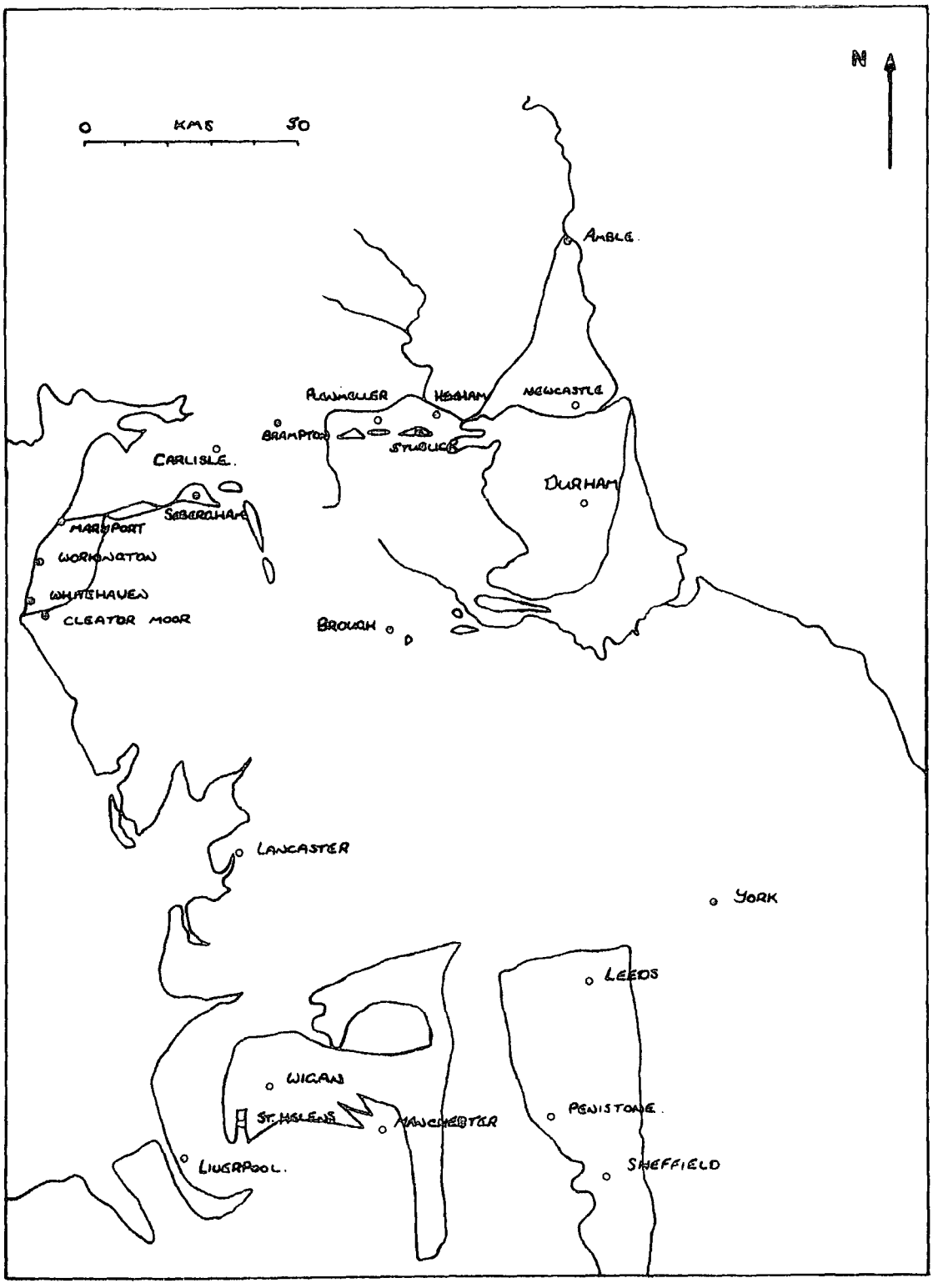
Fig.I.I

MAP OF THE BRITISH ISLES, SHOWING THE AREAS OF STUDY



Fig.I.2

DETAILED MAP OF THE NORTH OF ENGLAND, SHOWING THE PRINCIPAL AREAS OF INTEREST



strip some 1100 sq. kms in area. To the west, the Coal Measures are underlain by a Namurian sequence of sediments, and to the east are overlain by Permo-Triassic deposits.

The Durham area has a long history of coal-mining, from at least Mediaeval times. There are numerous records of coal exploitation by the monks of the area, dating back to 1188 (Simpson, 1910) and the first recorded colliery lease was given by the Prior of Durham in 1447. From this time onward, coal-mining gained impetus, until County Durham was one of the most important household coal-producing regions in Britain. Coal was exported from the sea-ports of Newcastle, Sunderland and Hartlepool, among others, to London and other parts of the country.

In 1821, the first coal was extracted from beneath Permian cover in the eastern part of the county and a previously unexploited area was thus opened up. After the middle of the 19th century, the household coal trade declined as the railway network connected London with other nearer coalfields, but in its place grew a demand for coking coal to supply a rapidly expanding iron and steel industry (Smailes, 1935; Galloway, 1904).

After the First World War, the coal-mining industry contracted, particularly through the economic depression of the 1920s and 1930s. Following nationalization of the industry in 1947, more and more collieries were closed until, at the present day, only a handful remain. (Reviews of mining development are given in Smailes (1935) and Smith and Francis (1967)).

However, during and since the Second World War, with the development of large earth-moving machinery, there has been a steady increase in interest in opencast coal exploitation and this is currently thriving at a time when colliery working has all but ceased.

1.2.2 Northumberland

The Northumberland coalfield is an extension of that in the Durham area, together named the "Great Northern Coalfield". As with Durham, the outcrop comprises a north-south-trending belt totalling 550 sq. kms in area, bounded by Namurian strata to the west and the coastline to the east. The width of the outcrop belt tapers northward from 25 kms at Newcastle to Nil near Amble, some 45 kms further north (Figs. 1.1, 1.2).

Northumberland has arguably the longest history of mining in the British Isles, with records dating back to Roman times, and certainly the lengthiest record of commercial exploitation. The development of the coalfield is similar to that in Durham (Smailes, 1935), right up to the present day, with opencasting currently the principal method of extraction.

1.2.3 Midgeholme

A number of small (up to 40 sq. kms in area) faulted outliers of Coal Measure rocks occur on the south side of the upper S. Tyne valley between Hexham and Brampton (Figs. 1.1, 1.2). These are mostly elongated east-west, and consist of southward-dipping Coal Measures, underlain by Namurian strata to the north, and terminating abruptly against faulted margins to the south. The major fault boundaries to these outliers form part of the Stublick-Ninety Fathom fault system, an important regional structural lineation. Of the various areas, those at Stublick and south of Plenmeller are the most significant, and have supported mining enterprises in the past. Opencast extraction in this region is due to commence in the near future.

1.2.4 Cumbria

On the northern edge of the Cumbrian mountain range lies an arcuate outcrop belt of Coal Measures, about 275 sq. kms in area (Figs. 1.1, 1.2). This stretches northward along the coast from around Cleator Moor to Maryport, continues in a more easterly direction inland to around Sebergham, and then swings southward along the western side of the Vale of Eden. The Coal Measure sediments are underlain by a condensed and truncated Namurian sequence, and overlain by Permo-Triassic sediments.

In many ways, the Cumbrian coalfield has had a similar history of development to that of Northumberland and Durham, though not as long. Coal exploitation is believed to have begun in the 16th century and spread rapidly (Moore, 1905). The geographical location of the area, the large reserves of coal and a nearby supply of iron ore led to a very prosperous development after the industrial revolution, with shipbuilding and iron and steel manufacture making a prominent contribution.

As with the other coalfields of Great Britain, coal-mining fell into decline after the Second World War, and only one colliery remains working at the present time. Coal exploitation in the most recent past has turned, as with Durham, toward opencast working. A limited number of opencast coal sites are currently working in West Cumbria, but are beset by severe problems of faulting and deterioration of coal quality.

1.2.5 Stainmore

On the western slopes of the Pennine mountain range, near Brough-under-Stainmore, lies a small (1.5 sq. kms) outlier of Coal Measures (Figs. 1.1, 1.2). Here, Coal Measures dipping to the east are underlain by Namurian strata to the west and terminated by two

major north-south-trending faults to the east. Coal has been extracted in the past from several adits and small pits. Records of development are, however, very poor.

1.2.6 Other Areas

In addition to these main areas of study, observations were made in various other parts of Britain where Coal Measure rocks are exposed (Figs. 1.1, 1.2).

These are: (1) South Yorkshire - the area around Penistone, 16 kms north of Sheffield.

(2) Lancashire - the area around St. Helens and Wigan.

(3) Pembrokeshire - the areas of the Littlehaven-Amroth and Nolton-Newgale coalfields.

1.3 THE NATURE OF THE EXPOSURE

The coalfields of Great Britain are, characteristically, poorly exposed, except where the area of outcrop forms part of the coastline. In the Durham area there is no coastal exposure and, there being no major escarpments, the only substantial natural exposures lie along the courses of the larger rivers. Fortunately, these are supplemented by numerous excavations for sand and sandstone, clay, ganister and coal, which create quarry faces of various sizes, and also by exceptional exposures in opencast coal sites.

It has been the author's privilege to visit a number of opencast workings at intervals throughout their active lives, and the data obtained from these visits forms the main part of this thesis. It is relevant at this stage to give a brief description of the opencast method of working.

The first phase of working an opencast site involves the removal of topsoil, subsoil and unconsolidated deposits to expose the outcrop of solid rock, or "rockhead" (Plate 1.1). Following this, strata overlying a coal seam are removed in blocks or long strips, exposing the surface of the coal roof (Fig. 1.3), (Plate 1.2). After all traces of other sediment have been removed from the roof surface, the coal seam is broken up and transported away (Plate 1.3). Excavation may then continue to greater depth, if it is considered economical to work a deeper seam.

The depth of excavation will vary according to several factors, among them the number, thickness and quality of coal seams, the ratio of total coal thickness to total stratal thickness minus coal thickness in a section, the stability of rock faces, water seepage and the density of old workings in coal seams (Plate 1.4).

As mentioned above, masses of rock and coal are usually removed in long strips, called "cuts", which give an ordered progression to the operation. As one cut is excavated, the spoil is dumped in the void left by the previous one (Plate 1.5). After the excavations are complete, all remaining voids are filled with rubble, and the subsoil and topsoil are relaid across the ground surface, thus restoring the land to its former status and value as far as possible.

Opencast cut walls provide excellent, though only temporary, exposure of Coal Measure sediments in the Durham area. Furthermore, by visiting sites at intervals, as the excavations progress across the site area, an understanding of the sedimentary record in three dimensions may be gained (See Chapter 1:5).

Coal Measure outcrops in the other areas considered vary greatly in character. In the Stainmore and Stublick/Plenmeller areas outcrops are predominantly in stream beds, and typically of low quality. In

EXAMPLE OF AN OPENCAST WORKING PLAN. Fig.I.3

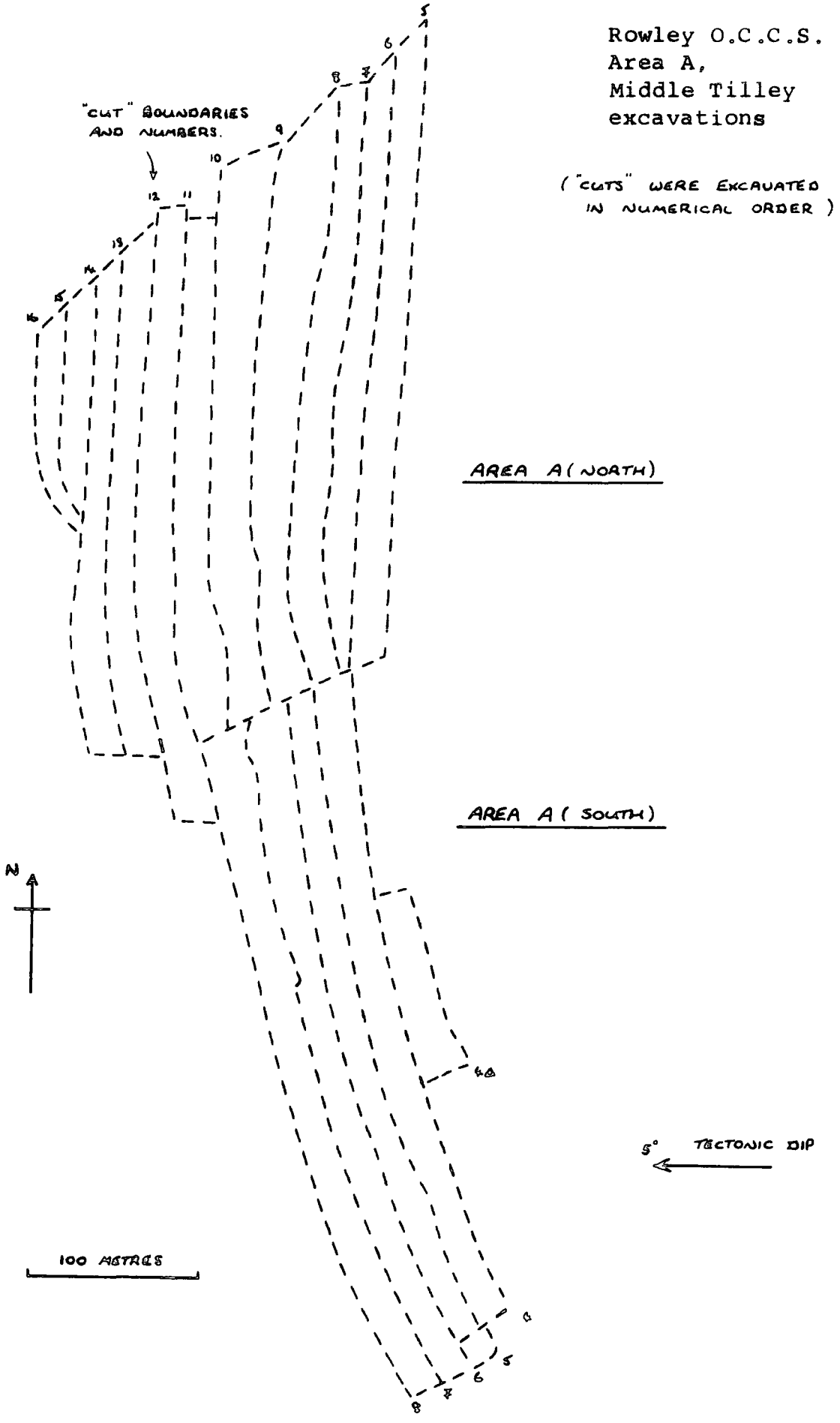




Plate I.I - Panorama of Tanners Hall O.C.C.S., facing north, showing stripping and excavating operations.



Plate I.2 - View of an opencast "cut" - Area D, Deborah O.C.C.S.



Plate I.3 - View showing removal of coal from an opencast cut - Hutton seam, Wooley O.C.C.S.



Plate I.4 - "Pillars" of coal left by old mining operations, exhumed during opencasting - Bottom of Broomhill seam, Acklington Extension O.C.C.S.



Plate I.5 - View showing excavation of solid rock, and dumping of rubble in earlier "cuts" - Mown Meadows O.C.C.S.

Northumberland a combination of opencast and natural coastline exposure gives excellent quality, though only a limited number of outcrops. In Cumbria a great variety of outcrop type occurs, varying from large opencasts and coastal cliffs down to small, poorly exposed stream sections.

The exposures examined in the Pembrokeshire coalfield were all coastal cliffs, creating superb continuous exposure, but with limited lateral control. In South Yorkshire and Lancashire, quarry excavations for clay, coal and sandstone were found to give good quality exposure. Opencast workings also occur in these last two areas, but detailed study has not been possible.

1:4 METHODS OF WORK

Standard techniques for recording information in the field were employed in the course of this study, notably the construction of vertical sedimentary logs, notes on lateral consistency or variability of sediments, and the extensive use of field sketches and photography.

Sections were logged using a metre tape, and drawn on cm graph paper at various scales (typically 1:100), according to the purpose and degree of detail required. Opencast exposures were visited at intervals to observe the progressive advance of faces.

Palaeocurrent measurements were taken extensively, and were of great importance in the construction of sedimentary models. Where significantly affected by tectonic dip, measurements were rotated back to the horizontal plane by stereographic methods. Vector means were calculated after the method described by Curray (1956).

Samples collected in the field were studied using polished slab sections, thin sections, X-ray diffraction and Scanning Electron Microscope techniques.

Field observations were supplemented by borehole and other data from N.C.B. and I.G.S. archives.

Literature surveys were undertaken on modern and ancient fluvial, deltaic and coastal sedimentary environments, with emphasis on coal-forming settings, to provide a basis for comparison and an assessment of previous research.

1:5 FACIES ANALYSIS - DEVELOPMENT AND APPLICATION

The science of sedimentology can be said to have moved into its modern stage of development during the 1960s. During this time, two major developments took place which allowed detailed interpretation of sedimentary sequences to be made, surpassing previous work which was largely descriptive.

Firstly, laboratory experiments using flume tanks, to aid an understanding of the processes involved in depositing sediment, were related for the first time to sedimentary structures and sequences preserved in the rock record (Simons, Richardson and Nordin, 1965; Harms and Fahnestock, 1965). During the same period the numbers of published descriptions of modern sedimentary environments grew significantly. With this increased understanding and awareness of sedimentary processes and environments, came the advent of facies analysis.

The concepts of facies and facies analysis were not new in the 1960s. The term "facies" was coined by Amand Gressly in 1838, who, while working on the geology of the Jura mountains, noticed significant variations between the lithologies of a single formation. "In the regions that I have studied, perhaps more than anywhere else, very variable modifications, both petrographic and palaeontologic, everywhere interrupt the universal uniformity that, up until now, has been maintained for different stratigraphic units

in different countries ... there are two principal points that always characterize the group of modifications that I call facies or aspects of stratigraphic units, one is that a similar petrographic aspect of any unit necessarily implies, wherever it is found, the same palaeontologic assemblage; the other, that a similar palaeontologic assemblage rigorously excludes the genera and species of fossils frequent in other facies."

Towards the close of the 19th century, Walther (1894) was possibly the first to realize the full implications of the concept, with his "Law of the Correlation of Facies". Walther wrote "the various deposits of the same facies areas, and similarly the sum of the rocks of different facies areas, are formed beside each other in space, though in cross-section we see them lying on top of each other ... it is a basic statement of far-reaching significance that only those facies and facies areas can be superimposed without a break that can be observed beside each other at the present time." Walther called this correlation of facies "comparative lithology". In the following years, his work was largely ignored by Western European and American geologists, although "comparative lithology" enjoyed popular usage with Russian sedimentologists.

The subject of facies, however, recieved rather more attention in the Western world. Numerous authors chose to change, modify or subdivide Gressly's original definition (e.g. Caster, 1934; Moore, 1949), until the term had almost as many meanings as it had adherents.

In 1958, Teichert, reviewing the concept of facies, denounced the ambiguous contemporary usages of the term, and argued that the original definition was wholly adequate in containing Gressly's concept. This work heralded a change of ideas on the facies concept, and a renewal of interest in comparative lithology, or facies analysis.

Visher (1965) re-emphasized the importance of Walther's work, pointing to the possibilities of using vertical sequences in facies analysis. By this time, numerous attempts at environmental interpretation of sedimentary sequences, of one variety or another, had already been made. However, early facies interpretations failed to appreciate the significance of Walther's reference to "sequences without major breaks."

Clearly a break in the succession may represent the deposition and subsequent erosion of any number of "facies", and render any attempt at evaluation of a "continuous facies sequence" invalid.

Many such interpretations of deltaic sediments appealed to the crudely cyclic nature of sequences, and erected models based on "cyclothems" (Wanless and Weller, 1932). The cyclothem approach has been widely criticised on three grounds:-

(1) the nature of the junction between lithological units is ignored or not reported,

(2) sequences may be forced into particular cycles, and there is a tendency to correlate cycles on very tenuous evidence, and

(3) the "ideal" cycle overlooks many of the complexities of actual sequences, leading to oversimplification of the causes of sedimentation and bias of opinion in interpretation (Reading, 1971).

De Raaf, Reading and Walker (1965), describing a cyclic succession of Westphalian sediments in south-west England, redrew attention to the significance of breaks in sedimentation, and to that of contacts between depositional units. In this study, a Formation was divided into facies on the basis of "lithological, structural and organic aspects detectable in the field."

This usage is in accordance with Gressly's original concept;

the facies will ultimately be given an environmental interpretation, but the definition itself is quite objective. The above is currently the most commonly used sense of the term, reiterated by Reading (1978):- "a facies is a body of rock with specific characteristics."

During the latter half of the 1960s, and the 1970s, facies interpretation as applied to fluvial and deltaic sediments drew away from the rigid cyclothem approach and became more integrated with the ever-increasing mass of data on modern environments. As the subject of facies analysis developed, it became apparent that simple models for broadly-defined sedimentary environments were of questionable validity. In the case of fluvial sediments, this was summarised by Jackson (1978) and Walker (1978), among others.

The most recent generation of facies models has taken into account the almost continuous range of variation between, and also within, so-called "end members", and has attempted to identify features of particular environmental significance for use as palaeo-environmental indicators (e.g., Walker, 1979). There has also been a recent trend in fluvial sedimentology towards investigation of the structure or "architecture" of entire sequences (e.g., Leeder, 1978).

Very recently, Miall (1981) drew attention to the continuing need for more detailed case studies, to help reach a full appreciation of nature's infinite variety. It is only from the widest possible data base that the method of facies analysis can hope to solve problems of environmental interpretation.

The success or validity of a facies interpretation depends to quite a large extent on the amount and nature of data available. Data collected from observations on sedimentary sequences may be of

three types:-

(1) one-dimensional, i.e., borehole information and stream sections where lateral control is non-existent,

(2) two-dimensional, i.e., from a cliff, quarry or other rock face, where both a vertical and horizontal component may be evaluated, allowing lateral control in one direction, and

(3) three-dimensional, from either changes in direction of rock faces or from a series of adjacent, possibly parallel, rock faces.

There are very few, if any, documented, truly three-dimensional case studies of sedimentary sequences, since such a study inevitably requires the removal of large quantities of rock!

The British Coal Measures have caused great problems in environmental interpretation, due partly to the former rigid cyclothemic method of analysis, and partly to the inability of two-dimensional exposure to provide a unique interpretation to a given case.

With the added reliability from inclusion of a third dimension, it is hoped to present a facies model for the depositional environment of a Coal Measure succession which is considerably less beset with ambiguity than previous attempts.

CHAPTER II - THE BRITISH COAL MEASURES

2.1 INTRODUCTION:- THE COAL MEASURES ENVIRONMENT

The Westphalian Coal Measures comprise the major coal-bearing sequence in Britain, and isolated remnants of these once nearly continuous deposits now form the various separate coalfields (Fig. 2.1). The Coal Measures are thought to have been laid down on a broad, flat, "paralic", coastal, deltaic plain, which stretched across what is now northern Europe and part of North America. This environment has never been repeated on the same scale in the geological record, and represents a somewhat unique coincidence of conditions suitable for the widespread accumulation and preservation of coal seams.

Recent palaeogeographical maps (Wills, 1951; Calver, 1969; Lovell, 1978; Ziegler, 1981) have shown that much of what is now central and southern Britain was situated on this east-west-trending coastal plain, which was characterized by having almost no relief. Only in certain areas was the ground surface elevated to form topographic highs, in many cases structurally inherited from the Caledonian orogeny (Fig. 2.2). Topographic highs are believed to have existed :

(1) in the Southern Uplands of Scotland,

(2) between Cumbria and the Isle of Man,

(3) in North Yorkshire, and

(4) between Wales, London and the Brabant region of Belgium,

though there is little agreement between authors as to the configuration or even existence of some of these landmasses.

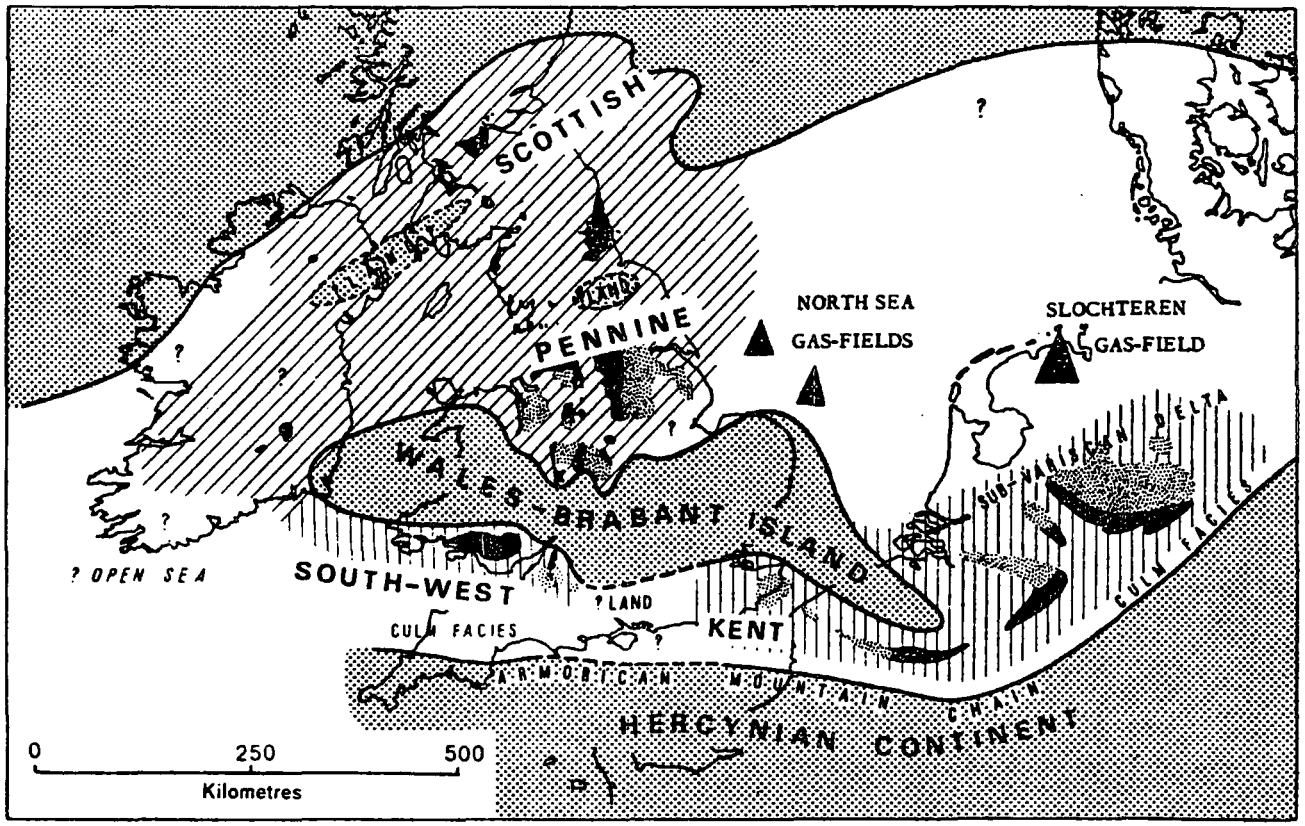
Fig.2.I

BRITISH WESTPHALIAN COALFIELDS AND DEPOSITIONAL PROVINCES (After Calver, I969)



Fig.2.2

LOWER WESTPHALIAN PALAEOGEOGRAPHY OF THE BRITISH ISLES
AND ADJACENT REGIONS
(AFTER WILLS, I95I AND CALVER, I969)



Large scale palaeogeographical reconstructions (for example, Scotese *et al.*, 1979; Johnson, 1981) place the Westphalian coastal plain in the tropics, possibly five degrees north of the equator, though agreement on this point is not total (Turner and Tarling, 1975). That weather conditions were (at least periodically) wet is evidenced by the abundant remains of vegetation preserved in the sedimentary rocks. The commonly-accepted climate for Westphalian times in Britain is humid tropical or subtropical (Schopf, 1973). Rather less well-accepted is the hypothesis that the predominant climate was seasonless, based on the lack of growth rings in preserved remnants of Westphalian trees, but see discussion in Scott (1976, Chapter 7).

Despite being undoubtedly a thriving ecosystem, the Coal Measures contain a comparatively poor record of faunal remains. This is due, at least in part, to the acid pore-water conditions prevalent during the deposition and burial of the sediments not being conducive to carbonate shell and phosphate preservation. The floral record, on the other hand, is very good, due both to prolific plant growth during Westphalian times and the predominance of reducing conditions favourable for preservation of plant material. The fossil record, stratigraphy and structure of the British Westphalian is considered in Chapter 2.2.

The Westphalian plain was crossed by a large number of channels carrying sediment from a postulated source in the north, to the "Upper Carboniferous Sea", lying to the south of Britain (Anderton *et al.*, 1979). However, despite a wealth of literature relating to descriptions of sequences and stratigraphy, comparatively little work has been done, until recently, on sedimentary environments. Previous

sedimentological studies of the Coal Measures are discussed in Chapter 2.3.

2.2 PALAEONTOLOGY, STRATIGRAPHY AND STRUCTURE

The first stratigraphic correlations of the British Westphalian Coal Measures were based entirely on lithological comparison. Use was made of prominent sandstones, coal seams and seatearths, as well as occurrences of more unusual lithologies, such as ironstones.

In the 19th century, the presence of marine fossil horizons was noted, and these "marine bands" became useful in stratigraphical correlation (Phillips, 1832; Looney, 1836; Binney, 1860). The first application of the concept to coalfield correlation was by Stobbs (1905) and Gibson (1905) in Staffordshire, and was swiftly followed by others.

Many descriptions of faunal assemblages and successions within these marine bands were subsequently made, and these have been reviewed by Calver, (1968a, 1969). Several marine bands are traceable across the British Coalfields and some even across parts of Western Europe. Recognition of a particular horizon may depend on the overall composition of a faunal assemblage, the vertical succession of faunal remains through the unit, or even on a particular species of very limited occurrence.

Marine bands of the Pennine Basin of northern England occur as belts or zones around the area of maximum basinal subsidence, i.e., Lancashire-South Yorkshire. The zones are arranged such that the marine development is at a maximum in the basin centre, where marine bands are thickest, and poorest in marginal areas. This areal pattern is often mirrored in the vertical sequence, which records the development and decline of

the marine incursion in a series of faunal "phases" (Calver, 1968a, b), (Fig. 2.3). Fully marine faunal phases are often characterized by the presence of goniatites, brachiopods, bivalves, gastropods, nautiloids and other forms.

Marine bands are of considerable use in correlation, and are employed to mark the boundaries of the major modern divisions of the Westphalian sequence (Fig. 2.4). They are not uniformly distributed throughout the stratigraphical succession, however, being concentrated in two groups. The first of these groups lies in the lowermost part of Westphalian A, and the second one at around the level of the Westphalian B/C boundary.

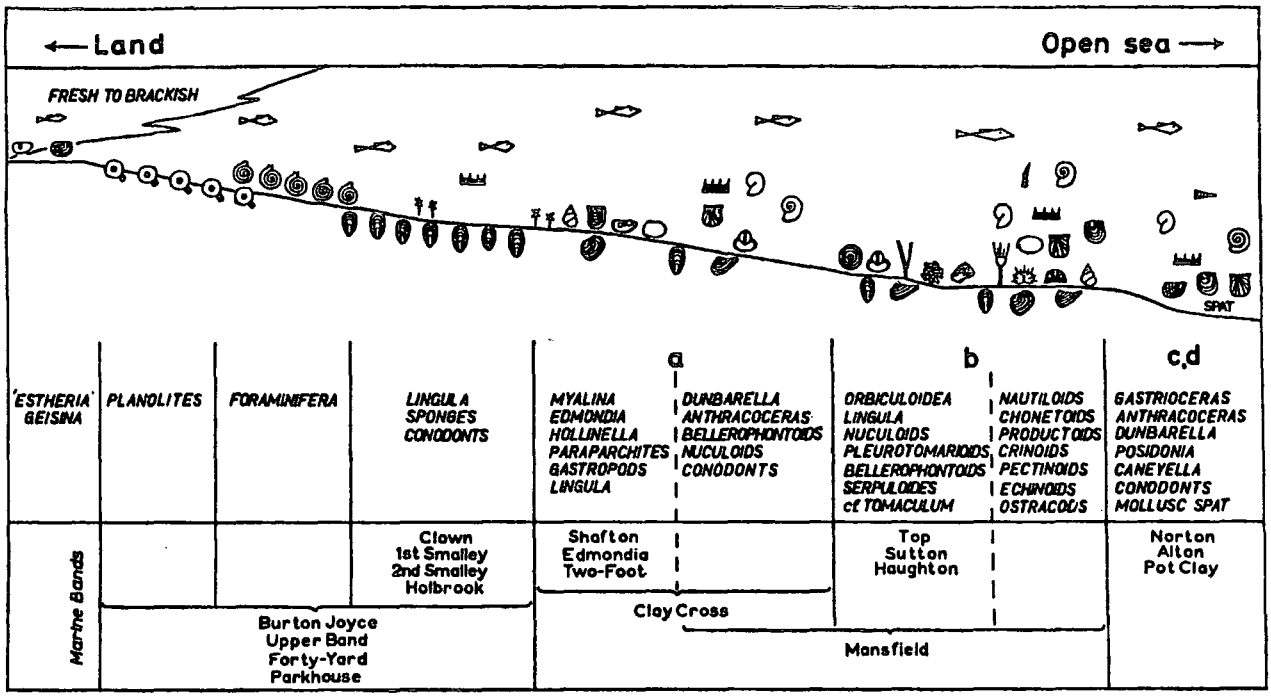
The recognition of non-marine bivalves came early in the development of Coal Measures research. However, it was not until the end of the 19th century that bivalves were used for stratigraphical zonation (Hind, 1893-6). Davies and Trueman (1927) erected a series of bivalve zones, later modified by Trueman and Weir (1946).

Calver (1956) introduced a number of faunal belts, following previous work by Wright and Eagar, based on assemblages of the non-marine bivalves. The bivalve zones of Trueman and Weir (1946) are still in use at the present time, and form one of the fundamental subdivisions of the British Westphalian sequence (Fig. 2.4). Ramsbottom *et al.*, (1978) proposed one major amendment to this scheme in suggesting that the *Anthraconaia prolifera* zone be abandoned (the uppermost unit of Trueman and Weir's series) and the underlying *Anthraconauta tenuis* zone extended upward.

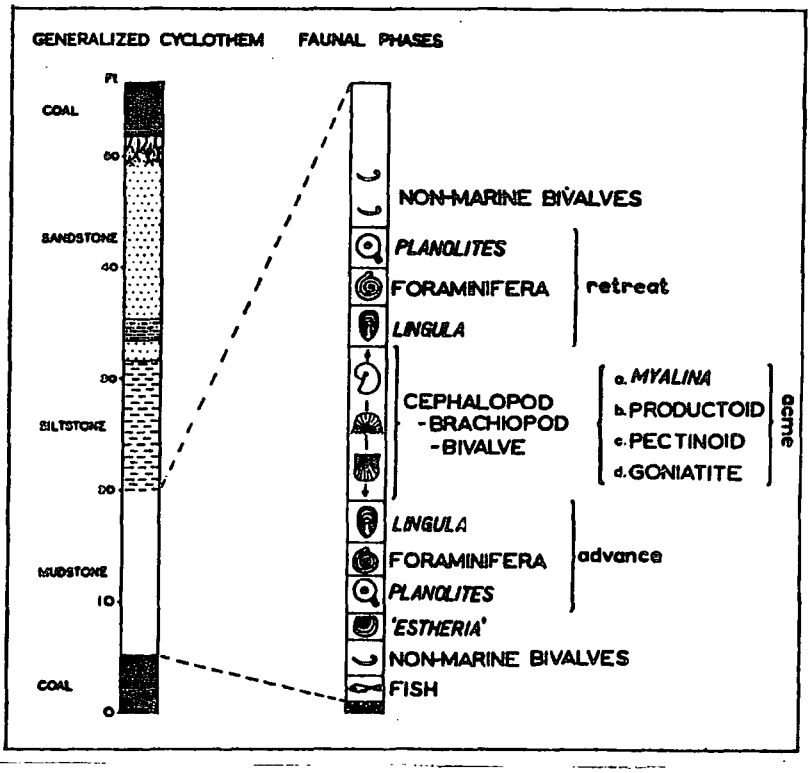
The bivalves of the Coal Measures are essentially very limited in type, being restricted to seven genera. However, with these seven genera are several hundred species, most of which have limited stratigraphical range. Identification of stratigraphical position

Fig.2.3

RELATIONSHIPS BETWEEN FAUNAL DISTRIBUTIONS IN BRITISH WESTPHALIAN MARINE BANDS AND THE DEVELOPMENT OF MARINE INCURSIONS (After Calver, I968a)



a) Idealized relationship of facies belts and their typical faunas (Faunal phases ; a.- Myalina, b.- Productoid, c.- Pectinoid, d.- Goniatite).



b) Vertical distribution of faunal phases associated with an idealized Westphalian marine incursion.

STRATIGRAPHICAL SUBDIVISION OF THE BRITISH WESTPHALIAN COAL MEASURES
(After Calver, I969)

Fig.2.4

SCOTLAND	ENGLAND & WALES	MARINE MARKER BANDS	PLANTS		MIOSPORES	NON-MARINE LAMELLIBRANCHS	
Macgregor 1960	Stubblefield & Trotter 1957		Heerlen 1927, 1935	Zones Dix 1934	Zones Smith and Butterworth 1967	Zones Trueman and Weir 1946	Faunal Belts Calver 1956
UPPER (BARREN) COAL MEASURES	UPPER COAL MEASURES		WEST. D	I	T. OBSCURA	PROLIFERA	
				H		TENUIS	
			WEST. C	G	T. SECURIS	PHILLIPSII	
	M	TOP (A. CAMBRIENSE)		F	V. MAGNA	Upper SIMILIS-PULCHRA	adamsii-hindi
M	MIDDLE COAL MEASURES	MANSFIELD AEGIR (A. AEGIRANUM / A. HINDI)	WEST. B	E		Lower SIMILIS-PULCHRA	atra
MIDDLE COAL MEASURES							caledonica
					D. BIRETICULATUS	MODIOLARIS	phrygiana
M	M	CLAY CROSS KATHARINA (A. VANDERBECKEI)		D	S. RARA		ovum, regularis, cristagalli
LOWER COAL MEASURES	LOWER COAL MEASURES		WEST. A	C	R. ALIGERENS	COMMUNIS	pseudorobusta, bipennis, torus
					D. ANULATUS	LENISULCATA	proxima, extenuata, fallax-protea
	M	POT CLAY SARNSBANK (G. SUBCRENATUM)					

from bivalves is only possible by use of faunal assemblages, and is not a very precise method. Nevertheless, it is one of the best available. That many of the bivalves are non-marine is based only on inference and association, in that these fossils rarely occur with proven marine forms and are found in rocks containing *in situ* roots and abundant plant debris.

The palaeoecology of Coal Measures non-marine bivalves has been discussed by Eagar (1960), Broadhurst (1964), Calver (1968b), Hardy (1970) and others. It is apparent that while many, if not most, of these animals lived as benthos on lake floors, some, particularly species of the genus *Carbonicola*, had a burrowing mode of life (Broadhurst, Simpson and Hardy, 1980). Some species of Naiaditids may have also existed by byssal attachment to floating vegetation (Trueman and Weir, 1955). Whatever their exact mode of life, it would appear from associations with various other fossils that many of these bivalves had a considerable range of salinity tolerance (Calver, 1968b).

Non-marine bivalves are most commonly found in claystone horizons immediately overlying coal seams, where they often define "mussel bands" or "shell beds". These units form distinctive local marker horizons in some instances, occurring often over the area of a single coalfield (Pollard, 1969).

Similarly useful in local correlation are thin horizons rich in the remains of small ostracods and bivalved crustaceans. Particularly common are the benthic ostracods *Geisina* and *Carbonita*, and the branchiopod *Estheria*. These forms may have inhabited slightly more saline waters than the bivalves.

Ostracods and branchiopods are often found in association with non-marine bivalves, as are remains of the coiled serpulid worm *Spirorbis*, which led an attached mode of life with bivalves.

Arthropods quite possibly formed an important component of the Coal Measure fauna, but seem to have been rarely preserved. The crayfish-like *Anthrapalaemon*, the xiphosurids *Belinurus* and *Euproops*, eurypterids and arachnids are all sporadically present.

Vertebrate remains are similarly sporadic in occurrence, but are occasionally found well-preserved. The teeth and scales of fish are common in fissile claystones above some coal seams (referable often to genera such as *Rhabdoderma*, *Rhizodopsis*, *Megalichthys* and *Elonichthys*). These are thought to have possessed quite a range of salinity tolerance, having been found in sediments of both marine and non-marine origin.

Well-preserved remains of tetrapods are exceedingly rare in Britain. Two localities which have yielded good specimens are Usworth colliery in the county of Tyne and Wear (Panchen, Tilley and Steel, 1967) and Newsham in Northumberland (Boyd, 1980, 1982). The tetrapods adapted to life in the Westphalian environment were largely amphibians, though some primitive reptiles are known (Westoll, 1968a, Johnson, 1980), and even primitive mammal-like reptiles (Carroll, 1964). It is evident that during this period, the conquest of the terrestrial environment was in progress, with the adaptation, for the first time in geological history, of many forms of vertebrates and invertebrates to an air-breathing, land-inhabiting mode of life.

The majority of faunal remains, other than some marine fossils, the non-marine bivalves and the conodonts, are of little use in strat-igraphical correlation. The same is not true of the floral record, however, considerable use of which has been made in the

stratigraphical subdivision of the Westphalian.

Plant fossils constitute the most abundant, and often the best-preserved, remains in the British Coal Measures. Several groups of plants are represented, from microscopic algae and fungi up to giant arborescent lycopods. Recent palaeoecological studies of Coal Measure floras in northern Britain (Scott, 1976, 1977a, b, 1978, 1979) have emphasized that the distribution of these plants was controlled partly by the original plant communities, and partly by subsequent depositional processes.

In evolutionary terms, the Upper Carboniferous was characterized by an unrepeated development of floral "gigantism" among the lycopods and horsetails, and possibly by a trend towards the establishment of the gymnospermous trees.

The coal swamps themselves were inhabited mostly by lycopods (club-mosses) such as *Lepidodendron* and *Sigillaria*, which then dominated the composition of the peat, eventually to form coal. The banks of rivers and sides of lakes supported the growth of giant horsetails such as *Calamites*, whereas the floodplain and river levees supported a rich flora dominated by pteridosperms (seed-ferns) such as *Alethopteris*, *Neuropteris* and *Pecopteris*, pteridophytes (true ferns) and some sphenopsids and lycopods (Scott, 1979). Possible remnants of an upland flora are represented by the gymnosperm *Cordaites*, and related gymnospermous conifers (Scott, 1976).

Although many of the arborescent genera have a very long stratigraphical range, and thus are of little stratigraphical use, most of the pteridophytes and pteridosperms have a much more restricted range, and have been used with some success in stratigraphical zonation and correlation. Kidston (1905) was the first to draw major stratigraphical conclusions from the macrofossil plant

record, followed by Dix (1934) and Crookall (1955-76). Their results show that plant macrofossils are only of use in broad zonation and correlation, since the stratigraphical ranges of most species are too long for detailed subdivision of the sequence. Miospores, however, have been found to be considerably more use in detailed correlation; spore assemblages have been used in coal seam correlation (Smith, 1968) and Smith and Butterworth (1967) have proposed a series of miospore zones for the Westphalian (Fig. 2.4).

The Coal Measures contain a restricted but quite widespread assemblage of trace fossils. Among these are the bivalve escape trace *Pelecypodichnus*, the locomotion trail *Cochlichnus*, and the burrows *Planolites, Skolithos* and *Arenicolites*. These were described by Guion (1978) and Haszeldine (1981a). Such traces may have some environmental significance, as has already been suggested for *Planolites opthalmoides* by Calver (1968b), for example.

The most widely used stratigraphical subdivision of the Westphalian is that proposed by Jongmans (1928) and Jongmans and Gothan (1937), which divides the Westphalian into stages, A, B, C and D. The boundaries of these stages are taken largely at the horizons of prominent marine bands. However, the bivalve zones of Trueman and Weir (1946) are still widely used, as are the "Lower", "Middle" and "Upper Coal Measures" subdivisions of Stubblefield and Trotter (1957) and MacGregor (1960), (Fig. 2.4). This study uses the stage scheme of Jongmans (1928) and Jongmans and Gothan (1937).

On a more local scale, lithostratigraphy still plays an important role in correlation. Williamson (1967) listed several features which might be of use in local correlation, among them the microscopic and macroscopic character of coal seams, tonsteins and other distinctive lithologies, spores, non-marine mussel accumulations, ostracod, fish and plant beds. Williamson (*op. cit.*) wisely stressed

the importance of using all available data in making a correlation, and not merely single criteria.

Particularly important in coal seam correlation over short distances are characters such as the thickness and nature of "leaves" of coal and clastic intraseam partings, presence of various mineral species, ash content, nature of surrounding lithologies and distinctive palaeontological accumulations. It is important to bear in mind, however, that coal seams cannot themselves be regarded as precise time-stratigraphical horizons, as they probably represent very long periods of accumulation and since the development of coal-forming conditions may be diachronous.

Structurally, the areas of Coal Measures outcrop in Britain are quite complicated, due largely to the high density of faulting. Faults are mostly minor in terms of vertical displacement (up to 20 m), but several large-scale faults are known, with throws of up to hundreds of m. Broadly speaking, two major populations of fault trends may be distinguished, one oriented roughly north-north-west to south-south-east and the other east-north-east to west-south-west.

Tectonic dips are generally gentle (up to 10 degrees) in the British coalfields, except in the vicinity of major faults, and folding is usually restricted to broad, open anticlinal and synclinal flexures.

Igneous intrusions are rare, but in some areas sills, dykes and stocks of Permo/Carboniferous or Tertiary age are found in Westphalian sediments. In the East Midlands, a thick sequence of Westphalian A and C basic extrusive and intrusive rocks was discovered during subsurface borehole exploration (Burgess, 1982).

In the *Durham coalfield*, the Westphalian comprises a maximum of about 900 m of sediments, representing the Westphalian A-C zones

(Fig. 2.5). Only the major Marine Bands are present, including the Quarterburn (= *SUBCRENATUM*), Kays Lea (= *LISTERI*), Harvey (= *VANDERBECKEI*), Ryhope (= *AEGIRANUM*) and Down Hill (=*CAMBRIENSE*) horizons (Calver, 1968a; Ramsbottom *et al.*,1978). Many of these "marine bands" do not display a fully-developed marine fauna, being only of "lingula facies" (Calver, 1968a). There are several local lithological and palaeontological marker horizons present in the Durham coalfield, such as the "Blackhall Estheria Band", some of which may have correlatives in other areas. Local correlation is largely dependent on lithological comparison where palaeontological data is lacking, and this is reflected in the number of "major sandstone" stratigraphical markers. One problem with the local stratigraphy arises in the detailed correlation of coal seams. The rapid lateral changes in many seams have made correlation very difficult, and this is complicated by the confusion of local seam nomenclature (Jones, 1980). However, in recent times, the National Coal Board have standardized seam nomenclature by defining a series of "index names" for seams, each one also being given an alphabetical code (Figs. 2.5, 2.6). Many local stratigraphical uncertainties still exist, however, accentuated by the lack of outstanding lithologies in the sequence (Hindson and Hopkins, 1947; Whitworth, 1972). Detailed descriptions of the Durham stratigraphy are given in Smith and Francis (1967) and Mills and Hull (1976).

Literature pertaining to the palaeontological record in the Durham coalfield is dominated by the contributions of William Hopkins, whose work, (1927, 1930, 1933, etc.) on non-marine bivalves helped establish a reliable stratigraphical framework for the Durham and Northumberland areas. More recently, Pollard (1962, 1969) described a number of ostracod/mussel bands of quite widespread occurrence in the area, and Scott (1976, 1979) discussed the palaeoecology of

Fig.2.5

WESTPHALIAN STRATIGRAPHY OF THE NORTHERN PENNINE COALFIELDS

(After Ramsbottom et al., 1978)

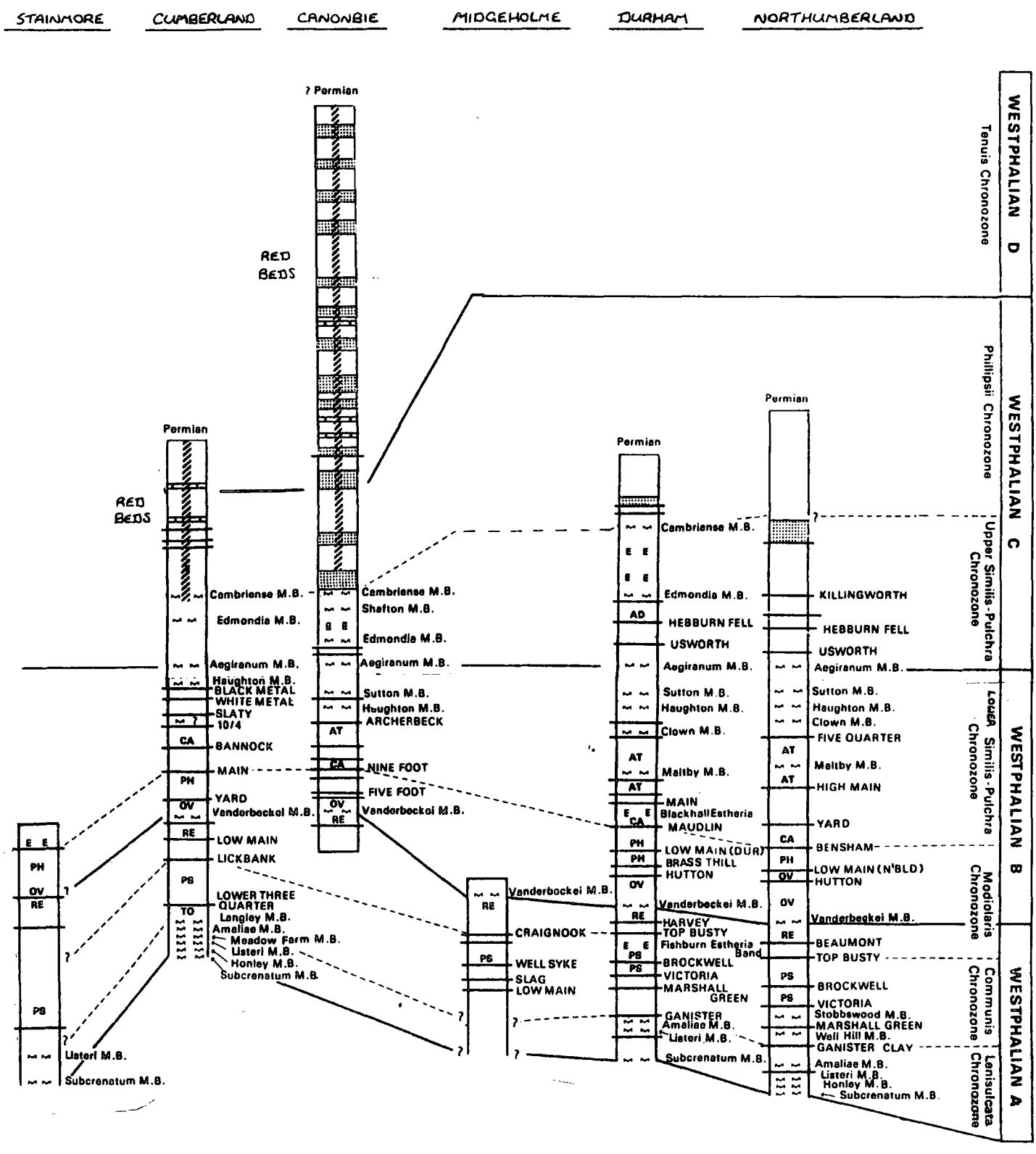
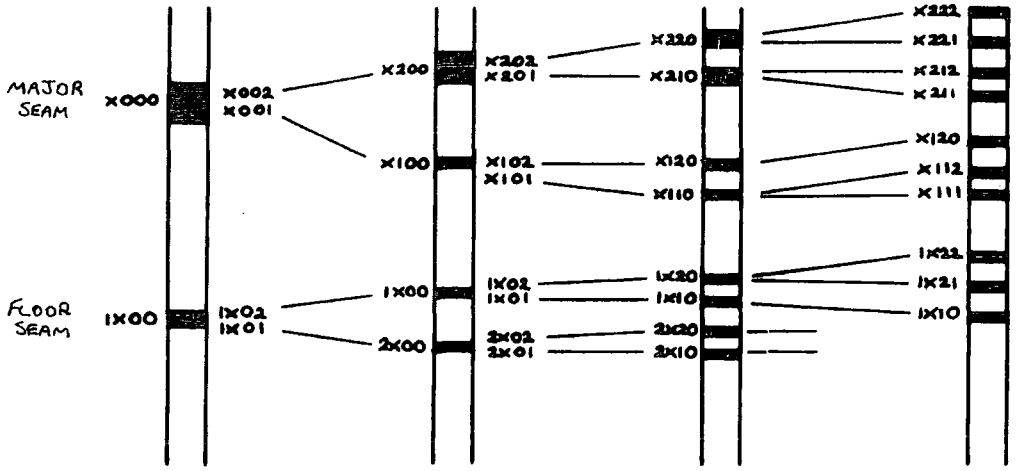


Fig.2.6

N.C.B. O.E. SEAM CODING SYSTEM, AND REGIONAL SEAM CORRELATION

a) Key to seam coding system, as used in this thesis.



N.B. This scheme is presently in use by the N.C.B. North--East Opencast Executive only.

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b) Regional correlation of major coal seams (tentative only between the N.E. and elsewhere).

Code	DURHAM	Northumberland	S.Tyne	Cumbria
A000	Hebburn Fell	"		F
B000	Usworth			E
C000	Ryhope 5/4	Hauxley		Black Metal
D000	Ryhope Little	Blackclose		Fireclay
E000	High Main	Diamond		Upper Yard
F000	Fivequarter	Radcliffe		
G000	Main	Albert/Yard		Tenquarter
H000	Maudlin	Bensham		Rattler/Bannock
J000	Low Main	Fivequarter		Crow/Main
K000	Brass Thill	Low Main		Metal
L000	Hutton	Broomhill Btm.	Old 5/4	Yard
M000	Ruler	Plessey		Lower Yard
N000	Harvey	Beaumont		I8 Inch
O000	Hodge	Tilley		
P000	Tilley	Widdrington Yd.	Bounder	Lickbank
Q000	Busty	Widd.Main/ 5/4	Craignook	Sixquarters
R000	Threequarter	"	Little	
S000	Brockwell	Bandy	Wellsyke	Upper 3/4
T000	Victoria	Brockwell	Slag	Lower 3/4
U000	Marshall Green	Choppington Vict.	Low Main	
V000	Ganister Clay	Cockhill		Top Albrighton

Westphalian floras, using examples from the Durham coalfield.

The present structure of the Durham coalfield is of a succession of Westphalian sediments inclined at generally less than ten degrees towards the east, and unconformably overlain by a very gently-dipping Permo/Triassic sequence (Fig. 2.7). Several phases of structural disturbance have contributed to this situation, and these are briefly considered in turn.

The earliest recognizable structural trends in the area are Caledonian in age (c. 400 M.y. B.P.) and are oriented in a general east-north-east to west-south-west direction. These are thought to have had a marked influence on later structural movements, and indeed on the subsequent structural development of the region (Leeder, 1982).

At the end of the Silurian period, the Weardale granite was intruded into the Lower Palaeozoic rocks of the northern Pennines, and this led to the development of a "block-and-basin" topography during Lower Carboniferous times in the north of England. The Alston Block was thus formed in the area of Co. Durham, bounded to the north and south by east-west trending hinge-lines (Fig. 2.7).

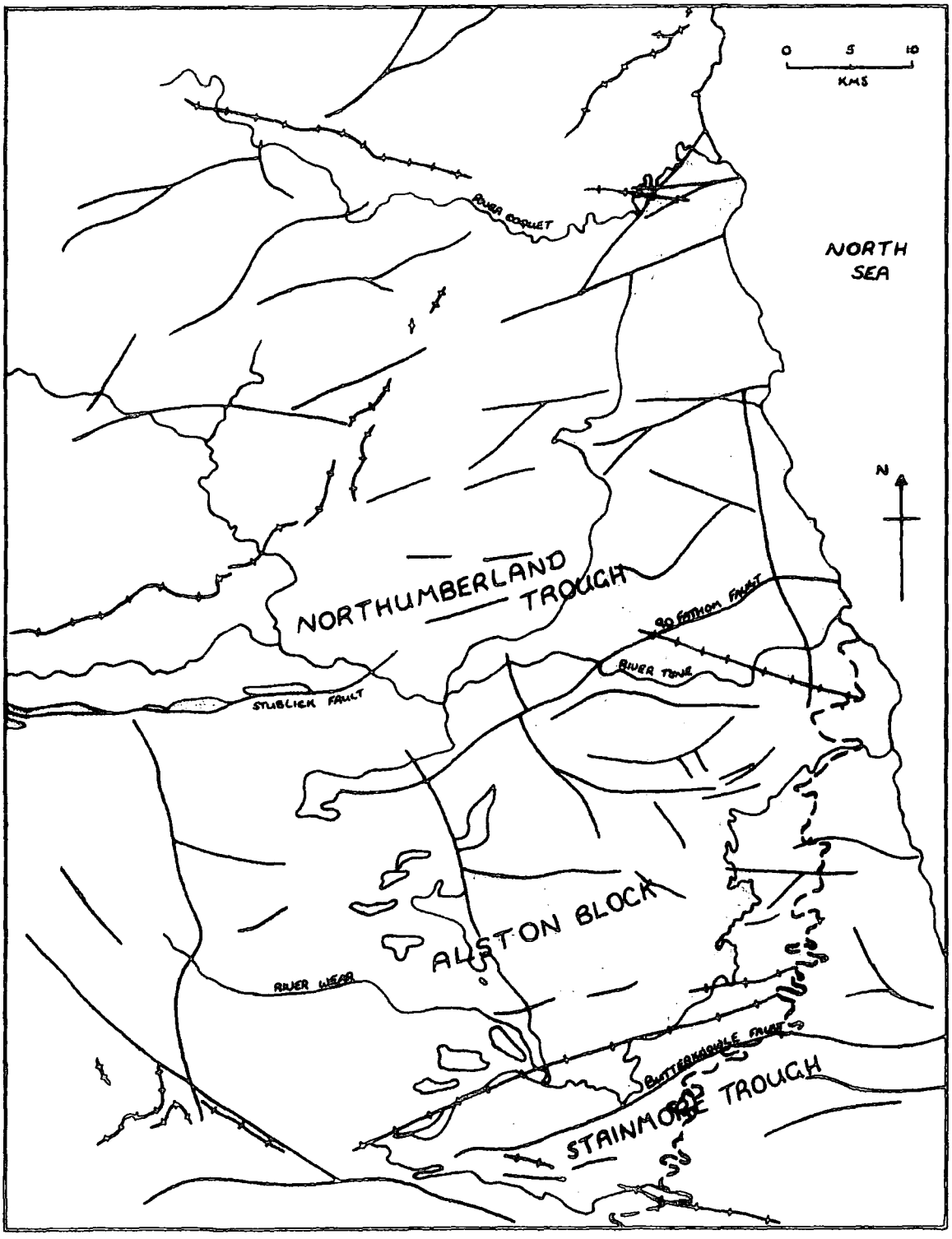
The presence of the Alston Block affected sedimentation during Dinantian and Namurian times, with a marked contrast in sequence thickness between adjacent "Block" and "Basin" areas. There is no evidence of such a significant contrast during Westphalian times, however, and the north of England is considered to have behaved as a single structural unit during this period (Johnson, 1967). The Carboniferous Pennine province is considered by Leeder (1982) to have developed due to rifting and subsequent crustal sagging, initiated by lithospheric stretching (Bamford *et al.*, 1976; Mackenzie, 1978).

The Hercynian orogeny (c. 295-270 M.y. B.P.) caused the most significant structural disturbance in the north-east of England.

Fig.2.7

STRUCTURAL MAP OF NORTH-EAST ENGLAND

(Modified, after Robson, I980)



MAJOR FAULT

IGNEOUS INTRUSION

EASTERN LIMIT OF EXPOSED COALFIELD

AREA OF WESTPHALIAN OUTCROP (UNDERLAIN TO WEST BY NAMURIAN/DINANTIAN, AND OVERLAIN TO EAST BY PERMIAN/TRIASSIC SEDIMENTS).

Numerous major and minor faults were active, a swarm of quartz-dolerite dykes and sills were emplaced, and the Westphalian sediment pile was subjected to some folding, and considerable uplift and erosion.

At this time the structural hinge lines along the edge of the Alston Block became active faults, particularly the Lunedale-Butterknowle and Stublick-Ninety Fathom fault systems (Fig. 2.7). A pronounced structural contrast was developed across these fault lines, between the comparatively undisturbed area of the Alston Block and the more intensely deformed areas to the north and south.

The Hercynian period of earth movement is thought to have involved largely north-west-south-east (Leeder, 1972) or east-west (Haszeldine, 1981a) extensional stress in the north-east of England, and this is manifested partly in the patterns of fault trends. The most prominent structural trend is east-north-east to west-south-west, quite possibly affected by the underlying Caledonian structural "grain" (Fig. 2.7).

The final structural upheaval in the geological history of the north-east came during Eocene times (c. 60 M.y. B.P.), possibly associated with the last stage of opening of the Atlantic Ocean (Bott and Johnson, 1972). At this time several faults were reactivated, particularly the major "boundary faults", and a gentle eastward dip was imparted upon the entire sedimentary succession, associated with the uplift of the Pennines to the west. Tertiary faulting in the north-east is mostly normal, and directed along older fault lines.

Some of these faults have (present-day) throws of up to 300 metres, although the larger fractures may have moved on several occasions. A further swarm of tholeiitic dykes was intruded during Tertiary times.

Reviews of the structure of the north-east coalfield are given in Robson (1980) and Haszeldine (1981a).

The succession in the *Northumberland coalfield* is similar in thickness and character to that of Durham (Ramsbottom *et al.*, 1978). Detailed descriptions of stratigraphy and palaeontology are given by Land (1974). The lateral equivalents of the Durham coal seams are shown in Fig. 2.6, indexed according to the N.C.B. standard nomenclature. Other than the work of Hopkins (1927 *et seq.*) on non-marine bivalves, palaeontological interest in Northumberland has focussed on an occurrence of well-preserved vertebrate remains at Newsham (Rayner, 1971, p. 451; Land, 1974). Here, skeletal remains of fish, amphibians and primitive reptiles have been found.

Structural aspects of the Northumberland coalfield are entirely similar to those of Durham; see above, and Haszeldine (1981a).

In *Cumbria*, the sequence is less well-established due possibly to a high degree of lateral variability. The stratigraphy and palaeontology of the area were described by Eastwood (1930), Eastwood *et al.*, (1931) and more recently by Taylor (1961), Eastwood *et al.*, (1968) and Taylor (1978). The succession comprises about 650 m of strata, ranging from Westphalian A-D, in age, and including representatives of eleven marine bands. Among these are the *SUBCRENATUM*, Solway (= *VANDERBECKEI*), Bolton (= *AEGIRANUM*) and St. Helens (= *CAMBRIENSE*) Marine Bands (Fig. 2.5, 2.6).

The uppermost part of the sequence in Cumbria is heavily reddened, and this feature, along with the occurence of several thick sandstone bodies, led early workers (Kendal, 1896) to the contention that these sandy, red beds lay unconformably on the main part of the Coal Measures. This unit was named the "Whitehaven Sandstone Series" and its supporters cited the abrupt change in lithology and colour and

change in position of the base of the unit laterally as evidence for an unconformity. Taylor (1961), however, proved that the "Whitehaven Sandstone Series" merely represented Coal Measures which had been subjected to extensive oxidative reddening during Permo-Triassic times, and proposed that the term be discontinued.

Patterns of faulting in the Cumbrian coalfield are similar to those in the north-east.

The *Midgeholme, Plenmeller and Stublick coalfields* are quite poorly known, despite a certain amount of past economic exploitation. The stratigraphy of the Midgeholme area was described by Trotter and Hollingworth (1932). The sequence contains about 200 m of strata, mostly of Westphalian A age (Fig. 2.5).

The base of the succession is indefinite, but the horizon of the *VANDERBECKEI* Marine Band has been found near the top of the sequence (Ramsbottom *et al.*, 1978).

The Plenmeller and Stublick outliers each contain about 100 m of strata, of Westphalian A age, and are described briefly by Jones (1980).

The structure of these areas is similar to that of adjacent coalfields, but dominated by the major boundary faults of the Stublick-Ninety Fathom system.

The succession in the *Stainmore coalfield* comprises about 350 m of sediments, all of Westphalian A age, described in detail by Burgess and Holliday (1979). Two major Marine Bands have been recognized, the Argill (= *LISTERI*) and Swinstone Top (= *SUBCRENATUM*). As with Cumbria, the upper part of the sequence is considerably reddened, and, similar to Midgeholme, the structure of the area is dominated by the major bounding faults.

The coalfields of Cumbria, Midgeholme, Plenmeller, Stublick and Stainmore are currently being subjected to detailed stratigraphal analysis, particularly by the National Coal Board. Detailed correlative work is in progress using, amongst other methods, spore assemblages in coals and roof shales (J.A. Knight, 1981, *pers. comm.*), and the degree of refinement in the different areas is variable. It is in the poorly-exposed areas such as Stainmore and Midgeholme where the lithological methods of correlation all but break down, since the occurrences of distinctive lithologies are few and far between.

The *Lancashire and South Yorkshire coalfields* lie close to the inferred "Pennine Basin depocentre", and as such, contain some of the thickest sequences of Coal Measures in the country. The succession in Lancashire has been estimated at 2000 m in thickness, and that of South Yorkshire as 1400 m (Figs. 2.8 and 2.9), (Ramsbottom *et al.*, 1978). Both areas contain rocks of Westphalian A-D age. There is a full development of marine bands in these areas, most of which are of truly marine facies. In total, records of nineteen marine incursions have been recorded (Calver, 1968a; Ramsbottom *et al.*, 1978). The stratigraphy of the Lancashire area is described in detail by Earp *et al.*, (1961), and in other Geological Survey Memoirs. Similarly, the succession in South Yorkshire is considered in some detail by Eden, Stevenson and Edwards (1957) and Goossens, Smith and Calver (1974).

Specialized palaeontological work has been carried out on the non-marine bivalves of the Lancashire area by Eagar (1951, etc.) and more recently by Hardy (1970), Hardy and Broadhurst (1978), and Broadhurst, Simpson and Hardy (1980). In South Yorkshire, Scott (1978, 1979) provided palaeontological data on the floral remains preserved in some Westphalian B sediments.

Fig.2.8

WESTPHALIAN STRATIGRAPHY OF THE WEST LANCASHIRE COALFIELD (From I.G.S. I:50000 Sheet 84(S) Wigan).

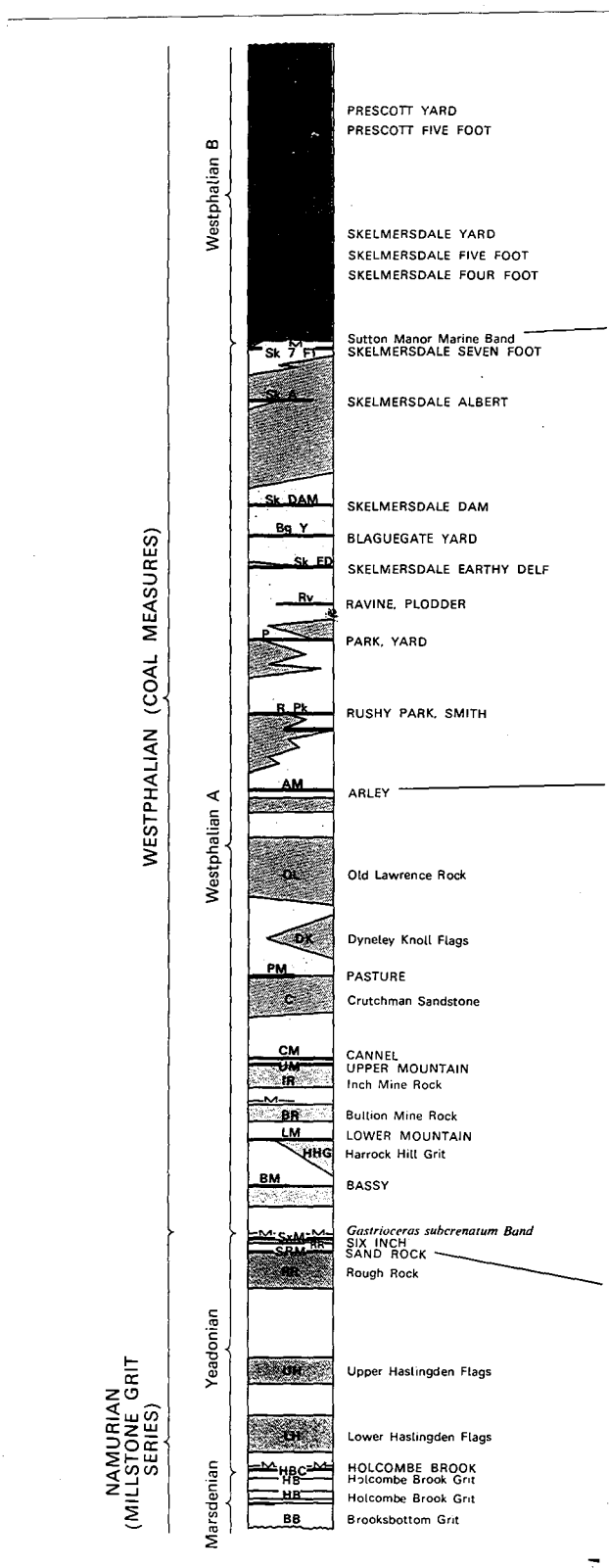
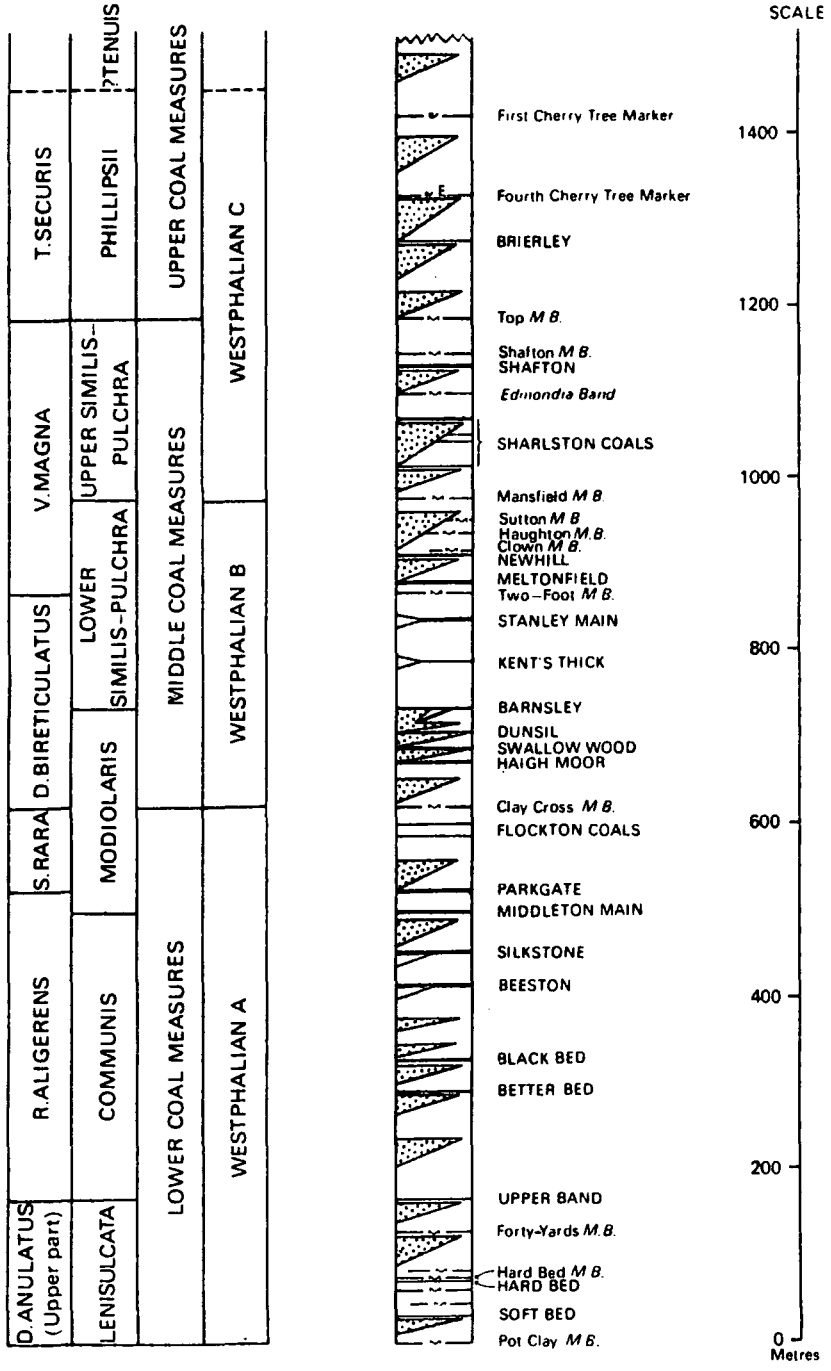


Fig.2.9

WESTPHALIAN STRATIGRAPHY OF THE YORKSHIRE COALFIELD

(After Goossens, Smith and Calver, 1974)



Structurally, the Lancashire and South Yorkshire coalfields are similar to the north-east, containing a high density of minor faults, along with a smaller number of major ones.

The *Pembrokeshire* Coal Measures are exposed in two separate outcrop belts, the Nolton-Newgale and Littlehaven-Amroth coalfields. In the Nolton-Newgale coalfield, five faulted blocks of Westphalian C and D age outcrop on the coast. Their stratigraphical relationships are, however, uncertain, due to intense tectonism, and no reliable thickness estimate has been recorded (Williams, 1966). In the Littlehaven-Amroth coalfield several exposures, largely coastal cliffs, show a Westphalian A/B sequence of about 500 m, together with a number of lowermost Westphalian C fault blocks. The sequence is attenuated with respect to the main South Wales coalfield (Ramsbottom *et al.*, 1978), but several Marine Bands are present, including the *SUBCRENATUM*, Amman (= *VANDERBECKEI*) and Picton Point (= *AEGIRANUM*) horizons. Some of these bands show development of fully marine facies (Calver, 1968a, 1969). The stratigraphy, palaeontology and structure of the Pembrokeshire coalfields were described by Jenkins (1960, 1962) and subsequently by Williams (1966, 1968), (Fig. 2.10).

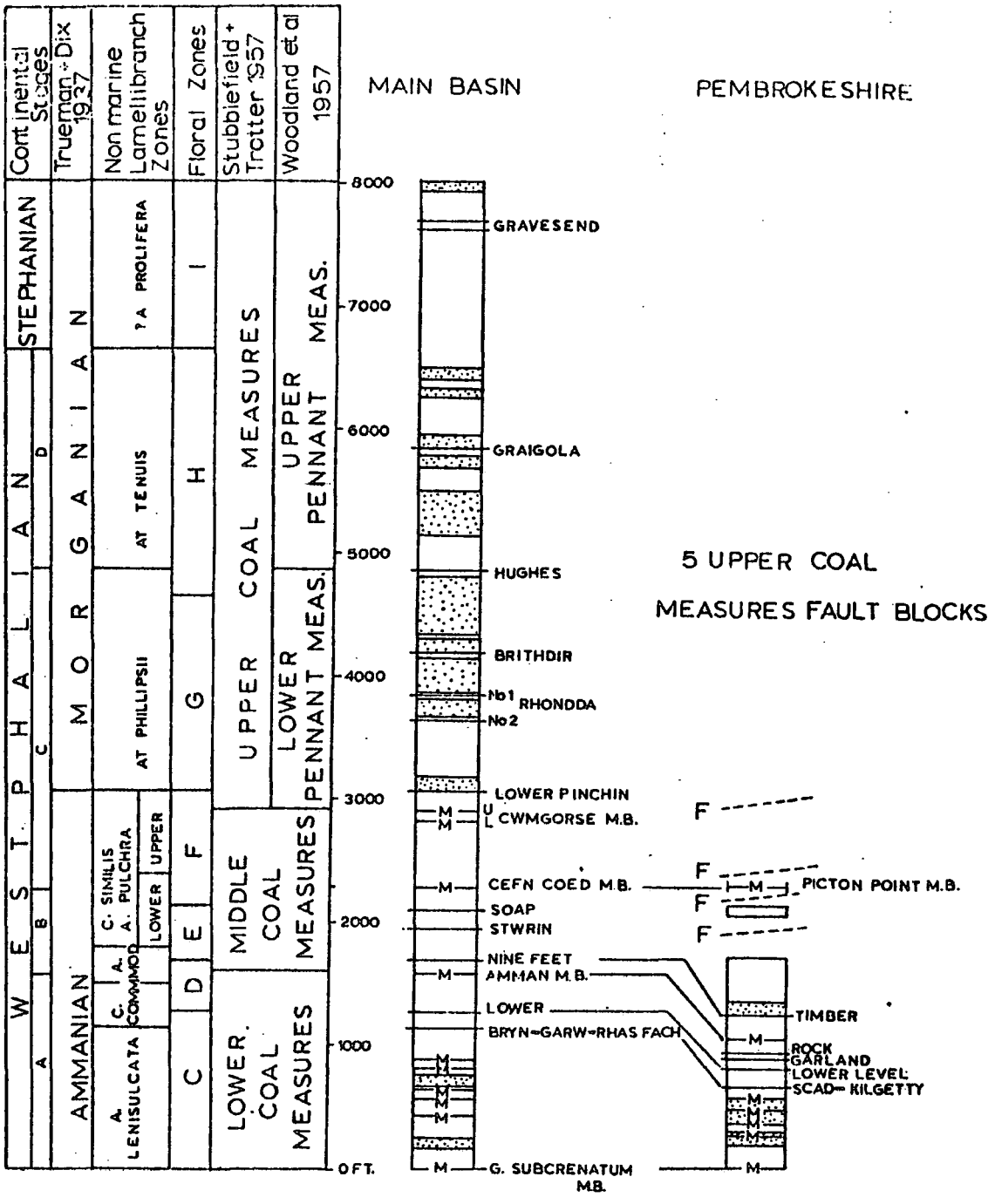
The comparatively severe structural deformation and compressional tectonic regime in the Pembrokeshire coalfield was the result of proximity to the Hercynian "collision zone", and the majority of preserved structural features in the area were formed during the Hercynian orogeny.

2.3 SEDIMENTOLOGY

Sedimentological observations, of a limited nature, date back to a very early stage in the development of Coal Measures research.

Fig.2.IO

WESTPHALIAN STRATIGRAPHY OF THE PEMBROKESHIRE COALFIELD, AND COMPARISON WITH THE SUCCESSION IN THE MAIN SOUTH WALES COALFIELD (After Jenkins, I962, and Williams, I968)



The Pembs. stratigraphical column refers to the succession in the Littlehaven-Amroth coalfield, and the "5 Upper Coal Measures Fault Blocks" to that in the Nolton-Newgale coalfield.

Early workers particularly noted the occurrence of seam "washouts" and other irregularities, for example, Buddle (1841), Hurst (1860), Jukes (1859). Sorby (1852), having contemplated the directional significance of cross-bedding, recorded palaeocurrent directions from Coal Measure sandstones exposed on the Northumberland coast and concluded that the sediments were derived predominantly from the north-west and south-east. This highlights an important conceptual problem encountered by early workers, the extreme and apparently illogical complexity of palaeocurrent distributions.

The broadly deltaic nature of the Coal Measures was first noted by Jukes in 1859. Seam washouts were mapped as linear belts and recognized as the remnants of channels (Buddle, 1841; Green *et al.*, 1878). However, the focus of attention towards the end of the 19th Century was on the origin of the coal seams themselves, rather than on their enclosing sediments.

Kendall (1918) and Kendall and Wroot (1924) contemplated the origin of "splits" in coal seams, taking into account the different compaction ratios of peat, mud and sand.

In 1939, Raistrick and Marshall provided what was then, and still is today, a comprehensive and succinct review of the formation of coal seams and their associated sediments. Summarizing the essential characteristics of the Coal Measures, Raistrick and Marshall (*op. cit.*) concluded that they were formed in a "peat moss or deltaic swamp" environment. Furthermore, they noted that "the rhythmic nature of the rock succession emphasizes the picture of a lowland area undergoing intermittent subsidence, in such a way that at one time that area was receiving fresh-water muds and sands from an area of inland drainage, and at another was inundated by the sea, with deposition of marine muds containing fossils of marine animals". By this time, comparisons

were already being made with modern deltaic systems (Raistrick and Marshall, *op. cit.*, p. 26).

With the surge of research into modern deltaic systems (and particularly that of the Mississippi River) during the 1930s, interest began to mount in the repetitious or cyclic nature of coal-bearing rocks, especially in the United States (Weller, 1930; Wanless and Weller, 1932). Weller (*op. cit.*) coined the term "cyclothem", defining it as "a series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian period." In the Eastern interior basin, and elsewhere in the U.S.A., sequences were seen to comprise stacks of cyclothems with consistently-occurring sequences of "members".

Analogous sequences were known in the British Dinantian and Namurian (Forster, 1809; Miller, 1887; Robertson, 1948; Moore, 1959), and the analogy was extended to the Westphalian. Raistrick and Marshall (1939, p. 24) noted the crudely cyclic nature of much of the Coal Measures, and ascribed the development of "rhythms" or "cycles" to periodic infilling and subsidence of shallow-water deltaic lakes. They considered that such sedimentary cycles were widespread in occurrence and could form the basis of a stratigraphical framework.

Trueman (1954) stated that the Coal Measures rhythmic unit consisted of marine shale → non-marine shale or mudstone → sandstone → rootlet bed → coal. Following this statement with the qualification that variations are frequent, and that every conceivable modification exists, however, does not lend the concept a great deal of credibility.

The origin of these cycles was the subject of great controversy between the 1930s and 1960s. There was a complete lack of agreement on a common causal mechanism to the various "cyclothems". Regional

diastrophism and eustatic sea-level changes as the controlling influences were gradually superceded by the concept of an autocyclic mechanism, that is, localized, compaction-induced subsidence.

Duff and Walton (1962) and DeRaaf, Reading and Walker (1965) criticized the cyclothem method of analysis on several grounds, most importantly that rigid application of the concept had effectively obscured an understanding of the sedimentary processes involved (Chapter 1.5). However, this approach is still adhered to by some, for example, Jones (1980), albeit to a lesser extent.

Another related angle of study was initiated by Duff and Walton (1962, 1964), that of statistical analysis of vertical sequences. In this approach lithological data pertaining to Namurian and Westphalian coal-bearing rocks were subjected to a variety of increasingly complex statistical techniques, among them trend surface analysis (Duff and Walton, 1964; Read, Dean and Cole, 1971), Markov chain analysis (Read, 1969), linear regression analysis (Read and Dean, 1967, 1976), principal component analysis and factor analysis (Read and Dean, 1968, 1972). These methods, however, often simplify data to a considerable extent and seem to produce few meaningful results. Again, these techniques are still in use by some workers (for example Read, 1979; Read and Dean, 1982), despite having added little to our knowledge of the Coal Measures.

True sedimentological research into the Coal Measures began in earnest during the 1960s, with the exception of a few earlier studies (Kellett, 1927; Kuenen, 1949; Green, 1954; Armstrong and Price, 1954).

Bluck (1961), Bluck and Kelling (1963), Thomas (1967) and Kelling (1964, 1968) made observations on sediments in the South Wales

coalfield, and concluded that the patterns of drainage, both in terms of sediment provenance and channel type, changed with time through the Westphalian. Palaeocurrent patterns defined the South Wales area as a distinct sedimentary basin, separated from the Pennine coalfields by an uplifted area of non-deposition.

Clarke (1963), discussing the Coal Measures of the South Durham area, considered that the Westphalian coastal plain must have been characterized by very low gradients, and crossed by numerous channels "as much as twenty miles wide", which periodically flooded adjacent overbank areas at high stage. He furthermore suggested that water and sediment might have crossed the plain "not necessarily in continuous channels, but perhaps sometimes in sheets, sometimes in short channels between adjacent ponds, pools and lakes up to tens of miles across." Clarke (*op. cit.*) also offered an explanation for the extreme palaeocurrent variability of the Coal Measures : ".... regional surface gradients appear to have been low and a very small change in surface level could have made great changes in the positions of the principal sources of sediment. Thus a more random than systematic change in the dimensions and relations of the bodies of rock is to be expected in the examination of the individual bodies ...". He concluded that "in general, the shape and extent of the bodies of rock other than the marine bands and the channel facies sandstones, appear to be extraordinarily variable."

Davies (1965) reported on the occurrence of contemporaneous deformation features in the Greenmoor Rock, a Mid-Westphalian A sandstone body in South Yorkshire, which he defined as convolute lamination and corrugated lamination, and ascribed to heterogeneity of the sediment and/or thixotropic behaviour. Davies (1966, 1967) considered the facies of the Greenmoor Rock in detail, concluding that the whole unit represented a series of superimposed fluvial deposits.

DeRaaf, Reading and Walker (1965) studied the non-coal-bearing Westphalian A Abbotsham and Northam Formations of north Devon, and recognized deltaic infills of a moderately deep basin, the sediment for which, they suggested, might be derived from the Bristol Channel area. These rocks, well exposed on the Devon coast, though severely tectonised in places, probably are the only outcropping sediments of the "Upper Carboniferous" basin margin into which the Coal Measure channels ultimately flowed, in Great Britain. This study also had wider implications in the development of sedimentological methodology (Chapter 1.5).

Further studies in the South Wales coalfields at this time were those of Parry (1966) on the role of differential subsidence in moulding the Coal Measures succession, and Williams (1966, 1968) on the sedimentation of the Pembrokeshire Coal Measures. Williams (*op. cit.*) delimited a numer of commonly-occurring facies, and, grouping them into "successions", described the complex sedimentary history of the Pembrokeshire area. While some of Williams' environmental interpretations are now a little outdated, the work remains as probably the first comprehensive sedimentological study of a Coal Measure basin.

Elliott, in a series of publications (1965, 1968, 1969, 1970), described the sedimentary characteristics of the East Midlands Coal Measures. Elliott (1968) described and defined ten facies, which he grouped into four recurring "successions". The same author, (1969) considered the interpretation of these facies and "successions" in terms of deltaic environments, and derived an "episodal theory" of Coal Measure formation, designed "to replace the traditional cyclic concept". Eath (litho) facies was given a direct environmental interpretation, after comparison with modern Mississippi sub-delta deposits. Despite application of this rather dangerous practice,

Elliott's (1969) contribution contains some very astute arguments pertaining to the development of Coal Measure architecture.

The publication in 1968 of the book "Coal and coal-bearing strata" (Murchison and Westoll, 1968) brought several new papers related to Coal Measure sedimentology, among them works by Hemingway and by Westoll. Hemingway (*op. cit.*), having noticed the common occurrence of interlaminated sandstone, siltstone and claystone in the Coal Measures, drew an analogy with tidal flat sediments on Modern coastlines, for example, as described by Evans (1965). At this time, unfortunately, it was not widely recognized that such interlaminated or "heterolithic" sediments may form in several environmental settings, and are not restricted to intertidal areas on coastlines. Westoll (1968b) provided a comprehensive review of the "cyclothem" concept, summarizing the differences in terminology and the various theories regarding the origin of coal-bearing sedimentary cycles.

Calver (1969) presented a "state-of-the-art" paper on the Westphalian of Britain, which included a summary of the palaeogeography during Westphalian times.

In a series of papers by Broadhurst and co-workers (Broadhurst, 1964; Broadhurst, Simpson and Williamson, 1968; Broadhurst and Loring, 1970, and more recently, Broadhurst, Simpson and Hardy, 1980), palaeoecological features were used to elucidate sedimentological problems within the Lancashire coalfield. Broadhurst (1964) and Broadhurst and Loring, (1970) used the distributions of non-marine bivalves, marine fossils and upright *in situ* tree trunks to infer relative rates of sedimentation. Broadhurst, Simpson and Williamson (1968) attributed the splitting of the Union Mine coal seam near Burnley, Lancashire,

to differential subsidence, leading to the formation of a shallow lake, citing the presence of a "20 degree depositional slope", and the distribution and directional arrangement of fossil logs as supporting evidence. (Several workers have subsequently questioned this interpretation, including Guion (1978), who considers that the split is more likely to represent the lateral margin of a palaeo-channel).

Reading (1971) suggested that the study of vertical sequences in coal-bearing sediments might be of use in sedimentological interpretation. He divided the facies from a number of Namurian and Westphalian successions into predictable and random sequences, which, he noted, might occur on several scales. The vertical sequence approach was later applied to Westphalian sediments in north Devon by Elliott (1973) and in the East Midlands by Heward (1976).

Guion (1971) made a detailed sedimentological study of the Crawshaw Sandstone Group of Lowermost Westphalian A age, in the East Midlands, and concluded that preserved sequences were deposited through the progressive advance of at least three deltaic lobes into a shallow marine basin.

Goossens and Smith (1973) presented the results of a mapping project involving Westphalian C and D sediments exposed in part of South Yorkshire. This paper included some details of the sediment characters, but unfortunately no detailed analysis was undertaken.

Detailed sedimentological and geochemical conclusions from the study of a lower Westphalian A sequence exposed near Penistone, South Yorkshire, were presented by Pearson (1973, 1979). Conditions surrounding the formation of a seatearth, coal, marine band and overlying shales were discussed, using largely geochemical criteria.

The sequence studied was that above and below the Alton (= *LISTERI*) marine band.

Kelling (1974) provided a review of research on the Upper Carboniferous sedimentary succession of South Wales. It is apparent from this study that (a) the South Wales basins had received rather more attention by sedimentologists than any other British coalfield at this time, and (b) the South Wales basin evolved under rather different conditions to those prevalent in the other coalfields of the British Isles. It seems that the South Wales basin was surrounded by land on three sides during at least part of the Westphalian. The proximity of the source terrain for the Coal Measure sediments to the basin of deposition is unparalleled in the British Westphalian on the same scale, and led to unique characters of basin evolution and sediment petrography, while at the same time broadly similar sedimentary environments to those in the Pennine province were operative.

In the same year, Goossens, Smith and Calver (1974) published a review of the Westphalian succession in Yorkshire which, lamentably, contained only a most perfunctory consideration of sedimentological features.

However, Scott (1976), as part of a detailed research project concerned with the palaeoecology of Westphalian B floras in northern Britain, made some progress towards the understanding of the Yorkshire succession, and also those of Durham, Sanquhar and Ayrshire. This was the first modern sedimentological study of Scottish Westphalian sediments and was followed up with publications concerning Ayrshire (1977a), Yorkshire (1978) and finally a review of all four regions initially studied (1979). In his palaeoecological work, Scott linked preserved floral assemblages firstly to particular sedimentary environments, and thence to inferred original plant communities.

Scott's case study of the sediments in the Swillington, Yorkshire area (1976, 1978) represents the first attempt at a three-dimensional sedimentary model, though in this case, is only of limited value due to lack of detailed information.

Heward (1976), following a review of deltaic environments, interpreted borehole records of Westphalian A and B sediments from Nottinghamshire and outcrop data from Westphalian A sequences in Pembrokeshire in terms of shallow-water, fresh-to-marine, elongate, fluvial-dominated deltas. In this study, the vertical sequence approach, advocated previously by Elliott (1973), was used, though it was noted that, for the British Westphalian, vertical sequence data alone is difficult to interpret unequivocally. Heward (*op. cit.*) recognized the deposits of distributary channels, distributary mouth bars and interdistributary sediments within his British case studies, and also in some Westphalian D/Stephanian A sediments from northern Spain.

Guion (1978) studied, in considerable detail, the sedimentary environments of Westphalian B rocks exposed in the East Midlands coalfield. Guion's study involved the detailed logging of coal seam roof sections from underground roadways in four collieries, together with a limited amount of data from one opencast site. Guion was concerned primarily with elucidating the charactieristics of palaeo-channels within the succession, and applying this to seam washout prediction.

The most significant results of his study are what constitute the first accurate estimates of the parameters characterizing Coal Measure palaeochannels. Guion (*op. cit.*) recognized several types of palaeochannels, which he attributed either to meandering rivers or deltaic distributaries. While Guion's data can be said to be almost three-dimensional, admittedly with a vertical range of generally

less than 3 m, it is still apparent that a good deal of detail is unavoidably missing. In his conclusions (p.597), Guion pointed to the need for an accurate, detailed, three-dimensional study of Coal Measure environments, such as might be possible from the observation of successive faces in an opencast site.

Guion (*op. cit.*) also derived a system of lithological classification, and gave each lithology a specific environmental interpretation, similar to the scheme of Elliott (1968). He did, however, point out the pitfalls of this approach in his concluding chapter.

Having worked on the Westphalian A reservoir sandstones of the Bothamsall oilfield, East Midlands, Hawkins (1978), distinguished distributary channel, overbank and shoreline barrier-bar facies from borehole data, and discussed the effect of facies and other controls on the diagenesis of these sediments.

Read (1979) discussed borehole data from Westphalian C and D sediments in the Kent coalfield "in terms of upward-fining and upward coarsening semicycles, transition probabilities and entropies." The sedimentary characteristics of the Kent succession are still poorly known.

Broadhurst, Simpson and Hardy (1980) proposed a seasonal interpretation to a sequence of regularly bedded and laminated Westphalian A sediments exposed in Lancashire, suggesting that successive increments of sediment were controlled by monsoonal cycles.

An exploration model for the Westphalian A-D sediments of the Nottinghamshire and Derbyshire coalfields was produced by Fatona

(1980) who recognized the deposits of a large-scale "deltaic complex". Fatona mapped courses of palaeochannels active during specific intervals from borehole data, and concluded that these features had a pronounced influence on the pattern of coal seam splitting in the area.

Haszeldine and Anderton (1980) proposed a braidplain model for the sedimentation of the Westphalian B Coal Measures in north-east England, advocating tectonic uplift of various localized source areas to explain patterns of extreme palaeocurrent divergence between major sandstone bodies. Heward and Fielding (1980), however, questioned this interpretation, maintaining that palaeocurrent variability was not simply apparent between the various major sandstones, but equally so within them, and saw no need to invoke tectonic uplift of separate source areas or the operation of braid-plains as a causal mechanism for these sediment bodies. Furthermore, the evidence for petrographic distinction of individual sandstone bodies and for the wholesale recycling of earlier sediments was considered to be questionable.

Haszeldine (1981a, b, in press) made a detailed study of certain Westphalian B "major sandstone facies" in the Northumberland and Durham coalfields, and concluded that these represent the deposits of major fluvial channels which acted as trunk distributaries and were the major avenues of sediment transport across the Coal Measures plain. Haszeldine (1981a) also contended that deposition of these channel sand bodies, and indeed the Westphalian B succession as a whole, was controlled by local, and more distant (source area) tectonic movements.

The occurrence of syn-sedimentary growth faults in the Westphalian C succession of the South Wales coalfield was reported by Elliott and Ladipo (1981). These were attributed to gravity sliding, caused possibly by overpressured/undercompacted conditions in buried muds.

Percival (1981) discussed the nature and origin of ganisters and quartz arenites of the Northern Pennines. True ganisters are highly siliceous sandstones containing *in situ* roots, which are commonly used in the manufacture of refractories. Percival (*op. cit.*) discovered that the generally thin (< 1m thick) "true" ganisters were formed largely by pedogenic processes, whereas the remaining quartz arenites, some of which are quite substantial units, were formed by shoreline and shallow marine reworking of less mature fluvial and deltaic sands.

Description and interpretation of a synsedimentary gravity slide, and of channel-floor bedforms in a Westphalian A palaeochannel, within the Scottish Coal Measures, are provided by Kirk (in press, a, b).

From the above review it is apparent that interpretations of British Westphalian sediments have reached quite a sophisticated level in some areas, notably Devon, South Wales, the East Midlands and Northumberland. However, it cannot be said with any confidence that the overall environmental setting has been satisfactorily interpreted, since detailed sedimentological data on many coalfields is still lacking. Furthermore, detailed, three-dimensional studies of Coal Measure sediments, necessary to obtain unequivocal interpretations of environments, have not been undertaken.

CHAPTER III - THE CHARACTERISTICS OF COASTAL PLAINS

The Coal Measures environment has often been described as a coastal plain:- this section will thus be concerned with a consideration of deltas, delta plains and alluvial plains.

"A delta is a partly subaerial, contiguous mass of sediment, deposited around the point where a river enters a standing body of water" (Galloway, 1975). The majority of deltas flow into marine basins, although others debouche into fresh/brackish/hypersaline lakes and lagoons.

Deltas can be subdivided into physiographic zones (Fig. 3.1). The *subaqueous delta* is that portion of the delta which lies below the low-tide water level (Wright, 1978). At the basinward edge of the delta, distal, fine-grained sediments are deposited from suspension; these are collectively named the prodelta, and form the foundation of a deltaic sequence.

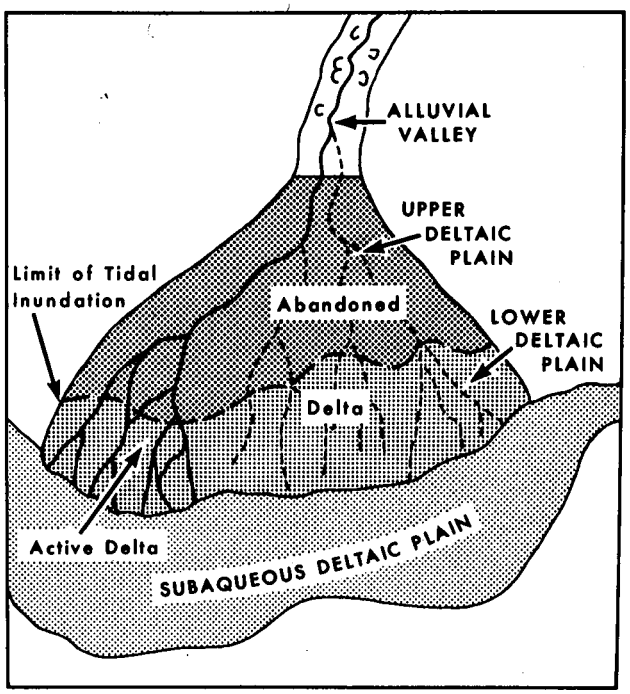
Prodelta sediments grade upward and landward into the more varied clays, silts and fine sands of the delta front. The delta front is often a complex of sedimentary environments, which can include distributary mouth bars, tidal ridges and shoreface beaches.

The *subaerial delta* is that portion of the delta complex which lies above the low-tide limit (Wright, 1978). It may be subdivided into two parts, the upper delta plain and the lower delta plain. The term "delta plain" is used as in Elliott (1978), and as with most other authors, i.e., to describe only the subaerial portion of the delta, and is not used as a general descriptive term for the entire delta complex, as in Wright (1978, p. 9). Delta plain deposits will often reflect a wide variety of processes, but will normally be much thinner than subaqueous delta deposits. The lower delta plain extends

Fig.3.I

BASIC PHYSIOGRAPHICAL ZONES OF DELTAS

(After Wright, I978)



from the lower tide limit up to the landward limit of tidal or marine influence, and the upper delta plain lies further landward.

Deltaic complexes may also be divided into active and abandoned portions (Fig. 3.1). The active delta is that part which is accreting, occupied by functioning distributary channels. Abandoned deltas are formed when the locus of deltaic sedimentation changes position, following a shift in the course of a channel towards a shorter or higher-gradient path to the receiving water body. Once abandoned, the "constructive" deltaic deposits may be re-worked and modified to varying extents by tidal, wave and other sedimentary processes to form the delta-destructive component of a sedimentary sequence (Elliott, 1978).

While the ultimate control on the existence and location of a delta is fluvial, the detailed morphology may be fashioned by several influences. The major controls on delta morphology are climate, relief within the source area, water discharge, sediment yield, river mouth processes, wave power, tides, alongshore currents, wind systems, shelf slope, receiving basin geometry and its underlying tectonic regime (Heward, 1976). Of these, the most important influence is the balance between fluvial, tidal and wave processes.

Fisher *et al.*, (1969) illustrated that various delta morphologies reflected the relative importance of these three major factors, Coleman and Wright (1975) defined six delta types depicted by sand distribution patterns, and Galloway (1975), after Fisher *et al.*, (1969), designated three main categories of deltas; wave, tide and fluvial-dominated types. These were used as the apices of a ternary scatter plot, and various deltas were represented according to their particular balance of influence.

Research on the processes of delta formation, and on deltaic facies, was dominated initially by the work of Gilbert (1885, 1890) on the lacustrine deltas of Lake Bonneville, U.S.A. Rigorous sedimentological analysis of modern deltas began in the 1920s, with the realization that ancient deltaic deposits contained huge reserves of coal, oil and gas. Early works on the Fraser River (Johnson, 1921, 1922) and Mississippi deltas (Trowbridge, 1930) were following by a focusing of attention towards the modern and Recent Mississippi systems which continued until the 1960s (Russell, 1936; Fisk, 1944, 1955; Coleman and Gagliano, 1965).

At the same time, facies analysis of ancient "deltaic" successions was undertaken, particularly in the U.S.A. These studies often emphasized the cyclic or "cyclothemic" nature of deltaic sequences.

While pre-1960 comparisons between deltas were largely concerned with demonstrating similarities, van Andel and Curray (1960) emphasized that the marked variations between deltas should not be underestimated. Subsequently, studies of modern deltas were noticeably more conscious of variability between deltaic forms and governing processes. Recently, several reviews of the deltaic environment have been published, describing the continuum of variation between wave, tide and fluvial-dominated deltas (Fisher *et al.*, 1969; Coleman and Wright, 1975; Wright, 1978; Elliott, 1978; Miall, 1979).

With the increase in documentation of modern deltaic sequences, including the results of drilling programmes, there was a resurgence of facies analysis during the 1960s, and also the advent of vertical sequence analysis (Oomkens, 1967, 1970). Elliott (1973) presented a synthesis of data on modern deltaic systems, recognizing vertical sequences characteristic of various deltaic environments, and then

applied vertical sequence analysis to Carboniferous deltaic sediments in the northern Pennines and north Devon areas of England. Heward (1976) presented an updated review of deltaic sequences and derived behavioural models for various hypothetical deltaic settings.

Another recent approach to deltaic sequence interpretation, here termed morphology analysis, attempts to delineate the general shape of deltaic sandstone bodies from regional thickness patterns (e.g., Brown, 1979; Greimel and Cleaves, 1979). From this data it is possible to suggest controlling influences on delta morphology. The method is based on the work of Fisher *et al.*, (1969), and is applied largely to arrays of borehole data.

Deltaic sequences deposited in shallow water, and in fresh or brackish water, differ considerably from those of deltas prograding into deep, marine basins.

Heward (1976) summarized the characteristics of *shallow- and fresh-water deltas* (Fig. 3.2). Essential features of shallow-water deltas are:

(1) thin sequences,

(2) channels cut through entire sequences,

(3) fluvially-dominated, high-constructive, elongate or lobate morphology,

(4) development of traction current-dominated distributary mouth bar deposits due to frictional attenuation of inflowing river water,

(5) thin prodeltaic and distal bar sediments, of suspension origin,

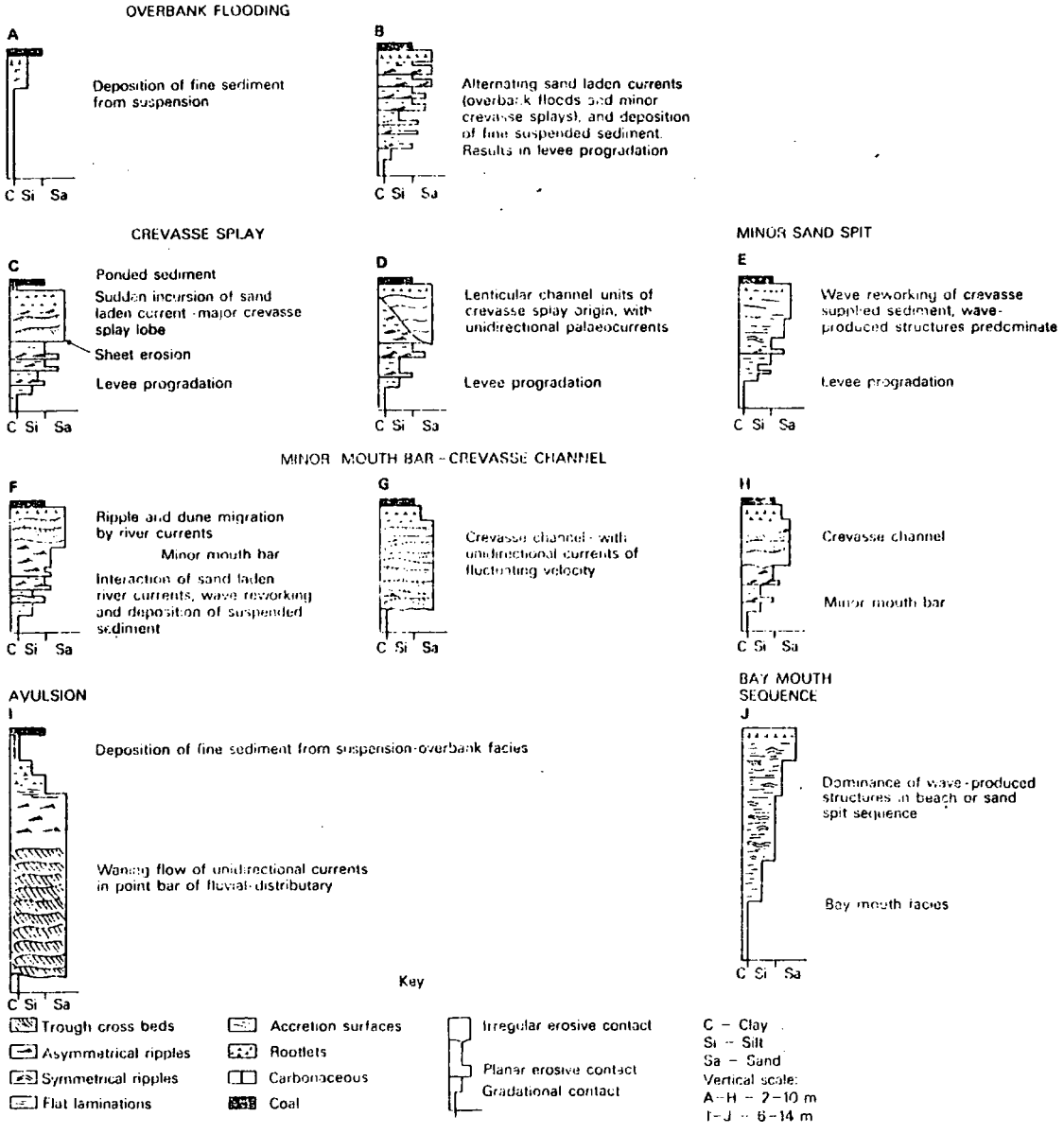
(6) thin progradational facies, partially or totally reworked by advancing distributaries,

(7) predominance of aggradational facies,

Fig.3.2

VERTICAL SEQUENCES PRODUCED BY SHALLOW WATER DELTAS

(After Elliott, I974).



(8) variable delta-destructive deposits, dependent on climate, degree of stability and degree of reworking, and

(9) a high proportion of delta-destructive deposits in a deltaic sequence.

Fresh-water deltas (modern examples of which are also shallow-water types) are characterized by:

(1) low salinity in the receiving basin,

(2) fresh/brackish water fauna,

(3) high-constructive elongate to lobate morphology,

(4) thin sequences (generally up to 10m),

(5) inflowing river water of equal density to or greater than that of the receiving basin (homopycnal or hyperpycnal inflow),

(6) traction current-dominated mouth bar sediments with complex networks of sand lobes, and

(7) common evidence of fluctuating base level.

Published studies of modern fresh- and shallow-water deltas are comparatively rare; notable works are those by McEwen (1969) on the Trinity River delta, Kanes (1970) on the Colorado River delta, Donaldson, Martin and Kanes (1970) on the Guadelupe delta, Oomkens (1967, 1970) on the Rhone delta, Coleman (1966) on the Atchafalaya basin, van Heerden and Roberts (1980) on the Atchafalaya delta, Butzer (1971) on the Omo delta and Hyne, Cooper and Dickey (1979) on the Catatumbo delta. These studies constitute the only described modern analogues to the fresh- and brackish-water deltaic systems which often seem to have been larger and more widespread in the geological record.

The majority of the described deltas are of the "suspended load" or "mud-dominated" type, and this also seems to have considerable

effect on the sedimentary sequences formed by these deltas (Meckel, 1972; Sneider, Tinker and Meckel, 1978). It is also significant that the majority of studied examples are situated in areas with tropical or subtropical climates.

Ancient shallow-water/fresh-water deltas have been described from several parts of the world, and geological periods, among them the Namurian of northern England (Elliott, 1973), the Westphalian of eastern and central U.S.A. (Ferm and Horne, 1979; Hyne, 1979), the Palaeocene of central-west U.S.A. (Flores, 1981), the Permian of South Africa (van Dijk, Hobday and Tankard, 1978) and, among many others, the Westphalian of Great Britain (see Chapter II).

Many of the described modern "suspended load" type shallow and freshwater deltas occur within the delta plain of a major marine delta (e.g., Oomkens 1967, 1970; Coleman 1966), which is the general setting often postulated for the Coal Measures of Great Britain.

Delta plains are typically extensive lowland tracts, comprising active and abandoned distributary channels separated by shallow water lakes, swamps, and near-emergent or emergent surfaces. The distributary channels act as a filter of the fluvial discharge, dividing it between themselves and transporting it to the delta front. These areas, situated close to or above the water surface, are especially sensitive to climatic conditions.

The lower delta plain, or the area between the delta front and uppermost limit of tidal influence, is characterized, predictably, by evidence of tidal processes. Distributary channels are typically straight, or nearly so, have a funnel-shaped form, and show evidence of bidirectional flow. Interdistributary areas of lower or tidal-influenced tidal plains take on the character of tidal flats, with lagoons and tidal creeks, often in very complex arrangements,

such as those of the Niger delta plain (Allen, 1965a).

Upper or fluvially-dominated delta plains are either enclosed by beach ridges at the seaward end, pass downstream into a tide-dominated or tide-influenced (lower) delta plain, or are open at the seaward end and pass directly into the delta front (Elliott, 1978). Distributary channels are characterized by unidirectional flow, some influence from basinal processes and variable sinuosity and channel type, ranging from highly meandering to straight, braided or anastomosing. The influence of basinal processes is characteristic only of distributary channels, not of alluvial channels, as is the frequency of channel avulsion or switching, caused by slight changes of gradient creating shorter, steeper distributary courses. Distributary channels thus commonly display low width/depth ratios, due to their relatively short-lived nature. Despite these differences, the sedimentary facies and sequences of distributary channels can be quite similar to those of alluvial channels, making the distinction between the two types in the rock record often rather difficult. In the ancient, however, the overall context of a sedimentary sequence will provide indications as the presence or absence of distributary channels.

The interdistributary areas of upper delta plains are usually enclosed shallow-water environments, often with little wave or current agitation (Elliott, 1978). However, during periods of flooding, excess discharge is diverted into these lakes and bays from distributary channels, either by crevassing or overbank/levee flooding. Flood discharge is the most important source of sediment for these environments; partially or completely infilled areas may become platforms for plant colonization in humid regions, or evaporite and calcrete development in areas of semi-arid or arid climate.

Interdistributary areas are characterized by a wide variety of facies and vertical sequences, reflecting the influence of several processes. The areal distribution of processes operating on the upper delta plain is governed largely by the proximity to active distributary channels; areas near channels will be characterized by levee and crevasse lobe sediments, and distal regions by fine bay floor sediments or crevasse channel/minor mouth bar couplets (Elliott, 1974). Wave reworking of crevasse and mouth bar sediments may be significant in open waters, such as are found in the interdistributary bays and lakes of the Mississippi delta (Fisk *et al.*, 1954; Saucier, 1963), (Fig. 3.2).

The upper delta plain of a river delta merges upstream into the *alluvial plain* of that river. The lower limit of the alluvial plain is usually taken where the lowland area carrying the river concerned begins to widen, on approaching the coast or other point of debouchement (Coleman and Wright, 1971). This, however, is an arbitrary boundary, and does not reflect any abrupt change in depositional processes or environments. Rather, the change is a subtle one, achieved over a considerable upstream distance from the fluvial and distributary channel-dominated upper delta plain to an entirely fluvial plain. Such a transition may be very difficult to detect in the ancient.

Alluvial plains may resemble deltaic plains in many respects; they are broad, flat areas traversed by rivers, between which are low-lying overbank areas and more elevated parts. Floodplains are overbank regions rarely inundated by waters from river floods, and floodplain sedimentation rates are low, due partly to high flood velocities, and low concentrations of suspended sediment during floods (Collinson, 1978). Floodplains may be almost continuously

subaerially exposed, may periodically dry out, leading to the development of dessiccation features, or alternatively, may remain permanently moist, waterlogged or even substantially below permanent water level, whereby floodbasin lakes and swamps develop. Close to channels, sediment may build levees, sloping away from the channel; these are most common on the concave banks of meandering rivers. Levees, however, have low preservation potential because of this. Crevasse splays are also common features, formed during flood periods when the channel bank is breached, and sediment-laden water courses down into the overbank area.

Sediments in overbank areas are very sensitive to climatic conditions; in arid and semi-arid settings vegetation is sparse and calcretes, leached soil profiles and dessiccation features may develop. Conversely, in humid areas, vegetation is often prolific and luxurious, and peat swamps are common. Semi-permanent or permanent lakes are most abundant in humid settings, and may be fed by river water and sediment, via lacustrine deltas, or isolated from channel influence and affected only by occasional flood sedimentation. This may be one way in which floodplain lakes could be distinguished from deltaic interdistributary bays; the further upstream, the more likely these standing water areas are to be enclosed. This feature may, however, be difficult to detect in the ancient, except with high quality exposure.

The rate and type of sedimentation in floodplain lakes will depend on a number of factors, including the rate of clastic sediment supply, rate of subsidence, the climatic regime and oxygenation of the lake.

Modern alluvial plains are described, among many others, by Fisk (1944), Wolman and Leopold (1957), Coleman (1969), Collinson (1978) and Nanson (1980).

River channels themselves are the subject of a vast literature, dealing with all aspects of channel formation and operation. Rivers have been classified by many authors according to a number of "end members" of the spectrum of channel morphology variation:- meandering, straight, braided and anastomosing (Miall, 1977). Rivers of each type are said to generate particular sedimentary sequences, and these are quite well-described, for example, by Miall (1977, 1978) for braided rivers, Allen (1965b), McGowen and Garner (1970) and Jackson (1976, 1981) for meandering rivers, Collinson (1970) and Bluck (1976) for low sinuosity rivers and Smith (1974) and Smith and Smith (1980) for anastomosing rivers. Unfortunately, it has recently become apparent that these sedimentary sequences are not diagnostic in themselves, and that considerable variety may occur within a given morphological type. This, in addition to the observation that there is a continuous spectrum of variation between the often-quoted morphological end-members (Walker, 1978), makes the identification of a particular channel type in the rock record very difficult to achieve without exceptionally good data control. Most recently a channel classification has been proposed which is based on the geometry of deposits (Friend, Slater and Williams, 1979; Friend, 1981; Atkinson, 1981).

Allied to the study of alluvial plains and channel development, essentially in two dimensions, is that of alluvial architecture, which examines the vertical structure of alluvial sequences (e.g., Allen, 1974). Numerous theoretical computer simulation models have been derived, for example by Leeder (1978), Allen (1978, 1979a), Bridge and Leeder (1979) and Crane (1981), and the concepts initiated in these models have recently been used in the interpretation of suites of ancient fluvial sediments (Atkinson, 1981; Hirst, Friend and Ramos, 1981).

It is not yet possible to relate these studies to modern environments, simply because there has not been, to date, a deep drilling programme undertaken to elucidate the three-dimensional structure of a modern alluvial plain.

There have been numerous sedimentological interpretations of ancient sequences in terms of deltaic and alluvial plain environments. It is not intended to provide a comprehensive review of these works, but it may be useful to mention a few important contributions. Ferm and Cavaroc (1968) provided the first integrated study of deltaic plain and alluvial plain environments, in the Upper Carboniferous of West Virginia, U.S.A., after previous work by Ferm and Williams (1965). Subsequently, Ferm (1974), Horne *et al.*, (1978) and Howell and Ferm (1980) modified and refined the original depositional model, and several more such models have recently been published (Pedlow, 1979; Beaumont, 1979; Flores, 1979, 1981).

Unfortunately, the distinctions between upper and lower deltaic plains and between upper deltaic and alluvial plains are very subtle, and the transition between these zones may take place over great distances. Furthermore, one or more of these zones may be very poorly developed in any given alluvial/deltaic system. Not surprisingly, these models seem difficult to apply, and are of questionable value in resource exploration (one of their original intentions; see Horne *et al.*, 1978).

One possible way in which environments might be distinguished is by the early diagenesis of their sediments. The composition of initial pore waters might be expected to differ between sediments of marine affinity and those of entirely non-marine sequences, and

perhaps between entirely subaqueous and subaerially-exposed/rootlet-penetrated parts of delta top sequences, leading to distinctive differences in early cementation/dissolution patterns. The early diagenetic history of emergent or shallow submerged sediments might also be expected to reflect contemporary climatic regime to some extent.

Jonas and McBride (1977, p. 101) and Fuchtbauer (1981) have discussed possible facies control on sandstone diagenesis, and case studies involving coal-bearing sequences have been documented by, for example, Ferm (1962) and Hawkins (1978).

CHAPTER IV - THE NATURE AND ORIGIN OF COAL AND SOME ASSOCIATED SEDIMENTS

4.1 COAL

"Coal" has been defined in many ways, but perhaps most adequately, from the geological point of view, by Schopf (1956):- "Coal is a readily combustible rock containing more than 50% by weight and more than 70% by volume of carbonaceous material, formed from compaction or induration of variously altered plant remains similar to those of peaty deposits. Differences in the kinds of plant materials (type), in the degree of metamorphism (rank) and range of impurity (grade) are characteristic of the varieties of coal."

There are several classifications of coal, based on type, rank and grade. One of the most commonly-used type classifications is that proposed by Thiessen (1931), and modified by Parks and O'Donnell (1956), (Fig. 4.1). In this scheme, the group of Banded (or humic) coals has been subdivided into Bright, Semisplint and Splint (Dull coal), and that of Non-banded (or sapropelic) coals into Cannel and Boghead. Whereas the Banded coals are composed largely of various groups of plant-derived macerals*1, the Non-banded coals are formed "from the physical and biological degradation products of existing coal-peat swamps, together with the addition of other remains" (Moore, 1968a). These include algae and spores, commonly in association with remains of fungal affinity. Boghead coals are composed largely of algal remains, whereas cannels are made up of miospores. Between these two end members are rocks comprising varying proportions of algae and spores.

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*1 Macerals may be considered as the organic equivalent of minerals.

Fig.4.I

TYPE CLASSIFICATION OF COALS

(After Thiessen, I93I, and Parks & O'Donnell, I956)

	Type	Main Components	Opaque Matter per cent	Anthraxylon per cent
I.	Bright coal	Anthraxylon + Translucent attritus	< 20	> 5
	Semisplint	Translucent and Opaque attritus	20 - 30	
	Splint	Opaque attritus	> 30	
2.	Cannel	Attritus with spores		< 5
	Boghead	Attritus with algae		

Notes

I. - Banded coals
2. - Non-banded coals

Anthraxylon - remains of woody parts of plants, giving rise to bright coal.

Attritus - macerated and degraded plant material, giving rise to dull coal.

Reviews of the properties and characteristics of coal are given by Barrabé and Feys (1965), Stach (1975) and Crelling and Dutcher (1980), among others.

The Durham coals exhibit a wide range of rank, quality and type, but are mostly bituminous coals of various grades and types (Smith and Francis, 1967). Coals of the other areas studied are similar to those of Durham in most respects.

Estimates for the ratios of compaction between peat and bituminous coal vary from 1.4/1 to 35/1 (Ryer and Langer, 1980), though values of 10-12/1 are most popular.

A number of workers have estimated rates of peat accumulation in modern swamp environments, and these may give some indication as to the periods of time involved in the accumulation of coal seams (Fig. 4.2). Some of these estimates, however, refer to mangrove swamps along present day coastlines, and as such are not strictly analogous to the British Westphalian peats.

Calculation of a rough "average" for fluvial/deltaic peats gives a figure of 1200 years for the accumulation of 1m peat, and assuming a compaction ratio of 10-1 and continuous, uniform accumulation, an estimate of approximately 12000 years for the "accumulation" of 1m of bituminous coal.

Using this figure, which may only be regarded as being "order of magnitude" in accuracy, estimates may be made for the time necessary to "accumulate" any coal seam in this study and also for for that involved in the deposition of clastic partings between two "leaves" of a split coal seam (Fig. 4.2).

Fig.4.2

PEAT AND COAL ACCUMULATION RATES, AND THE CALCULATION OF SHALLOW BASIN LIFE-SPANS FROM COAL SEAM SPLITTING PATTERNS

A. Published estimates of peat accumulation rates.

	Location	Source	Rate
I.	Everglades, Florida	Scholl, I964	I-2ft/IOOOyrs
2.	Borneo	Muller, I964	I2m/4OOOyrs
3.	Borneo	Stach ,I975	3ft/3-4OOyrs
4.	Okefenokee, Georgia	Spackman et al.,I976	Iin/26-97yrs
5.	Mississippi	Frazier & Osanik,I969	2ft/IOOyrs
6.	W.Germany (Eocene brown coal)	Stach ,I975	3ft/I-2OOOyrs

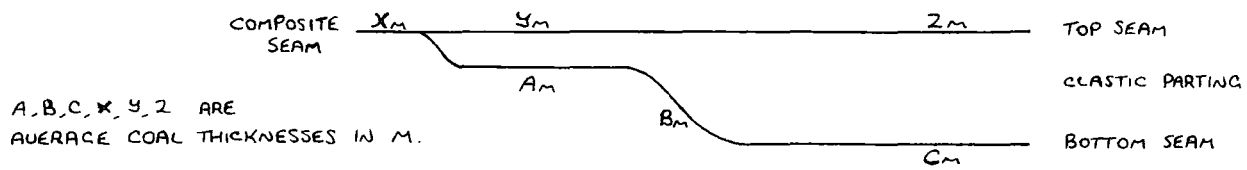
B. Estimation of a valid average peat accumulation rate for the British Coal Measures.

Cases I - 4,above, refer to coastal mangrove swamps, and are not strictly analogous to the Coal Measures. An approximate average of Cases 5 and 6 yields Ift peat $\simeq$ 4OOyrs,

and assuming a compaction ratio of IO:I,

Ift coal = 4OOOyrs and Im coal = I2OOOyrs

C. These figures may be used to estimate the "life-span" of inter-seam clastic sequences under certain conditions ;



The time taken to accumulate the Bottom-Top seam clastic parting at various points in proximity to such a seam split may be estimated as follows ;

at "AY", time = χ - (Y+A) x I2OOO
"B" , time = χ - (Y+B) x I2OOO yrs
"CZ", time = χ - (Y+C) x I2OOO

since the most valid estimate of "post-clastic parting" peat accumulation is gained from a position close to the line of splitting, and assuming I. uniform rate of peat accumulation, and 2. continuous peat accumulation at χ.

The realization that coal is derived from vegetable matter came probably in the 18th century with the writings of de Buffon (1778) and von Beroldingen (1778), (pre-20th century references not seen; reviewed in Scott, 1976). Botanists, becoming interested in the composition of coal, discovered that the remains of several types of plants were represented (Brogniart, 1828-38). Following this development, attempts were made to reconstruct the palaeobotanical environment of coal formation (Unger, 1847; Geinitz, 1855), and the picture of a coal swamp forest emerged.

Attention then turned towards detailed anatomical description of the plants preserved within and around coal seams, and also the role played by those plants in forming layers of coal.

The principal bone of contention concerned the relative importance of "*in situ*" plant growth and drifted "allochthonous" material. Further discussion related to the climatic setting of coal deposits; following the work of Potonié (1909) and White (1913), a tropical or subtropical environment was generally accepted. At this time, interest was aroused in the stratigraphic importance of plant fossils, and much work was published between 1880 and 1940, particularly by Kidston, Dix and Crookall.

The "*in situ*" vs. "derived" debate over the origin of coal seams remained unresolved for some time, following the initial arguments supporting (Cogan, 1841) and refuting (Fayol, 1887) the "*in situ*" contention. Most workers supported the "*in situ*" concept, pointing out that the presence of a seatearth beaneath most coal seams argues strongly towards development in place. However, some investigators, particularly those active in the "Gondwana" coalfields of Africa and Asia, contended that coals could be derived by drifting of plant remains into the environment of accumulation, for example, Fox (1930).

It has for some time been generally accepted that the majority of coals formed *in situ*, in large, freshwater swamps (Raistrick and Marshall, 1939). The water table conditions giving rise to the various types of peat/coal are by no means clear, however (Smith, 1962; Teichmuller, 1962; Smith and Butterworth, 1967; Hacquebard and Donaldson, 1969). Cannels and bogheads (sapropelic coals), in contrast to most humic types, are probably drifted accumulations of spore or algal material.

The arguments in favour of an "*in situ*" origin for British Westphalian coals may be summarized as follows:

(1) The occurrence of a seatearth beneath most seams, displaying roots and vertical compositional changes, implies that seams were underlain by a soil profile.

(2) The presence of separate floral assemblages (a) below and within, and (b) above, coal seams, implies that coal seam vegetation was not drifted in the same manner as plant debris deposited in enclosing sediments (Marshall and Smith, 1965).

(3) Clastic material, where present in coal seams, is generally confined to thin, discrete partings or "bands". The bulk of the coal itself is virtually free of clastic sediment contamination. This would be unlikely were the plant material washed into place.

(4) Coal balls, previously thought to be sedimentary particles, were demonstrated by Raistrick and Marshall (1939) to be formed in place by diagenetic processes.

(5) The presence of root structures within some coal balls indicates that plant growth was not merely confined to the initial stages of peat formation (Trueman, 1954).

(6) The wide lateral extent and uniformity of thickness of most coal seams is not consistent with a drifted origin, since much more variation in thickness and lateral extent would be expected were this the case.

Taken in combination, these arguments leave little doubt that British Westphalian humic coals are most adequately explained by an "*in situ*" growth mechanism. However, a number of features of these seams are considered by some workers to be not entirely compatible with "*in situ*" accumulation:

(1) The lack of any relationship between the thickness of many coals and that of their associated seatearths.

(2) The apparent lack of preserved root structures within coal seams.

(3) The almost perfect bedding in coal.

(4) The occurrence of different floral assemblages in seatearths, coals and roof sediments, and different spore assemblages within seams.

(5) The apparent lack of upright tree stumps in coal seams, as opposed to their relative abundance in roof sediments.

(6) The presence of pockets and layers of fusain within seams of bright coal.

(7) The interbedding of coal and fine clastic sediment often with transitional contacts, at the top of many seams, and the existence of "coaly shales" and "shaly coals".

(8) The occurrence of discrete clastic partings within coal seams, usually parallel to the bedding of the coal, and often composed of sand grade sediment.

(9) The presence of flattened, aligned plant stems on bedding planes within coal seams and associated lithologies.

It is thus possible that the contribution of allochthonous debris to coal seams has been seriously underestimated in the recent past. The origin of coal seams in the Durham coalfield will be considered, in detail, in Chapter 9, but it is relevant here to consider each of the above points in turn.

(1) The apparent lack of any relationship between the thickness of a coal seam and that of its' associated seatearth does not seem likely to be the result of "mutually exclusive" development of the two features. Moore (1968b) pointed out that the development of rooting represents the colonization of a sediment surface by "pioneer" hydrophytic plants, before eventual habitation by xerophytic swamp vegetation, and need therefore bear no relation to the overlying swamp-derived peat. In addition to the influence of floral community succession, the relative thickness of peat and rooted sediment will vary with the water table, decay rate and erosion of peat, compaction of sediments and the availability of nutrients, among other factors. Furthermore, Guion (1978) pointed out that after the inception of peat accumulation, swamp plants would become rooted in the peat itself, and have little further effect of the sediments beneath.

(2) The lack of preserved root structures within coal seams may be explained by the environment of fossilization. Whereas roots may be well-preserved in relatively uncompactable clastic sediment, preservation of root filaments is unlikely in a casing of peat, where compaction of up to 20:1 may take place, and where there is no contrast in sediment type.

(3) Bedding in coal is likely to be a compactional feature. In sediment composed of relatively fragile, incompetent particles where compaction may be of the order of 10:1, complete re-orientation and re-alignment of constituents must take place.

Curtis *et al.*, (1980), working on the development of clay fabrics in mudrocks, concluded that "preferred orientation in clay-rich sediments results almost entirely from compaction strain." If complete re-alignment of clay particles can take place in mudrocks (with a compaction ratio of perhaps 3:1), it seems probable that the development of a preferred orientation fabric can occur during the compaction of peat, resulting in a laminated rock.

(4) The occurrence and distribution of various types of floral remains beneath, within and above coal seams has been the subject of much discussion. Smith (1962, 1968) discovered a zonal distribution of spore assemblages within coal seams, which he attributed to the response of the plant community to changing water-table levels during the development of the peat bog. The commonest profile developed was described as *Lycospore* → *Transition* → *Densospore* → *Transition* → *Lycospore*, reflecting gradual build-up of the bog surface, followed by submergence, as subsidence overtook the rate of growth. The occurrence of well-developed *Transition* phases and the well-defined, restricted spore assemblage within each phase forms good evidence for the ecological succession argument. A further spore assemblage, however, named the "*Incursion Phase*" by Smith, contains a much wider range of

species, many of which exhibit a corroded character, implying an allochthonous origin.

Spores, however, make up only a small part of most humic coals, and distributions of these remains unavoidably emphasize those species which produce abundant spores (Scott, 1977a).

Evidence relating to the nature of the coal swamp flora (including that from spores) suggests that lycopods were the dominant type of native vegetation (Smith, 1968; Scott, 1976, 1978, 1979). Certainly the macroscopic floral assemblage associated with coal seams is dominantly, often exclusively, of lycopod affinity. Seatearths are dominated by Stigmarian root systems, intraseam bedding planes and permineralized coal balls commonly contain only *Sigillaria* and *Lepidodendron* fragments, and upright "tree trunks" preserved in clastic sediments above coal seams are mostly of lycopod types (Marshall and Smith, 1965).

Deviations from this pattern, for example *Calamites*-dominated seatearths and coals, pteridosperm-dominated roof shales, can be explained by floral community succession and by depositional processes subsequent to the termination of peat formation. (*Calamites* is well-known as a "pioneer", and may often have been the first plant type to colonize a sediment surface). One feature which has caused some concern is the almost complete termination of lycopod occurrences in roof shales overlying coal seams. However, it is likely that any sediment derived from outside the coal swamp will not contain or preserve significant remnants of swamp vegetation. Such blanket coverage of a coal swamp, effectively terminating plant growth and forming roof

sediments would leave only occasional upright trees protruding through the sediment cover. From the author's own observations, some coal seams with an upper boundary characterized by transition to laminated claystone (suggestive of very slow sediment accumulation) do contain flattened lycopod fragments in the "transitional phase". However, the comparative lack of large (horizontal) lycopod remains in roof sediments is still something of an enigma. Perhaps those trees left standing after partial burial by sediment were allowed to rot completely, breaking down into small pieces before being distributed over the lake floor. It is possible that the waters carrying the swamp-terminating sediment were rather better-aerated than those of the swamp itself, leading to more rapid and effective aerobic decomposition of any unburied vegetation.

(5) As with root structures, the preservation of upright tree trunks in a bed of coal seems extremely difficult to achieve. Encasement of very easily-compacted material in a matrix of similar composition is unlikely to prevent complete destruction of original structure. Furthermore, the style of preservation of most tree trunks in the Coal Measures, that of silicified pith casts, would not be possible in a casing of peat.

(6) The occurrence of lenses or discontinuous layers of fusain within coal seams is a feature difficult to explain purely in terms of autochthonous processes. Scott (1976), in a detailed study of the origin of fusain, concluded that there was abundant evidence to support the theory that this material represents the fossilized remains of charcoal. Given that many lenses and layers of fusain are probably

remnants of burnt plant material, there remains the question of how they arrived in their present location. Most accumulations of fusain are very localized and areally insignificant (a few square metres, or less). It is therefore rather more likely that these accumulations arise from subaqueous transportation of carbonised plant material from distant forest fires than that they were brought about by small fires "*in situ*". Significant in this respect is a study of the erosional disintegration of charcoal fragments in aqueous flows by Harris (1958), who concluded that charcoal will break down into small particles relatively rapidly, but then survive long periods of transportation in this state.

(7) The interbedding of roof coal and clastic sediments, and the presence of "high-ash" coals is unequivocal evidence for the deposition of clastic sediment concurrent with the accumulation of vegetable matter. What is not entirely clear is the contribution made by current deposition; much of the fine grade sediment (ash) found in coal seams may simply have fallen out of suspension from the water column, and can hardly be said to be "allochthonous". Intervals rich in clastic detritus may merely reflect more rapid fallout from suspension, due possibly to a change in water chemistry or circulation patterns. Related to this is the observation that a coal swamp characterized by dense vegetation is likely to act as a successful sediment filter, reducing the effectiveness of any current movement to a minimum.

(8) Clastic partings within coal seams are quite common, and usually lie concordantly within a seam. These partings, or

"dirt bands", are difficult to account for in terms of an autochthonous origin. Certain coal seam "bands" may be ascribed to "*in situ*" processes (pedogenesis, diagenesis and soft-sediment injection; see Chapter 4.4). However, a significant proportion are almost certainly of primary sedimentary origin.

(9) The presence of flattened, aligned plant stems within and adjacent to coal seams, particularly in association with mudstone partings and high-ash coals, is also difficult to reconcile with the idea of an exclusively autochthonous accumulation. The alignment in these plant stems can only have been produced by hydrodynamic processes, implying the action of currents capable of transporting and depositing sediment.

From the above discussion, it is apparent that many coal swamp deposits may have been in part allochthonous, particularly towards the end of a particular swamp's effective life, when the rate of subsidence may have been overtaking that of *in situ*, organic accumulation. Autocompaction of basal layers in the swamp peat may have assisted subsidence in this respect. Plant debris might then have floated a short distance, under the influence of aqueous currents or winds, before becoming waterlogged and sinking to the lake bottom. It is extremely unlikely, in a fresh-water forest swamp setting, that vegetation was derived from any great distance, since any persistent, strong currents transporting vegetable matter would also be certain to introduce large quantities of clastic sediment.

4.2 COAL BALLS

"Coal balls consist of rounded, spheroidal or irregular masses of mineral matter preserved within a coal seam ..." (Moore, 1968b). These masses of permineralized (petrified) coal are most commonly composed of calcite and dolomite, with traces of other minerals, and occur mostly within coal seams underlying marine sediments. Similar concretionary masses are commonly found in seatearths underlying these seams, and in marine shales overlying them.

Coal balls have been the subject of considerable interest in the past, for two reasons; firstly these hard masses of mineral matter constitute a safety risk in mining and an obstruction to efficient coal extraction, and secondly, they often contain plant and animal fossils in an exceptional state of preservation (Stopes and Watson, 1909; Mamay and Yochelson,1962).

That coal balls are formed under the influence of marine conditions is fairly certain. However, the mode and timing of formation has been open to some debate. The mineralizing fluids must have percolated through the affected seams very shortly after, or even during, accumulation of the peat, as evidenced by the uncompacted nature of fossil preservation. Theories advanced for the derivation of mineralizing fluids include:

(1) upward migration of marine-derived waters (Evans and Amos, 1961),

(2) mixing of meteoric and marine waters (Hanor, 1978), and

(3) downward migration of marine waters (Moore, 1968b).

Mineralization is inferred by many to have taken place subsequent to peat formation. However, the discovery in America (Mamay and Yochelson, 1962), and recently in Great Britain (Holmes and Scott, 1981), of marine animal fossils within coal balls has led to the development

of a concept of short-lived marine incursions concurrent with peat formation (Moore, 1968b).

In a recent stable isotope study of coal balls, a model was presented involving successive formation of coal ball zones upward through a peat seam, as it accumulated, (Anderson, Brownlee and Phillips, 1980). These authors invoked a complex origin for the mineralizing fluids.

Coal balls, particularly those containing marine faunal remains, are comparatively rare in Britain and seem confined in occurrence to the central Pennine coalfields, close to the inferred depocentre of the Westphalian Pennine basin and in the area of maximum marine influence.

4.3 SEATEARTHS AND PALAEOSOLS

The rootlet-penetrated sediments beneath coal seams have for a long time been described as fossil soils or palaeosols, hence the name "seatearth".

Moore (1968b), discussing the nomenclature of rooted sediments, considered the term "seatearth" to be misleading since, he argued, rooted sediments often bear little or no relationship to the coal seam above it. Moore, however, did not propose any alternative name, other than suggesting the term "palaeosoil" may become useful in the future.

The present author does not accept this argument, for the following reason; the term "seatearth" implies a base or platform of soil development, upon which further growth and accumulation may subsequently take place. The word does not necessarily imply any association with seams of peat/coal.

Any rootlet-penetrated sediment may be termed a soil, since soils need not be restricted to subaerial settings, but may develop under water (the so-called "hydromorphic" soils). Therefore, it is felt that in the context of the Coal Measures, the terms "palaeosoil", "palaeosol" and "seatearth" may be regarded as synonymous and equally valid.

A great deal has been published on seatearths, relating to their origin, field characteristics and relationships, geochemistry and mineralogy. Seatearths are root- and rootlet-penetrated sediments, and as such may be of any sedimentary type. They are, however, most commonly of clay or silt grade, and grey in colour. The composition of seatearths is variable, but the minerals quartz, kaolinite, illite, mixed-layer clays, chlorite and calcite predominate in any sample. Rootlets present within seatearths vary in disposition and mode of preservation, but are most commonly vertical, and preserved as root casts (Klappa, 1980). Other features common to seatearths are the presence of ironstone nodules, pyrite, listric surfaces, "slickensides" and a variable development of "horizonation". The presence of crude horizonation in seatearths has been reported, amongst others, by Weller (1957) and Moore (1968b), although their schemes appear to be simplistic and not widely applicable.

Guion (1978) reported a bipartite horizonation in Coal Measure seatearths of the East Midlands, the upper unit being pale-coloured, unstratified and heavily rootlet-penetrated, and the lower unit containing numerous ironstone nodules.

Having accepted that seatearths are sediments which may have once supported plant growth, the manner in which they acquired their character is still open to question. Various theories proposed in the past include:

(1) action of acid bog-waters (Weiss, 1910; Long, 1920 not seen - referenced in Grim and Allen, 1938),

(2) action of carbon dioxide from the decomposition of organic matter (Endell, 1910; Stremme, 1912 - as above),

(3) action of sulphuric acid in groundwater,

(4) sedimentation of vegetable matter and clastic material in oxidizing swamps (Stout, 1923),

(5) origin as water-laid sediment, subsequently modified (Hodson, 1927; Lovejoy, 1925),

(6) water-laid sediment without subsequent modification (Grim and Allen, 1938; Wilson, 1965).

(7) wind-deposited sediment (Weller, 1957),

(8) action of soil-forming processes (Worthen, 1866; Weller, 1957; Huddle and Patterson, 1961), and

(9) the action of burrowing organisms (Scheinfeld and Adams, 1980).

Some of these hypotheses are based on tenuous or questionable evidence, and many are obviously impracticable for the vast majority of seatearths.

Following a review of some previous hypotheses, Huddle and Patterson (1961) presented a well-considered theory for the origin of Pennsylvanian seatearths and flint clays (see Chapter 4.4) in the U.S.A., involving the deposition of fine clastic sediment and the crystallization of kaolinite in acid swamp environments preceding colonization by the main peat-forming flora. The possible contributions to the character of the seatearths made by leaching, other soil-forming processes and the action of "nutrient-accumulator" plant types were considered. Development of the peat-forming phase was inferred to have taken place immediately after the depositional

stage, causing further modification of the sediment, and the final character of the rock was considered to have been moulded during compaction and diagenesis. Guion (1978) proposed a similar model of seatearth formation, emphasizing the role of water-table levels.

These models are probably quite widely applicable, but it is evident that the infilling of shallow-water environments, necessary for the establishment of plant communities, may be achieved in several ways.

It is the author's opinion that the character of seatearths is largely the product of two factors:

(1) depositional processes, and

(2) pedogenic/weathering processes.

Since only these horizons penetrated by roots and rootlets possess their particular mineralogical composition and other characteristics, amongst Coal Measure sediments, it may be safely assumed that colonization by plants played an important role in producing those characteristics. It is relevant in this respect to note that soils may form in any type of sediment, given favourable conditions, and that initial lithology will be a controlling influence on the final character of the seatearth/palaeosol. Diagenetic modification may also play a signficant role, in some cases.

All seatearths are to some extent soil profiles, since the preservation of roots *in situ* is unquestionable evidence of pedogenesis in some form. Little detailed research has been carried out on Coal Measure palaeosols. However, from a review of literature concerning British Coal Measure sediments, and from the author's own observations, it would appear that examples of several types of soils

are probably preserved within the Coal Measures, notably podzols, podzolic soils and gleyed podzols (Percival, 1981), gleys (Elliott, 1968; Guion, 1978), vertisols (Williams, 1968), ferrisols, ferrallitic soils and ferruginous soils (Besly, 1979), organic soils inceptisols and fluvisols. It is thus relevant at this point to consider each of these soil groups, particularly in the context of a tropical, coastal plain.

Podzols and Podzolic Soils

The development of a podzol or podzolic soil (Podzols, podzoluvisols and luvisols according to the FAO-Unesco (1974) Classification) results from leaching (eluviation), to varying extent, from the upper part of the soil profile, and accumulation in a lower horizon (illuviation), usually in conditions of free drainage (Muir, 1961). Podzols, developed typically beneath heath or coniferous forest, display the characteristics of leaching to the greatest extent. In these soils, an extremely acidic surface humus formation develops, decomposing slowly. Water percolating through the surface levels develops an acidic character and collects water-soluble breakdown products from the plant material, which then form organic complexes with various cations, and move downward through the ground.

Thus iron, aluminium and other ions are mobilized and removed from the upper parts of the soil profile (A horizon), leading to a breakdown of the clay minerals. At the same time, silica, in the form of quartz, accumulates relatively, thereby forming the eluviated or albic horizon. Lower down in the profile, leached ions are precipitated, forming the illuvial or spodic (B) horizon (Fig. 3.6 of Bridges, 1970). Explanations for this deposition include pH changes, breakdown of organo-metallic complexes, presence of flocculating ions and wetting/drying cycles.

Podzolic soils, while also displaying features indicative of leaching, are developed under less acidic conditions than those governing formation of podzols. In these soils, a richer soil fauna allows a more rapid breakdown of plant material. Clays are washed down from the A horizon and deposited in the B horizon, producing an upper leached zone and a lower, clay-enriched or argillic horizon. In this process the clay is not chemically broken down, as in podzolization, but mechanically washed downward through the soil profile (a process known as "lessivage"), (Fig. 3.7 of Bridge, 1970).

Gleyed podzols are those soils which display characters indicative of both podzolization and gleying (waterlogging). They will be discussed in the following section.

The soil profiles produced by podzols typically have a thin peaty surface layer (A_0/A_1), a light grey bleached A_2 horizon and an illuvial B horizon which is usually strongly coloured, containing an iron-rich zone and often a humus-rich zone also. The B horizon usually grades downward into weathered parent material (C horizon). While the boundary between the A_1 mixed organic/mineral zone and A_2 bleached zone is commonly transitional, that between the A_2 and B horizons is most commonly abrupt, as are the junctions between the separate zones within the B horizon, where more than one is developed.

On a microscopic scale, the bleached A_2 horizon will, if well-developed, be composed almost entirely of quartz, with occasional heavy minerals and very little clay or feldspar. The illuvial horizon should be very rich in iron oxides, carbonates, silicates, etc., and organic matter.

Podzolic soils are similar in appearance and structure to podzols but lack the sharply-bounded iron/aluminium-rich and humus-rich B horizon accumulations characteristic of podzols. In their

place are paler-coloured (often yellow or brown), clay-enriched zones with a much greater development of transitional boundaries between horizons. As the B horizon displays less evidence of illuviation, so the A horizon will show fewer signs of eluviation, and will often be grey-brown in colour. In addition, the surface organic layer and A_1 organic/mineral layer are commonly thin or absent.

Under the microscope, the A horizon of a podzolic soil will display quartz enrichment, as with that of podzols, possibly to the extent of being composed exclusively of quartz. The B horizon, however, will display progressive enrichment of clays downward, followed by impoverishment. Much of this washed clay material may be deposited as argillans, or clay cutans*1, which form rims around and between "skeleton" grains in soils. In these areas, sepic plasmic fabrics*2 may also be found. Other features characteristic of such soils include diffusion ferrans (iron-rich cutans), surface crusts, well-developed peds and insect burrows (krotovinas!), (Retallack, 1976; Brewer, 1964).

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*1 Cutan: "A modification of the texture, structure or fabric at natural surfaces in soil materials due to concentration of particular soil constituents or *in situ* modification ..." (Brewer, 1964, p. 206).

*2 Plasma is defined as that part of the soil material which is capable of being moved or has been moved, reorganized and/or concentrated by the processes of soil formation (Brewer and Sleeman, 1960); *plasmic structure* is the organization of the constituents of the plasma that have not been concentrated or crystallized to form pedological features and the associated very small voids which result from the packing of grains; *sepic plasmic fabrics* are plasmic structures in which there are recognisable anistropic domains with various possible patterns of preferred orientation (Brewer, 1964; Percival, 1981).

Podzols and podzolic soils are not common in the tropics, being confined mostly to areas with cool, humid, temperate climates. However, examples do occur (Vine, 1966; Hardon, 1937), particularly in association with other features, such as gleying. Many leached soil profiles in the tropics develop on alluvial floodplains, in sandy parent material, and in climates with high rainfall (Kalpagé, 1976; Young, 1976), while others form at higher altitudes, on mountain-sides. It is therefore apparent that, given conditions of free drainage, podzols and podzolic soils could have formed in the environment postulated for Westphalian times in Northern England.

The most striking feature of a podzol or podzolic soil is the textural and colour contrast developed between the A and B horizons, and it is this which is most likely to remain as a diagnostic attribute when such a soil is preserved in the ancient. Apart from the tonal contrast, the passage from a quartz-enriched upper zone down into clay-enriched or iron/humus-rich zones should make podzols and podzolic soils relatively easy to recognize in the sedimentary record, even (or particularly) after diagenetic modification.

Previous research on podzol and podzolic palaeosols includes work by Percival (1981), Retallack (1976,1977) and Pearson (1973). Pearson (1973) interpreted a palaeosol profile in the Westphalian A of South Yorkshire as the product of a leached, oxygenated, soil-forming environment. Retallack (1976, 1977), describing a series of palaeosol profiles from the Triassic of New South Wales, Australia, recognized remnants of grey/brown podzolic soils in an inferred cool,temperate,coniferous forest environment. Percival (1981), after consideration of highly siliceous rooted sandstones

(ganisters) in the central and northern Pennines of northern England, interpreted many of these rocks, and their associated sediments, as podzol and podzolic soil profiles. Many of Percival's (*op. cit.*) ganister profiles display a very pronounced lithological contrast between the inferred A and B horizons, in that the base of the ganister itself (A horizon) is sharp and noded, and underlain by clay-rich sediments (B horizon).

Hydromorphic Soils

The presence of poor drainage conditions in soils leads to the process of gleying, and to the formation of hydromorphic soil profiles (Gleysols and planosols, according to the FAO/Unesco (1974) Classification). Gleying occurs when water saturates a soil, filling all the pore spaces and driving out all the air (Bridges, 1970). In such a situation, anaerobic, reducing conditions are soon established, and in the presence of unoxidized organic matter, ferric iron compounds are reduced to the ferrous state. In this condition, iron is very soluble, and removed from the profile, leading to the commonly-developed drab grey colouration of gleys.

Two basic types of hydromorphic soils may occur:

(1) true gleys (groundwater gleys), and

(2) surface-water gleys (pseudogleys).

(1) True gley soils, or groundwater gleys, are formed under the influence of fluctuating groundwater, whereby water rising in the soil from an impervious horizon beneath the soil profile saturates the ground. Partial aeration of the soil may occur along cracks, burrows and root channels, and if the water table lies beneath the surface at any time, may also occur in the uppermost levels of the soil.

(2) Pseudogleys, or suface-water gleys, are formed above the normal groundwater table by stagnation of pluvial water usually in clayey soils, through the development or presence of an impervious horizon within the soil profile. This impervious horizon may be formed by a clay-rich illuvial horizon, by a dissolution residue or by a lithological contrast. Such conditons often develop temporarily in normally well-drained soils subjected to seasonal flooding, resulting in temporary water-saturation until pluvial water eventually drains through cracks and other channels in the soil. Water within such channels is generally reducing.

The drab grey colouration of gleys is produced by reducing conditions, occasionally broken by mottled patches representing local aeration, often along root channels. Alternatively, if the groundwater level is below the ground surface, only the lower part of the soil may be reduced. Iron- and/or manganese-rich mottles and concretions are common and may be concentrated along root passages (Keller and Frederickson, 1952). Iron sulphides are sometimes present, and may be either disseminated or concentrated in patches and blebs. The tone of grey in the soil will vary to a large extent with the amount of contained organic matter, which in turn depends on the Eh signature of the profile; the more reducing the conditions, the more unoxidized organic matter is likely to be preserved, and where the groundwater table lies above the surface, substantial accomulations of organic matter may develop in the top-soil. In this respect it is significant that gleys "are often transitional to organic soils" (Bridges, 1970).

On the microscopic scale, gley soils are characterized by lack of red pigment, presence of iron-rich accumulations, particularly around root passages, iron sulphides and abundant, well-preserved organic material. Root and rootlet impressions are unlikely to be destroyed by oxidation, and are usually preserved as black, carbonaceous casts (Klappa, 1980). Clay skins (argillans) do not normally form beneath permanent groundwater table unless they are weathering products of primary minerals (Brinkman *et al.*, 1973), and where originally present are likely to have been destroyed by reduction. Thus asepic, or occasionally undulic, plasmic fabrics are present (Brewer, 1964).

Pseudogleys are broadly similar in appearance to true gleys, but show more pronounced mottling effects. Concretions are again common, but are not concentrated along root passages, and organic material should be largely restricted to root and rootlet impressions. Pseudogleys often develop a sharp, highly irregular contact between the upper, permeable part of the profile and the impervious layer, due to the formation of "drainage channels" through a former illuvial horizon (Buurman, 1980). It is important to note that pseudogleys are usually formed by periodic or progressive superimposition of water-saturation on previously well-drained soils, and may thus display any stage of a spectrum of development (Buurman, 1980). Often, only the areas around root passages in a soil will show evidence of reduction. Beneath the impervious layer, well-drained conditions may predominate down to the permanent groundwater table.

Microscopically, pseudogleys will show signs of reduction superimposed upon features of an aerated, well-oxidized soil fabric

(destruction of argillans, sepic plasmic fabrics and red pigment, and preservation of organic matter). Overprinting of gley and pseudogley features is also possible.

At the present day, gley and pseudogley soils are widespread throughout the world, their formation being dependent only on conditions of poor drainage, and not on any particular climatic regime. They are common in lowland areas, particularly on river floodplains and coastal areas, often associated with mangrove swamps. Gley soils are thus likely to be the dominant form of palaeosol in the British Westphalian environment, accepting the standard model of a low-relief, coastal plain crossed by numerous channels.

The features of gleys and pseudogleys most likely to be preserved in the ancient are the grey colouration and mottling, associated abundantly-preserved rootlets and plant debris, iron sulphide/carbonate nodules and concretions and poor horizonation. In the absence of other diagnostic features, gleys may be distinguished from pseudogleys by the presence or absence of concretions along root passages. In a gley paleosol profile where the groundwater table was below the surface, it may be possible to determine the water-table level, and degree of fluctuation, from the distribution of grey colouration and mottling characteristics of the palaeosol.

Published work on gley and pseudogley palaeosols is scarce. Roeschmann (1971) studied Carboniferous "Coal Measure facies" palaeosols in West Germany, and offered some comments on the possible palaeoclimatic and stratigraphical significance of these rocks. Retallack (1977) recognized humic gley and gleyed podzolic profiles in the Triassic of New South Wales, Australia, which he interpreted as having developed on a low-lying coastal plain. The most recent study to be published is that of Buurman (1980), who invoked stagnating pluvial water and fluctuating groundwater

conditions associated with fluviomarine sedimentation to explain inferred monogenetic and polygenetic gley and pseudogley profile development in Palaeocene sediments of the Isle of Wight, England. These sediments were shown to display several features indicative of varying groundwater conditons; abundant contemporary red colouration, clay illuviation, iron and manganese segregation, destruction of argillan structures and clay-enriched horizons, and bleaching along voids.

Similar, though not as detailed evidence for fluctuating groundwater conditions was discussed by Allen (1964), Daley (1973), McBride (1974) and Stewart (1981a). Several sedimentological studies of Coal Measures facies mention the abundance of hydromorphic soils (for example, Elliott, 1969; Huddle and Patterson, 1961), but only in passing.

Organic Soils

Organic soils (Histosols, according to the FAO/Unesco (1974) Classification) are usually developed on poorly-drained ground, often in association with hydromorphic soil types. Peat accumulations are encouraged by wet conditions, caused by high rainfall, high ground-water levels, seepage or flooding. Seepage waters and high groundwater levels are usually responsible for maintenance of lowland peat accumulations, commonly in the form of raised bogs. Upland peat often accumulates in "blanket bog" conditions, though other varieties are known.

Peat soils generally consist of relatively thick layers of organic debris in various stages of decomposition, and often admixed with fine mineral matter, underlain by a grey (commonly water-logged) mineral horizon.

"Peat" and "muck" soils (Coulter, 1950) occur quite extensively in the humid tropics, generally in low-lying, ill-drained areas. Also fairly extensive are the "cat-clays" (Kalpagé, 1976) which develop through periodic drainage and aeration of peats, causing streaks of ferric sulphate to penetrate the profile.

It is apparent that preservation of peat by burial under reducing conditions will eventually lead to the development of coal, and thus organic soils are likely to be well-represented in the Coal Measures! Organic palaeosols, i.e., coals, are the subject of a vast literature; see Chapter 4.1.

Latosols

Ferrallitic soils, ferrisols and ferruginous tropical soils (known as latosols according to FAO/Unesco (1974)) are leached, red and yellow soils, developed under freely-drained conditions, in a climate with high rainfall and temperatures.

The process of ferrallitization involves the development of moderately acidic conditions in the upper part of the profile, leading to silica removal from clay minerals in preference to iron and aluminium, which accumulate and oxidize to sesquioxides. Hardened iron and/or aluminium crusts (laterites) may form by this process, particularly if the climatic regime involves a marked dry season.

As silica moves down through the soil profile, the acidic conditions may allow some recovery in the form of kaolinite crystallization. Much of the silica however, along with sodium magnesium, calcium and potassium, is lost, and there is little or no development of an illuvial B horizon. One exception to this may occur in climates with a pronounced dry season, where precipitation of silica in the lower part of the profile may form a hardened "duricrust" or "silcrete" horizon (Smale, 1973).

Ferrallitic soils represent the most evolved products of this weathering and leaching process. They have little horizonation and are deep, friable, porous soils with kaolinite enrichment and occasional ferruginous concretions in the lower levels of the profile (Bridges, 1970).

Ferrisols resemble ferrallitic soils in most respects, but display one marked difference. The peds* of the soil frequently have glossy surfaces, composed of alumino-silicate gel which moves through the profile. Glossy ferruginous concretions may also form in these soils.

Ferruginous soils are formed in areas experiencing a pronounced dry season.

They display rather more stratification than the previous two types, often having well-developed eluvial and illuvial horizons.

Microscopic characteristics of these soils will reflect the leaching process and the breakdown of clay minerals to form sesquioxides. Authigenic kaolinite should be well-developed, possibly in association with silica and iron oxide/hydroxide concretions. Trends in silica depletion may be recognizable in some cases, and argillans may be well-developed, particularly in the case of ferrisols.

The ferrallitic, ferrisol and ferruginous soils, are widespread throughout the humid tropics, tending to occur in well-drained upland areas. In lower-lying topographic settings, similar soils with more yellow colouration often occur, where moister conditions are prevalent. These are known as yellow latosols.

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* Ped - "an individual natural soil aggregate consisting of a cluster of primary particles, and separated from adjoining peds by surfaces of weakness"; Sleeman (1963).

The most striking feature of the latosol group is the red or yellow colouration. It is this and certain microscopic features, such as authigenic kaolinite, silica and iron oxide, silica depletion and clay mineral breakdown, and the ubiquitous presence of iron oxide dust rims to skeleton grains, that are likely to be preserved in the sedimentary record. Stratification in these soils, where present, is often subtle and likely to be masked by widespread oxidation of minerals.

Besly (1979) described red-bed sediments and palaeosols in the Westphalian C Etruria Marl Group of central England. He interpreted many of these palaeosols as polyphase "laterite-type" profiles, involving the accumulation of iron and silica at certain levels, but with periodic flooding and development of reducing conditions, witnessed by the development of coals and bivalve-bearing mudstones.

Latosol profiles were also described by Bown and Kraus (1981) and Johnson (1981) from Wyoming, U.S.A. and the Himalayas respectively.

Vertisols

A further group of soils common to lowland areas in the tropics, particularly those subject to periodic wetting and drying, is the Vertisol group. Vertisols, or "Vlei soils", are usually dark-coloured and contain abundant mixed-layer and smectitic clays. The presence of expandable clays leads to the widespread development of large, deep cracks as the soils dry out, and by this process the soils may even become inverted. Peds may have glossy surfaces in the upper parts of vertisol profiles, and in the lower parts, ferruginous streaks and calcareous nodules may be common. Micro-relief features are often developed, called gilgai or pseudo-anticlines. The black colouration of these soils, in association with a high content of expandable clay and the presence of vertical cracks may be diagnostic

of vertisols when preserved in the sedimentary record. Cracks will tend to be filled and subsequently slightly folded on compaction.

The author has encountered no direct study of ancient vertisol palaeosols in the literature. However, Williams (1966, 1968), working on the Westphalian Coal Measures of Pembrokeshire, West Wales, described seatearth profiles ("sphaerosiderite-bearing coarsening-upward sequences") containing little-deformed, sand-filled cracks in the upper levels. These were interpreted as "penecontemporaneous deformation structures" by Williams (op. cit.), and the profiles themselves were ascribed to "infills of enclosed or partially enclosed freshwater lakes". It seems more likely, however, that these cracks are due to dessiccation of wet, clay-rich sediment.

Recent vertisol palaeosols were described by Butzer (1971) from the Omo delta plain, Ethiopia.

Inceptisols

The final group of soils to be considered are those set aside by the (American) Soil Survey Staff classification 7th Approximation (1960) as "Inceptisols". These are incomplete developments of soil profiles, and may be of any type, previously described or otherwise. The author believes that this is a useful category, particularly with respect to study of the Coal Measures, where soils often may not have had sufficient time to develop fully. The diagnostic features of inceptisols are the developments of part-profiles, or incipient development of profiles. Many of these units may simply be preserved as virtually undisturbed sedimentary units, the only evidence of pedogenic development being a few rootlets penetrating the lamination.

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Several groups of soils have not been taken into consideration in this discussion of tropical soils, notably halomorphic soils, calcimorphic soils and desert soils. These are all associated with arid and semi-arid environments, and as such bear little relevance to studies of the Westphalian Coal Measures of Great Britain. As far as the author is aware, no primary development of these soil types has taken place in the major coal-bearing facies of the British Westphalian.

There are several features, particularly on a microscopic scale, which are characteristic or suggestive of soil development in general, but not of any type in particular. These include pedotubules, glaebules, crystallaria/subcutanic features, faecal pellets and many plasmic fabrics, according to Brewer (1964). Teruggi and Andreis (1971), however, contend that several of these features, particularly voids, glaebules and crystallaria, can be produced by other processes, or are unstable under diagenesis, and are thus unsuitable as pedogenic indicators.

The preservation of soil profiles in their original form is dependent on a mild diagenetic evolution, and little structural deformation. In this respect, it is significant that the majority of well-preserved, documented palaeosols are little older than Tertiary in age, for example, those described by Buurman (1980), Brown and Kraus (1981) and Johnson (1981). Overprinting, particularly of different Eh and pH conditions, may easily destroy many diagnostic features of palaeosols. Johnson (1981) postulates that "soils likely to be preserved in the rock record are commonly those which have undergone incremental addition of new material (alluvium) and which therefore represent depositional systems in which the pedogenic

"clock" must have frequently been reset to zero." On the other hand, a greater period available for soil development will result in thicker and better-defined profiles, greater textural maturity and better-developed peds (Retallack, 1976).

In a depositional system which was sporadically accreting, such as the Westphalian Coal Measures of Britain, the pedogenic "clock" must have frequently been reset, and partly or fully-developed pedogenic profiles temporarily or permanently buried. One might, therefore, expect to find abundantly-preserved evidence of pedogenesis in these rocks, some of which may indicate considerable profile maturity.

4.4 KAOLINITE CLAYROCKS AND INTRA-SEAM PARTINGS

4.4.1 The characteristics of kaolinite clayrocks

In the Westphalian Coal Measures of Great Britain, and in many other coalfields of the world, there exists a suite of sedimentary rocks characterized by being composed predominantly of kaolinite. These rocks are known variously as tonsteins, flint(y) clays, toasted clays, fragmental clayrocks, bauxitic clays and kaolinite clayrocks. They are generally massive, light grey-coloured, unlaminated rocks, which break often with a conchoidal fracture. They are commonly well-indurated and brittle, though some occurrences are less well-consolidated, even plastic in nature.

The mineralogy of kaolinite clayrocks is dominated by kaolinite in various structural states (a complete range from structurally disordered to well-ordered has been recorded; Loughnan, 1978), often to the virtual exclusion of other components. Organic matter is the other major constituent of these rocks, and accessories include quartz,

rock fragments, feldspars, illite and other clays, zircon, rutile, epidote, sphene, tourmaline, apatite, garnet, siderite and hematite.

Kaolinite clayrocks occur as thin (usually up to 10s of cms thick) units, generally with well-defined boundaries. They occur most commonly, though not exclusively, in association with coal-bearing rocks, and often within coal seams themselves. Loughnan (1978) argued that the suite of kaolinite clayrocks display sufficient common properties to warrant their grouping in a single sedimentary facies, the "kaolinite clayrock facies."

While it must be accepted that the various types of kaolinite clayrocks do display many common features, it is equally apparent that similar lithologies may be produced in various ways, particularly in the context of kaolinite genesis in tropical swamp environments.

4.4.2 The origin of kaolinite clayrocks

Various theories have been proposed to explain the occurrence and genesis of kaolinite clayrocks around the world. These are reviewed in turn.

4.4.2.1 Theories involving kaolinite formation outside the swamp environment

Air-borne transport

Deflation of soil cover has been suggested by some authors to explain concentrations of kaolinite in clay grade sediments (Ashley, 1928; Wanless, 1952).

Water-borne transport

Termier (1923) suggested that if soils in the swamp hinterland were eroded, kaolinitic sediment might be flushed into coal-forming swamps. Teichmuller, Mayer and Werner (1952) suggested that redistributed kaolinite might form tonsteins (kaolinite clayrocks). Loughnan (1978) considers that "the majority of authors ... favour an allochthonous origin for flint clays", citing the absence of weathering profiles associated with flint clays as precluding an autochthonous origin. However, he includes formation from a colloidal gel in his "allochthonous" category. Loughnan (*op. cit.*) believes that detrital particles of kaolinite commonly form kaolinite clayrocks, withstanding the rigours of subaqeous transport and undergoing some form of sorting and grain selection. The use of such diagnostic features as the presence of well-preserved leaf impressions and worm burrows! however, hardly lends credence to such a hypothesis, and the origin of the kaolinitic material itself remains unresolved.

Transport of kaolinite in a colloidal gel would seem a rather more feasible proposition (Keller, 1968), but still involves problems of sediment sorting.

4.4.2.2 Theories invoking kaolinite formation within the swamp environment

Alteration of volcanic ash

Many kaolinite clayrocks have been interpreted as altered volcanic ash falls. Quoted diagnostic features include lateral continuity and uniformity of profile over a very large area (up to several thousand sq. kms) despite a thickness, often, of only

5-10 cms, presence of euhedral, splintered or embayed quartz grains, restricted (non-diagenetically modified) heavy mineral assemblages, fresh sanidine feldspar and biotite,pseudomorphs after biotite and hornblende, volcanic rock fragments, sediment particle grading, lateral passage into bentonite (mica-montmorillonite) deposits, trace element criteria and sharp contacts with other lithologies (Williamson, 1970).

Such beds of kaolinite mudstone occur widely in the Westphalian Coal Measures of Western Europe, and have been named "tonsteins". Many tonsteins are traceable over much of north-west Europe, and are thus of great stratigraphic use as they represent (on a geological timescale) instantaneous deposition. Both acidic and basic types of tuff have been recognized (Spears and Kanaris-Sotiriou, 1979), though in Western Europe the basic varieties appear to be confined to Great Britain, implying a relatively local volcanic source. Those tonsteins thought to be produced by acidic volcanism, however, are widespread across Europe, and may be derived from the Armorican orogenic belt.

Elsewhere, kaolinitic bands in the Cretaceous coal-bearing sediments of Utah (Ryer *et al.*, 1980) and Montana (Rodgers, 1914), the Upper Carboniferous of Pennsylvania (Ashley, 1928) and the Namurian of central Scotland (Francis, Sabine and Young, 1961), among many others, have been interpreted as being of volcanic derivation. In all these rocks, kaolinite is inferred to have formed by alteration of feldspars, biotite and other minerals, in the coal swamp environment into which the ash fell (Stach, 1950).

The term "tonstein" has been widely applied to kaolinite clayrocks, only some of which may be satisfactorily interpreted as tuffs. At present, the most widely-accepted definitions of the word

are those with no genetic implication at all, such as that of Williamson (1970):- "tonsteins are dense mudstones containing kaolinite aggregates and crystals within essentially similar matrices". The term has thus become synonymous with "kaolinite clayrock." Possibly the best recent classifications of "tonsteins" are:

(1) the scheme proposed by Schuller (1951) and modified by Schuller and Hoehne (1956), based on the textures present within these rocks, and

(2) that of Burger (1980) which is based on the composition of the rock, including that of its' groundmass (Fig. 4.3).

Allied to the proposal of volcanic origin is that which involves the transport of ashes, produced by the burning of peat and vegetation, in the air, and deposition in swamps, where various alterations take place (Pietzner and Werner, 1963).

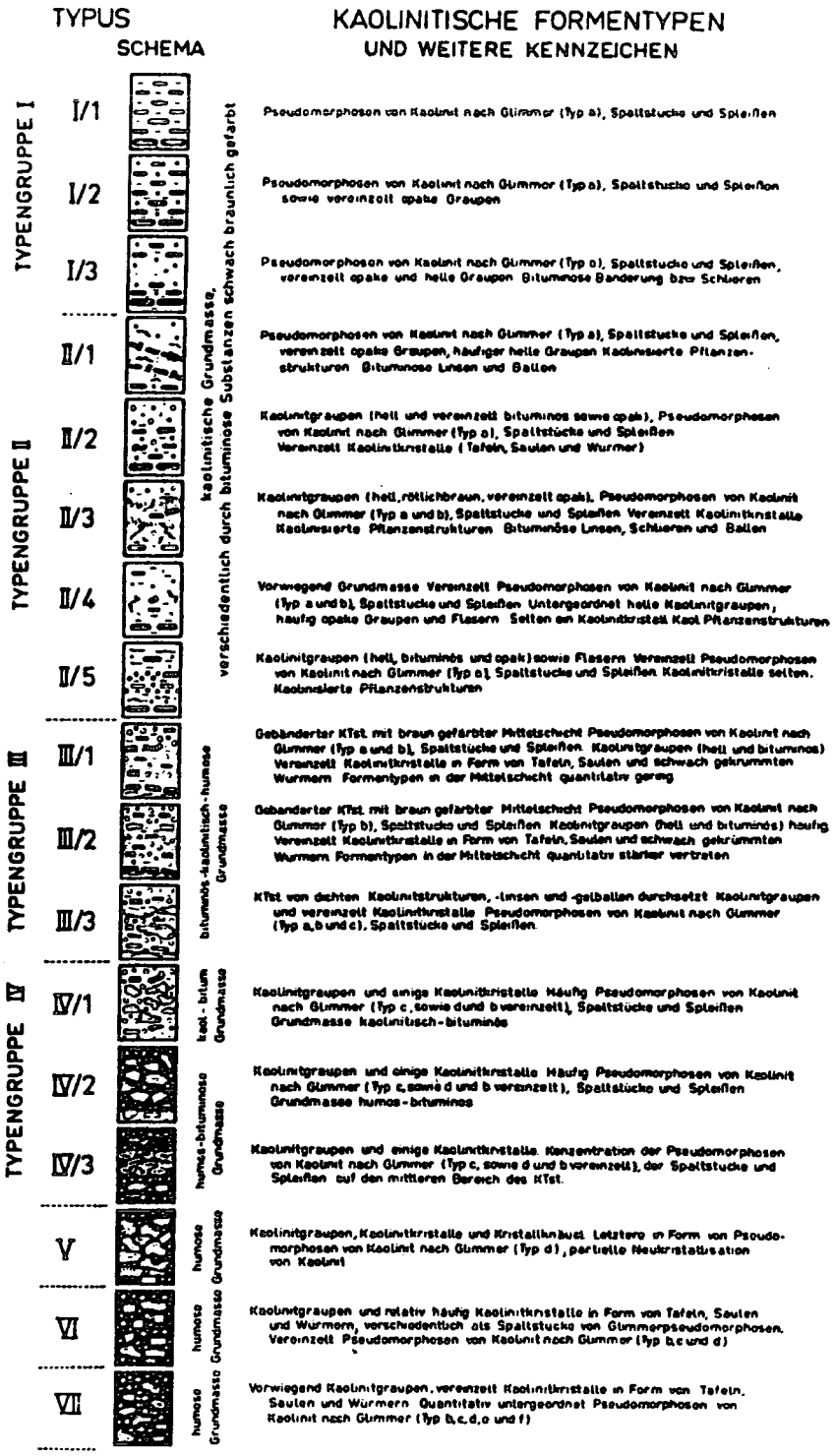
Alteration of water-borne allochthonous material

It has been suggested that "normal" clastic sediments, particularly those of clay grade, could be altered to kaolinite in the acid environment of a coal swamp. Support to this theory has been given by Rodgers (1914), Kulbicki and Vetter (1956), Scheere (1955), Moore (1968b), Keller (1968, 1981) and Tankard and Horne (1979), among others.

Keller (1968) concluded from a study of Upper Carboniferous flint clays in Missouri that the cryptocrystalline nature of the kaolinite present suggested an origin as a colloid or gel composed of alumina and silica. However, he suggested that most of the colloidal kaolin was produced by desilication reactions in soils fringing the coal swamp before being "washed in".

CLASSIFICATION OF TONSTEINS Fig.4.3

a) After Burger, 1980.



b) After Schuller, 1951, and Schuller & Hoehne, 1956.

1. Crystal tonsteins - with abundant kaolinite crystals, set in kaolinitic matrix.
2. Graupen tonsteins - similar, but containing crypto/micro-crystalline graupen
3. Dichte tonsteins - containing kaolinite crystals, quartz splinters and isotropic or aggregate-polarised matrix
4. Pseudomorph tonsteins - CONTAINING PSEUDOMORPHS OF KAOLINITE AFTER MICAS AND FELDSPAR
5. Transitional tonsteins - CLAYSTONES WITH SOME TONSTEIN AFFINITIES.

Tankard and Horne (1979), following consideration of the geochemistry of flint clay formation, contended that kaolinite and sanidine feldspar may have been products of the alteration of (detrital) illite in an acidic swamp. Their model involved erosion and transport of clays from weathered soil profiles, deposition in acidic swamps, rapid gel formation and conversion of illite to kaolinite by dialysis and dissolution. These authors used isopach maps to support their claim of an allochthonous origin for the parent material.

Keller (1981) proposed a similar model of flint clay formation in which detrital sediment was altered by synsedimentary diagenesis, involving desilication, partial removal of iron, alkaline and alkali earths to produce a kaolinitic mud, which then underwent recrystallization into interlocking crystals of crystallographically well-ordered kaolinite. Keller (*op. cit.*) concluded that the most important common conditions surrounding all flint clay formation were:

(1) presence of quiet-water swamp or flood-basin conditions,

(2) warm, humid climate conducive to prolific plant growth,

(3) abundant rainfall to aid the movement of ions,

(4) unconfined upper surface exposure,

(5) favourable inorganic and organic geochemical conditions for leaching of silica and metal ions,

(6) presence of abundant organic acids,

(7) adequate source of fine-grained aluminium-bearing parent material,

(8) relative geomorphic and structural stability of the area of sedimentation,

(9) simultaneous and continued maintenance of all these conditions throughout a long period.

Adequate evidence for the very early, essentially pre-burial formation of the kaolinite is cited by Keller (*op. cit.*), and by Kraus *et al.*, (1979).

Similar long-lived swamp and lake environments to those described above were previously invoked by Huddle and Patterson (1961) to expalin the mineralogy of some underclays, and by Richardson and Francis (1971) to account for the mineralogy of "fragmental clayrocks".

Organic/kaolinitic "oozes" seem common in modern swamp, lacustrine and even in fluvial settings (Staub and Cohen, 1979; Hyne, Cooper and Dickey, 1979; Jackson, 1981) and kaolinite has recently been discovered in high concentrations in the prodelta sediments of a lacustrine delta (Hyne, Laidig and Cooper, 1979).

Alteration of autochthonous material

It has become apparent that kaolinite residues or concentrations may have been formed by weathering, combustion or soil-forming processes.

Weathering of a basalt lava surface, followed by resilication of gibbsite and other high-aluminium minerals to form kaolinite, is thought by Curtis and Spears (1971), after Wilson (1922), to have formed the Ayrshire bauxitic clays, although this hypothesis has been challenged by Keller (1981) on geochemical grounds. Curtis and Spears (*op. cit.*) contended that the process of resilication was responsible for the prominent cracks and fractures displayed by flint clays, including the "fragmental clayrocks" of Scotland and northern England. Tankard and Horne (1979), however, explain these features as synaeresis and dewatering cracks.

In the Ayrshire occurrences, there is also evidence for some sediment redistribution and development of soil profiles. As has been noted in Chapter 4.3, kaolinite may be precipitated in the B

horizons of leached, ferrallitic/latosol tropical soils, and this is another potential major source of kaolinite-rich sediment.

Wanless (1952) contended that oxidation of peat, following emergence of a coal swamp, could lead to the formation of a mineral residue, rich in kaolinite, and Lapparent (1923) suggested a similar genesis, produced by forest fires. Moore (1964), in a study of the Erda tonstein, a kaolinitic mudstone bed of wide lateral extent in western Europe, concluded that an oxidized mineral residue origin was unlikely in that instance, and that the most feasible explanation for the genesis of the unit was as a soil, possibly lateritic, formed *in situ*. He considered that the most important factor controlling the development of a kaolinitic concentration was the position of the water table. Crystallization of kaolinite itself from a colloidal gel was considered to be an early diagenetic phenomenon. Moore (*op.cit.*) suggested that the groundwater level might be controlled by eustatic base-level changes, whereas, for a similar case, Tankard and Horne (1979) invoked a climatic control on water-table levels.

Patterson and Hosterman (1962) also suggested leached soil profiles to explain occurrences of Upper Carboniferous flint clays in Kentucky. However, Keller, Westcott and Bledsoe (1953) showed that in the Missouri flint clays, major and trace element distributions were exactly the reverse of that to be expected were the profile a leached palaeosol, and invoked a model of upward diffusion of ion-carrying fluids. Richardson and Francis (1971) and Loughnan (1978) pointed out that leaching of any kind in a hydromorphic soil profile was unlikely to be sufficiently effective to lead to kaolinite concentration.

Precipitation from solution

It has been suggested by some workers that silica and alumina may precipitate from aqueous solution to form kaolinite, which can then accumulate to form kaolinite clayrocks. Rodgers' (1914) study of a Cretaceous/Tertiary flint clay occurrence in Montana concluded that the most likely mode of origin of the kaolinite was as a chemical precipitate. Similar conclusions were made by Schuller (1951), Hoehne (1954) and Bouroz (1964), (not seen:- reviewed by Spears, 1970).

It is, however, unlikely that acidic swamp waters could hold large quantities of silica in solution (Blatt, 1966).

Diagenesis

Features suggesting that burial diagenesis (i.e., chemical changes taking place some time subsequent to the covering of the sediment) may play a part in the final development of kaolinite clayrock textures have been described by several authors. Kimpe (1966) suggested that the change in crystallinity of tonsteins in the European coalfields from Westphalian A to Westphalian C age was diagenetic in origin. Richardson and Francis (1971) invoked compactional failure of kaolinitic sediments during burial, leading to mechanical brecciation and flowage, to explain the texture of fragmental clayrocks.

4.4.2.3 Discussion

It is apparent from the preceding review that kaolinite clayrocks may be formed in many ways. Some theories, however, are rather open to question.

The formation of leached soil profiles, in what is essentially a waterlogged environment, requires substantial lowering of the water table. Eustatic lowering of sea level is hardly likely to take place at quite the periodicity required to explain all occurrences of kaolinite clayrocks, and it is equally difficult to envisage periodic climatic changes of the longevity required to form soil profiles.

It seems rather hard to imagine Coal Measure channels depositing thin layers exclusively composed of kaolinite particles, such as those described by Loughnan (1978). In any case, the existence of sedimentary particles of kaolinite merely implies erosion of a previously-existing kaolinite clayrock, and does not explain the genesis of the kaolinite.

The problems of sorting inherent in the hypothesis of allochthonous derivation of previously-formed kaolinite seem difficult to surmount, but it is worthy of note that in a tropical, coastal plain environment where kaolinite-rich units of sediment were forming, a very significant supply of "detrital" kaolinite might arise from erosion of those very units. Thus, the kaolinite within many kaolinite clayrocks may well be "polyphase" in derivation.

The recognition of volcanic derivation within a kaolinite clayrock is not easy; many criteria previously used to infer a volcanic origin are at best ambiguous, and at worst plainly invalid. Some mineralogical and petrological criteria are particularly open to question. For example, feldspars including sanidine, may be derived authigenically within sediment (Jonas and McBride, 1977, p. 84), and heavy mineral suites consisting of combinations from zircon, tourmaline, sphene, apatite, rutile, epidote and garnet are characteristic, not only of tonsteins, but also of Coal Measure sediments in general! Euhedral crystals may arise by development of authigenic overgrowths on detrital cores (Scholle, 1979; Ali and Turner, 1982), and even

features such as embayed quartz grains are not diagnostic. Clearly identification of a volcanic origin should be based on a consensus from several lines of evidence, and not from any one criterion. It is quite possible that erroneous interpretations have been made in the past, particularly on the basis of petrological evidence.

The formation of kaolinite from colloidal gels within the coal-forming swamp sediment seems to be a widely-applicable theory. Clearly though, conditions of pH, Eh and ion activities need to have been very specific, and the frequent association with coal seams may well be significant; perhaps certain organic acids released by peat under specific conditions were conducive to kaolinite formation. In this respect, the lateral passage of kaolinite clayrocks into "normal" clastic clayrocks is probably, though not definitively, indicative of a detrital origin for at least the host material.

In the author's opinion, the models of kaolinite clayrock formation involving fine-grained clastic sediment deposition, followed by kaolin gel formation and subsequent crystallization or recrystallization, such as those proposed by Tankard and Horne (1979) and Keller (1981), are the most widely applicable. There are still problems with these models, however; in a situation where a unit of fine sediment is undisturbed in a coal forming swamp for a lengthy period of time, without burial by clastic sediment, a higher organic matter content might be expected than is customarily present. Perhaps crystallization of kaolinite from kaolin gel took place after burial by organic debris or other sediment, by which time the chemical and physical conditions necessary to initiate formation may no longer have been needed to complete the process. The formation of thick flint clay beds such as those in the Upper Carboniferous of Missouri (Keller, 1981) demands the maintenance of special conditions over

very long periods of time, and evidently are somewhat exceptional.

Clearly, several origins are possible, and each individual occurrence deserves consideration on its' own merits.

PART B

THE DURHAM COAL MEASURES

CHAPTER V - STRATIGRAPHICAL SUBDIVISION AND TREATMENT OF DATA

5.1 STRATIGRAPHICAL SUBDIVISION

The most reliable method of subdividing the British Coal Measures is by use of "marine bands" (Calver, 1968a). These horizons tend to be concentrated in two groups, around

(1) the base of Westphalian A, and

(2) the boundary between Westphalian B and C,

and do not, therefore, allow a regular subdivision of the sequence (Fig. 2.4). In some parts of Britain, marine bands are supplemented by other horizons of widespread occurrence and chronostratigraphical significance, such as the volcanically-derived "tonsteins" of the Midlands.

However, in the Durham area there are few such horizons, and there are only occasional marine bands which are often difficult to identify and correlate with other regions. In local correlation, use has inevitably been made of coal seams, non-marine "fossil bands" and prominent sandstones, and the stratigraphical nomenclature is replete with a confusion of extremely local terms (Jones, 1980).

While the use of such lithostratigraphical markers does aid correlation of the local sequence to the extent of providing a usable stratigraphical column, probably few units have chronostratigraphical significance. Clearly, most sandstone bodies did not form instantaneously, and seams of coal, representing tens of thousands of years of peat accumulation, cannot be regarded as synchronous across their area of occurrence.

Similarly, there is little indication that widespread (non-marine) faunal accumulations formed simultaneously over their area of occurrence, although they probably imply the development of quiet-water conditions over a considerable period of time.

On the other hand, widespread marine bands seem to be the products of marine incursions controlled by external processes, and are likely to be more chronologically "discrete". Even then there may be a "slack" of possibly tens of thousands of years involved in the widespread development of a marine band, depending on the balance between the rates of sedimentation, local and regional, subsidence, and ? eustatic sea-level rise.

Accepting their limitations, coal seams and fossil marker horizons can still be used successfully to subdivide the Durham Coal Measures. In this study, the sequence is divided on the basis of, firstly, the occurrences of marine bands, and secondly on the many areally extensive coal seams in the region. These beds are thus used both as lithostratigraphical datum planes and, within the constraints discussed above, as coarse chronostratigraphical markers, in the absence of any superior method of stratigraphical subdivision.

The diachroneity of some coal seams will be aptly demonstrated in following Chapters, and wherever possible, attempts made to assess the time involved in the formation of particular sedimentary units or sequences.

5.2 TREATMENT OF DATA

5.2.1 Subsurface information

The difficulty in arriving at an unambiguous interpretation of one- and two-dimensional data has been mentioned previously. However, in this study, borehole information, essentially one-dimensional, often

forms a valuable addition to surface outcrop data.

While many older records (pre-1900) are somewhat questionable in their accuracy, more recent borehole and mining records are generally more reliable. Identifications of coal seams are probably accurate, as a result of the extensive history of mining in the Durham area and consequent knowledge of regional seam behaviour. Thicknesses of inter-seam partings seem accurate enough, as do those of coal seams themselves, although in the latter case these are often complicated by the presence of impure, shaly coal or "bands" within a seam.

Because the vast majority of borings and sinkings through the Coal Measures have been undertaken to prove occurrences of coal seams, the lithologies between those horizons are often poorly described, and the nature of contacts between sedimentary units ignored.

It is thus difficult,if not impossible, to make any environmental interpretation from the majority of borehole records, and these are generally used only as supporting data.

5.2.2 Channel belt maps

However, in association with patterns of seam "washouts" (areas where a coal seam has been erosively removed by later channel acitivity), borehole information has been used by the author in preparation of a series of "channel belt" maps for the Durham coalfield. These maps were produced from the recorded occurrences of major (10 m +), erosively-based sandstones, interpreted as channel deposits, in an attempt to assess the magnitude and position of

palaeochannels operating during specific stratigraphical intervals.

In many cases, particularly in the lower part of the Westphalian A succession, lateral control is poor, and so is the resulting resolution. However, higher in the succession, where records are more extensive, greater accuracy may be attained.

It is apparent from the size of these channel belts, the presence of "islands" of non-channel sediment, and the distribution of washouts and palaeocurrent vectors from outcrops, that each belt may represent a single stable channel, a belt of numerous co-existing smaller channels, or may be the deposit of a channel system which migrated across a broadly-defined area with time.

The channel belt maps are based on a thorough search of I.G.S., N.C.B. and other sources of subsurface information. Data points are not plotted on individual maps, to retain clarity and also at the request of the N.C.B. However, in general, maps are based on more than 200 data points, along with more generalized information from opencast sites, etc.

Despite their limitations, the channel belt maps are useful in providing palaeogeographical base-maps for each stratigraphical interval, and a regional context within which individual surface exposures may be placed.

5.2.3 Coal seam correlation

While the majority of workable coal seams in the Durham coalfield are persistent over hundreds of square kms, frequent changes in character occur, commonly over short distances. Where coals are of workable thickness, they are easy to trace laterally, but in the case

of thin seams (less than about 0.20m), lateral correlation becomes difficult. Because of uncertainty in the correlation of thin seams, no detailed interpretations have been made in this study which depend on such correlations.

The N.C.B. seam coding system used in this thesis is that recently devised by the N.C.B. Opencast Executive (Fig. 2.6). This scheme is not the same as that in use by N.C.B. Deep Mines.

5.2.4 Coal analyses

Chemical analyses of coal seams are commonly carried out by the N.C.B., two of the most widely-assessed parameters being potentially useful in environmental interpretations, namely:

(1) ash content, and

(2) sulphur content

Ash content is a measure of the non-combustible component in a coal, and provides an indication of the proportion of clastic material present. The sulphur content of a coal seam has been considered by many workers (Horne *et al.*, 1978; Bailey, 1981; among others) to relate to the influence of marine conditions on sedimentation. In the environmental models of Horne, Ferm and co-workers (see Ch. 3), Sulphur values of 2% or more are associated with coals from lower delta plain and back-barrier settings, whereas those from upper delta plain and fluvial plain environments contain much lower sulphur values. These associations do not, however, appear to be ubiquitous (see discussion by Flores and Ethridge, 1981).

Chemical analyses will be considered in conjunction with specific case studies.

5.2.5 Sandstone petrology

Sandstone petrology is a potentially valuable tool for the interpretation of depositional environments, environment-related diagenesis and climatic conditions. Textural and compositional parameters of sandstones are commonly used in environmental interpretations, and several textbooks discuss this topic (for example, Folk, 1974; Pettijohn, 1975; Jonas and McBride, 1977; Blatt, Middleton and Murray, 1980; Tucker, 1981). With this in mind, a study of Coal Measures sedimentary environments would be incomplete without incorporating some petrological data.

Unfortunately, the majority of sandstones in the Durham Coal Measures have been subjected to intense burial diagenesis, almost to the extent of zeolite/greenschist facies metamorphism. This has tended to produce complete recrystallization of any detrital matrix (< 30 μm) which originally existed (possibly up to 30% in some cases), elimination or drastic alteration of unstable detrital grains and fundamental changes to the fabric of framework quartz grains.

Clearly, any interpretations based on grain size, shape, sorting and even sandstone composition are inconclusive, given these conditions. However, original shape and size of quartz grains are often distinguishable from examination of dust rims, sorting can be at least approximately determined and original composition inferred from the characteristics of the remaining detrital fabric, and from the diagenetic style.

In the case of sediment sorting, the recrystallization of detrital matrix and of small, unstable framework grains will have caused an "improvement" in the sorting coefficient of any sandstone.

On the other hand, the computation of sorting parameters from thin sections has been shown to underestimate the degree of sorting in any sandstone (Harrell and Eriksson, 1979). Any measure of textural maturity (Folk, 1974), which is based on primary depositional fabric, is thus necessarily tentative.

Similarly, the compositional maturity of Coal Measure sandstones is likely to have been "improved", by the selective loss of unstable grains during diagenesis.

What can be said generally about the Coal Measure sandstones, despite their extreme diagenetic alteration, is that they contain a variety of original grain sizes and shapes, probably contained a high primary clay content, and probably were texturally and compositionally immature. Much of the original clay content of these sandstones is now represented by an abundant association of finely crystalline kaolinite and an illite-like mica (Plate 5.1),(Appendix 2).

The proportion of "non-detrital" phases in the Coal Measures sandstones is now commonly greater than 35%. Only some of this, however, may be called "cement" (minerals precipitated from pore fluids), or "authigenic" (new minerals formed "in situ"), since a large proportion of non-detrital material is derived from re-crystallization of original clay-grade sediments. This highlights another problem inherent in description and interpretation of the Durham Coal Measure sandstones.

The extensive recrystallization and cementation in the sandstones has also considerably reduced the original sediment porosity. In the case of fine-grained types, which constitute the majority of the Coal Measure sandstones, porosity is reduced to such an extent that it is almost impossible to impregnate blocks of sandstone thoroughly

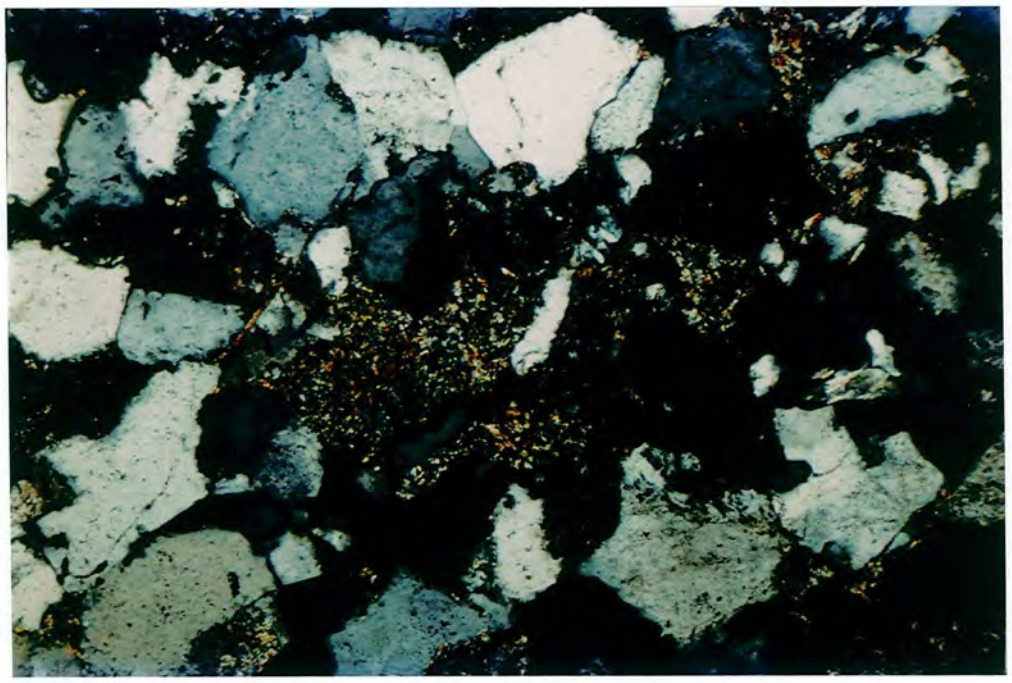


Plate 5.I - Photomicrograph of a typical Durham Coal Measure sandstone, showing the characteristic kaolinite/ /illitic mica cement association. Low Main Post, Croxdale Beck. Length of photomicrograph I.2mm. (Crossed polars).

with the coloured epoxy resin and impregnation facilities currently used in the Durham department. Some coarse-grained sandstones proved possible to impregnate however, and these have been point-counted for porosity.

Thin section petrology has been augmented by data from X-Ray Diffraction techniques, using Copper Kα radiation. This is particularly useful in identifying clay minerals, and can give semi-quantitative estimates of mineral proportions present in a sample.

5.2.6 Appendices and Enclosures

The basic field information for this study comprises Appendix 1, and is presented in the form of graphic sedimentary logs and other notes, particularly regarding lateral variation along opencast faces. Where appropriate, generalized or composite sedimentary logs of specific localities are also presented as text Figures.

In Appendix 1, vertical sections are numbered in the order in which they were compiled, i.e., chronologically, and presented informally, to save time and effort. These have been drawn using a standard legend, loose copies of which are included with the thesis.

For all exposures, national grid references are given to locate the outcrop. For the larger exposures where several localities have been examined, notably Opencast Coal Sites, plans showing the location of logged sections and exposed rock faces are also included as Enclosures. More disseminated information on lateral variation, etc., is not included on these Site Plans, to retain clarity; the reader is referred to Appendix 1.

All petrological data is contained within Appendix 2; where particularly relevant, details of individual samples are included in the text. Full petrological descriptions are avoided in Chapters 6-8, to shorten descriptive passages in the text.

In considering environmental interpretations, the initial assumption is made that the large-scale setting of the British Coal Measures is a coastal plain. This assumption avoids the necessity for much repetitious discussion. The coastal plain setting is evident from the areally widespread association of coal seams, non-marine and marine sediments, and from previous studies of the British Coal Measures (e.g., Williams, 1968; Elliott, 1968; Guion, 1978).

In the following Chapters, the abbreviation "O.C.C.S." will be used in place of "Opencast Coal Site".

CHAPTER VI - THE WESTPHALIAN A OF THE DURHAM COALFIELD

6.1 INTRODUCTION AND FOREWORD

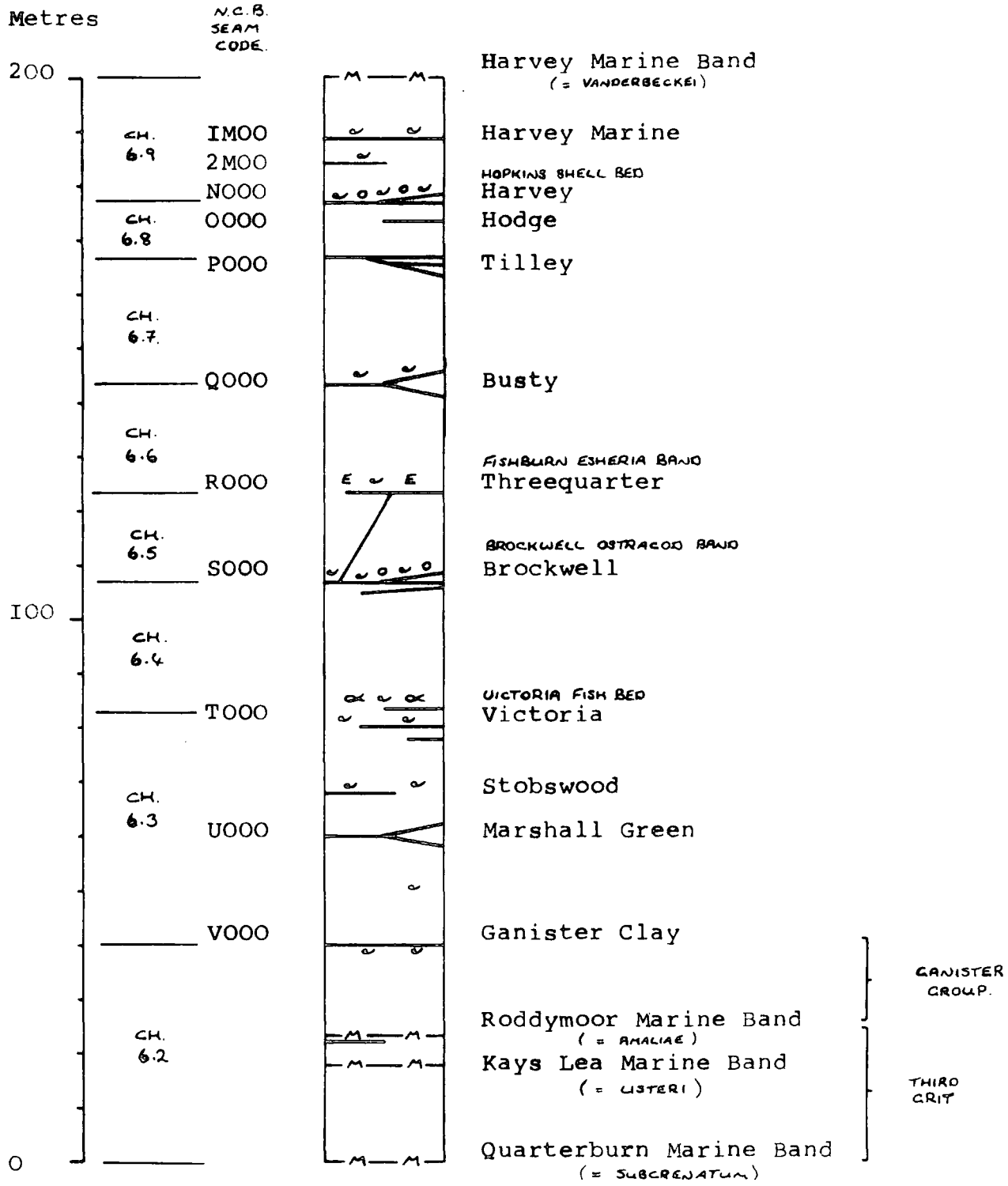
The Westphalian A succession of the Durham coalfield is approximately 200 m in thickness (Fig. 6.1). This sequence, lying between the Quarterburn (=*SUBCRENATUM*) and Harvey (=*VANDERBECKEI*) Marine Bands, contains up to thirteen workable coal seams, which are fairly evenly distributed throughout. The lowermost part of the succession, however, below the Ganister Clay coal, is characterized by a virtual absence of workable coals, but contains a marked abundance of siliceous sandstones (quartz arenites and ganisters), marine bands and major (10 m + thick), laterally extensive sandstones.

Lithologically, the basal Coal Measures are quite similar to much of the underlying Namurian Sequence, and the latter is now briefly considered, to preview a discussion of the evolution of the north Pennine area during Upper Carboniferous times (Ch. 6.2.4.).

The Namurian succession of the northern Pennines can be considered as the sedimentary record of a southward-prograding delta system. The sequence marks a change in sedimentary "style" from the "Yoredale facies" shallow marine and deltaic assemblage, deposition of which was controlled in part by the Lower Carboniferous "block and basin" topography, to an association containing increasingly abundant, major, channelized sandstone bodies, interpreted as deltaic distributaries. This and abundant other evidence for increased sediment transport and accumulation in the region is interpreted as the result of the locus of deltaic sedimentation advancing southward across the Pennines, infilling topographical hollows and leading to progressively more terrestrial and less marine-influenced conditions with time. It is also significant that the number and lateral extent

Fig.6.I

WESTPHALIAN A STRATIGRAPHY OF THE DURHAM COALFIELD



M - MARINE BAND E - ESTHERIA BAND O - OSTRACOD BAND ∝ - FISH BED

∽ - MUSSEL BAND

of coal seams in the sequence increases progressively through the Namurian succession.

At the top of the Namurian sequence in the northern Pennines are the "Durham Grits", a series, up to 115 m thick, of laterally extensive, coarse-grained, commonly erosively-based sandstones. These were recognized by the earliest workers in the area (for example, Forster, 1809). The Primary Geological Survey recognized three "grits" which were assigned to the "Millstone Grit Series" and subsequently adopted widely by stratigraphers.

More recently, palaeontological evidence has shown that only the "First" and "Second Grits" are of Namurian (Kinderscoutian/R1 to Yeadonian/G1) age, the "Third Grit" being Westphalian A in age (Mills and Hull, 1968). It has also recently become apparent that the architecture of the Durham Grits is such that it is commonly difficult or impossible to distinguish three discrete sandstone units. Rather, a stacked sequence of sandstones is the norm, each separated by thinner, fine-grained partings.

Examination of the limited available outcrops by Percival (1981) and the author, largely in the area north of Stanhope and Wolsingham, has established that the "First" and "Second Grits" probably consist of sediments deposited in distributary channel, interdistributary bay and marine-influenced shoreline environments.

6.2 QUARTERBURN MARINE BAND TO GANISTER CLAY COAL

6.2.1 Introduction

The lowermost Westphalian interval in the Durham coalfield lies between the Quaterburn (=*SUBCRENATUM*) Marine Band and the Ganister Clay coal. The interval varies in thickness from 30-55 m, tending to decrease northward across the coalfield, although records from this part of the Coal Measures are rare.

The true palaeontological base of the Coal Measures was first recognized, in this area, in the Geological Survey Woodland borehole (Mills and Hull, 1968), named the Quarterburn Marine Band and subsequently discovered in other borings. While not containing the diagnostic goniatite *Gastrioceras subcrenatum*, the productid/lingulid fauna of the horizon, and lithological factors, support its' identification (Mills and Hull, *op. cit.*). Previous to the recognition of the *G. subcrenatum* marine horizon, the base of the Coal Measures was taken at the base of the lowest workable coal, usually either the Ganister Clay or Brockwell seam (Fig. 6.1).

Above the Quarterburn Marine Band lies a sequence of sediments which may contain up to four further Marine Bands, notably the Kays Lea (=*LISTERI*) and Roddymoor/Gubeon (=*AMALIAE*) horizons (Figs. 2.5, 6.1), (Mills and Hull, 1976). The measures between the Quarterburn and Kays Lea Marine Bands, and between the Kays Lea and Roddymoor Bands, are often referred to as the "Third Grit", since they contain thick sandstones, which often cut out the above-mentioned marine bands.

These sandstones are, however, laterally discontinuous, causing much of the variation in thickness in the basal interval across the coalfield.

Several thin, laterally impersistent coal seams may occur in the basal Coal Measures, one of which, the Gubeon seam, lies immediately beneath the Roddymoor Marine Band and may be locally up to 0.46m in thickness.

Above the Roddymoor Marine Band, the sequence is markedly variable both in thickness and lithology, and often contains several ganister horizons. For this reason, the measures between the Roddymoor Marine Band and the Ganister Clay coal have been referred to as the "Ganister Group" by the National Coal Board.

The Ganister Clay coal marks the base of the productive Coal Measures in the Durham coalfield, being the lowest laterally extensive coal seam in the sequence. As such, it represents a convenient upper limit to a consideration of the basal Coal Measures. It also constitutes the upper limit of the *Anthraconaia lenisulcata* bivalve zone.

Exposures placed stratigraphically within the basal Coal Measures interval are described and interpreted in the following pages. Following these case studies, a discussion of conclusions is given in Ch. 6.2.4. While some of the examined exposures are quite large, they are almost all single rock faces, that is, two-dimensional exposures, and as such are often difficult to interpret unequivocally.

6.2.2 Sediments between the Quarterburn Marine Band and Ganister Clay Coal

6.2.2.1 Cross's Upper Ganister Quarry

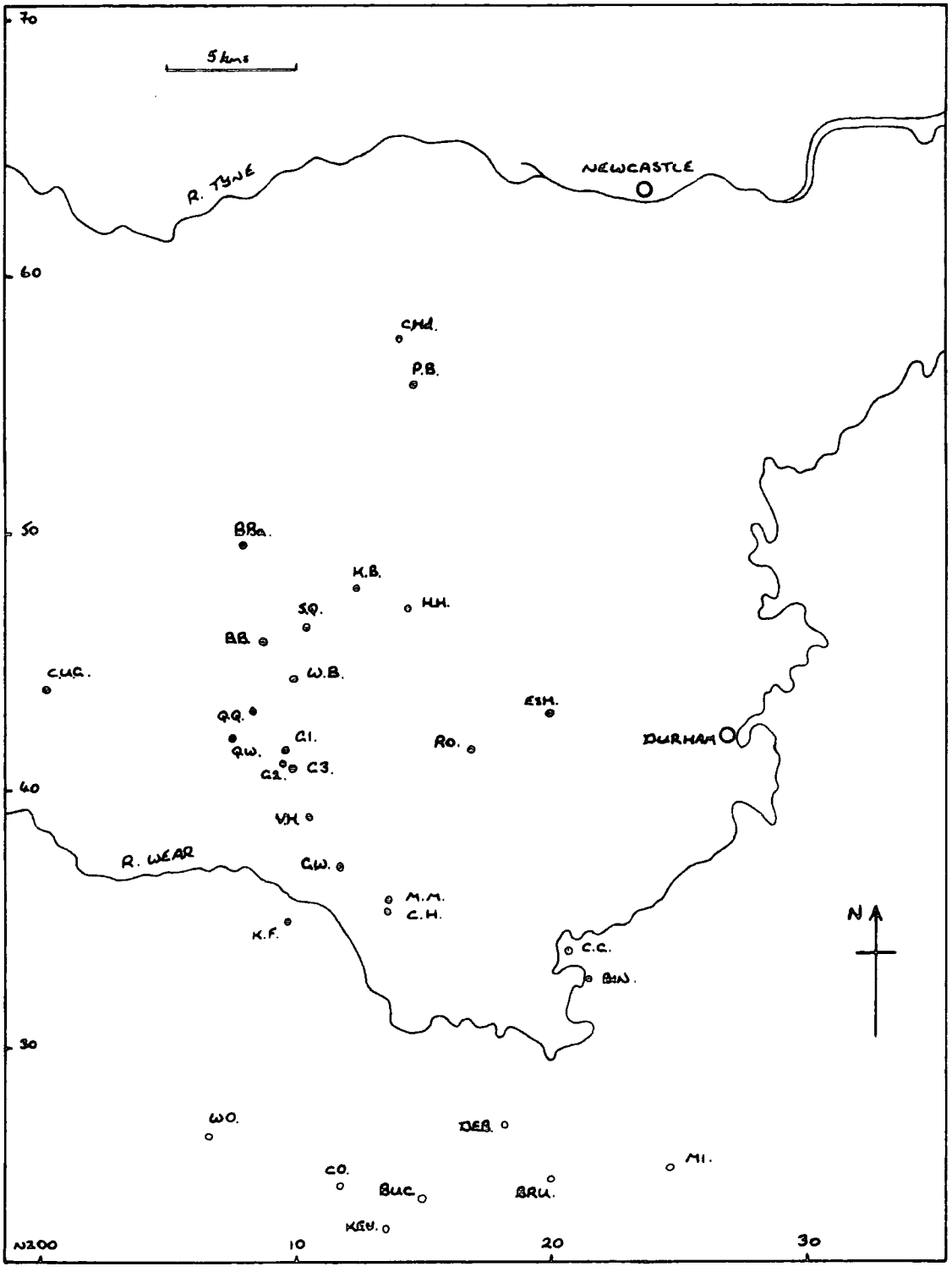
Description

Cross's Upper Ganister Quarry (G.R. NZ002447), (Fig. 6.2) is a disused quarry which is said to expose the horizon of the Quarterburn (=*SUBCRENATUM*) Marine Band (Fig. 6.3), and thus straddles the base of the Coal Measures.

The ganister horizon formerly worked in the base of the quarry is no longer exposed, due to partial restoration, but is recorded as being 1.52 m in thickness (Strahan, 1920). Above this lie the dark grey silty claystones of Unit 1 (Fig. 6.3), which contain small (2 mm diameter) *Planolites* burrows. Indeterminate grazing trails were preserved as convex hyporeliefs on the sharp, basal surface of Unit 2, and the overlying well-laminated siltstones (Unit 3) show occasional signs of bioturbation.

Fig.6.2

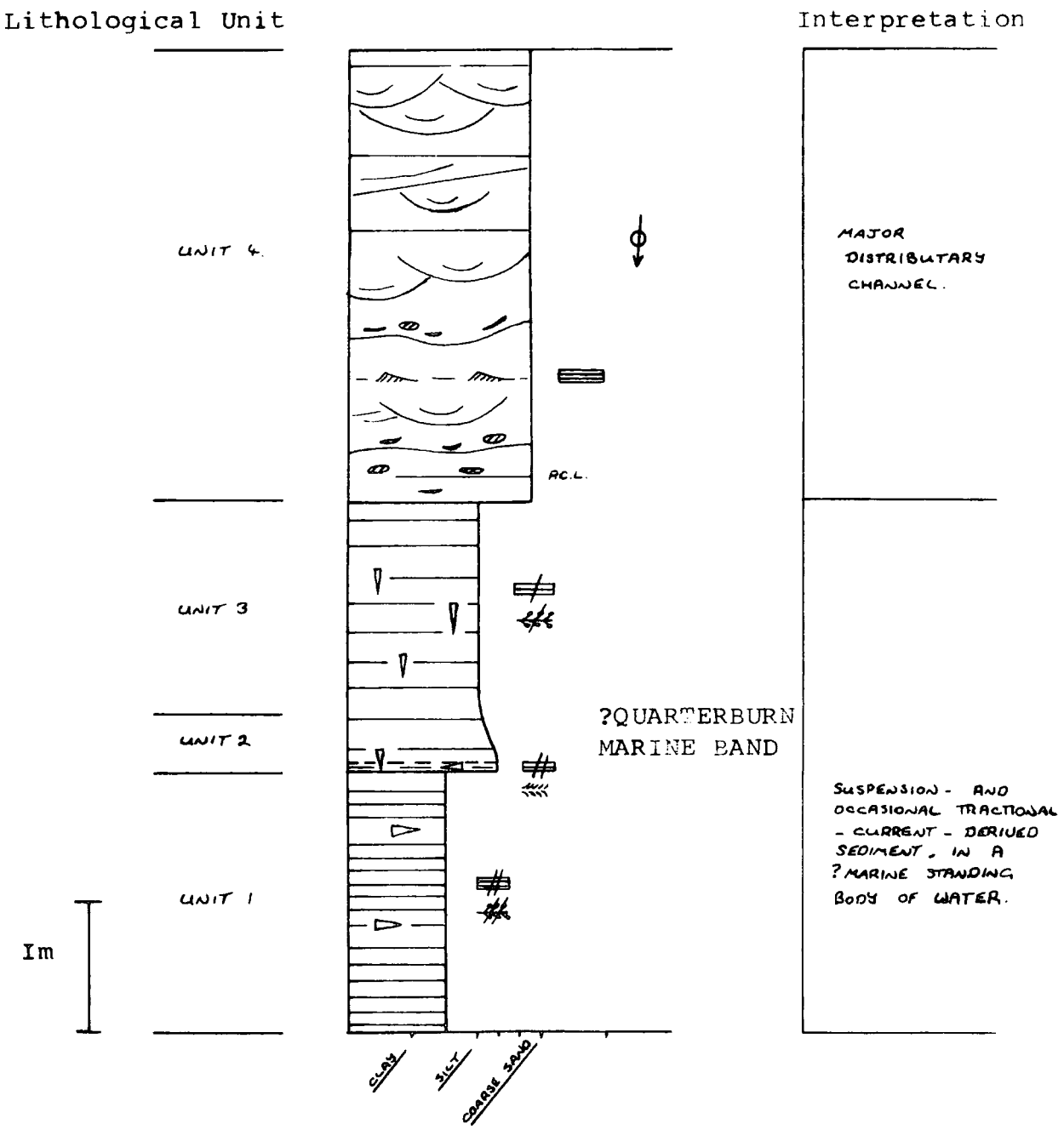
LOCATIONS OF EXAMINED EXPOSURES IN WESTPHALIAN A SEDIMENTS



BBa. - BESSY'S BANK QUARRY
BB. - BLACK BURN
BIN. - BINCHESTER CRAGS
BUC. - BUCKHEAD O.C.C.S.
BRU. - BRUSSELTON WOOD.
CUC. - CROSS'S UPPER CANISTER QUARRY
CHd. - CRAG HEAD
C.H. - CABIN HOUSE O.C.C.S.
C.C. - COBEY CARR QUARRY
CO. - COCKFIELD REEVES
ESH. - ESH WINNING O.C.C.S.
C.W. - CREY'S WELL QUARRY
C1. - GREENFIELD No. 1 QUARRY
C2. - " No. 2
C3. - " No. 3
HH. - HUMBER HILL QUARRY
K.F. - KNITSLEY FELL QUARRIES
K.B. - KNITSLEY BRIDGE QUARRY
MI. - MIDDRIDGE QUARRY.
M.M. - MOWN MEADOWS O.C.C.S.
P.B. - PONT BRIDGE.
QQ. - QUICKBURN QUARRY
RO. - ROWLEY O.C.C.S.
S.Q. - SHEEPWALKS QUARRY
V.H. - HEWLY HILL QU.
W.B. - WEST BUTSFIELD QU.
WO. - WOODLAND O.C.C.S.
DEB. - DEBORAH O.C.C.S.
Q.W. - QUARRY WOOD QUARRY

Fig.6.3

GENERALISED VERTICAL SECTION THROUGH
CROSS'S UPPER GANISTER QUARRY (NZ002447)
(Based on Section **388** ; Appendix I)



The major, cross-bedded sandstone of Unit 4 is medium-grained, though it reaches granule grade in places, and overlies Unit 3 with a planar, erosive contact. The sandstone is at least 3.5 m thick, the upper contact not being exposed. Records from a nearby borehole on Collier Law (G.R. NZ 017417) show that this sandstone achieves a total thickness of almost 20 m.

Palaeocurrent measurements from Unit 4 indicate sediment transport towards the south (Fig. 6.4) and the only lateral facies variation visible along the quarry face is a progressive downcutting of the Unit 4 sandstone towards the south-west.

Interpretation

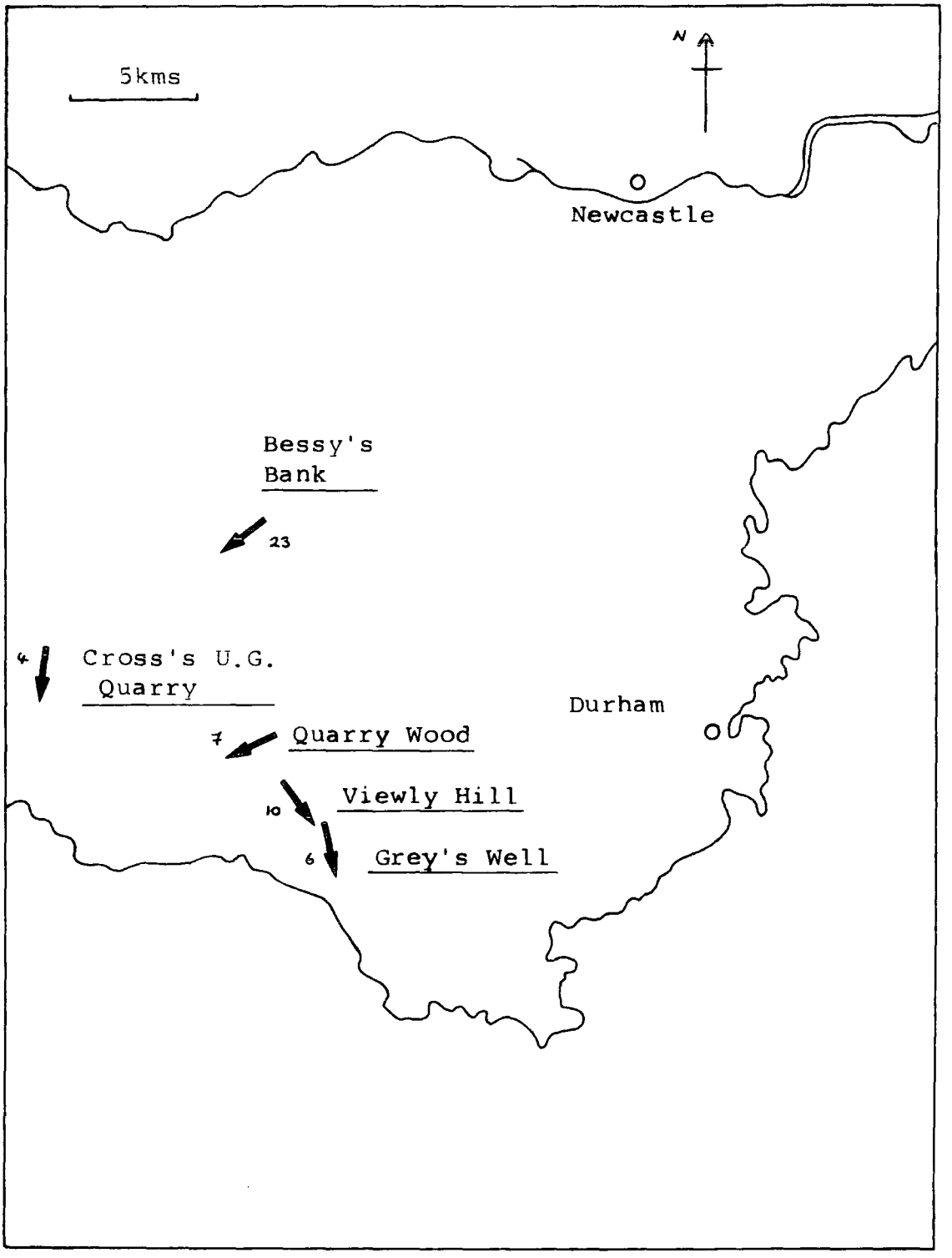
Units 1-3 are interpreted as sediments deposited in a standing body of water, largely from suspension, but including occasional contributions from tractional currents. This sand grade sediment might represent distal crevasse splay or overbank deposition, or may possibly have been laid down by storm reworking of earlier sediments. The presence of *Planolites* and grazing trails implies that both the sediment subsurface, and probably also the surface, were sufficiently oxygenated to allow animal life to exist.

Units 1-3 lie at the inferred level of the Quarterburn (=*SUBCRENATUM*) Marine Band. No marine body fossils were found from this exposure, possibly due to the sediment being too coarse-grained.

From the overall thickness of the sandstone, and contained structures, Unit 4 is interpreted as the product of a fluvial or distributary channel which, by switching from a former course, passed southward across the body of water in which Units 1-3 were deposited, and cut through any early progradational deposits which may have been formed. The internal erosion surfaces in the lower part of the sandstone and its' erosive base perhaps indicate that the examined sediments lay close to the initial axis of transportation.

Fig.6.4

"THIRD GRIT" MAJOR SANDSTONE PALAEOCURRENTS



= Vector Mean at each locality.

8 = Number of measurements at each locality.

(Palaeocurrent data are almost entirely from trough cross-bedding.)

Initiation of sand deposition was probably by channel bank crevassing and crevasse splay lobe formation (Elliott, 1978), and the overall thickness of the sandstone implies that this crevassing caused a major diversion in channel course.

The succession exposed at Cross's Upper Ganister quarry represents the infilling of a shallow, ? marine body of water believed to have been formed by the *SUBCRENATUM* marine incursion.

It is apparent from the overall thickness of the major sandstone, and consideration of shallow, deltaic sequences (Elliott, 1973, 1974; Heward, 1976), that water depth may have been as much as 20 m before infilling commenced, but was probably somewhat less than this.

6.2.2.2 Bessy's Bank Quarry

Description

Bessy's Bank Quarry (G.R. NZ 076495), (Fig. 6.2) exposes sediments not far above the horizon of the Quarterburn Marine Band (Fig. 6.5).

A major (10 m +) sandstone ("Third Grit") was formerly worked for moulding sand in the lower part of the quarry (Plate 6.1), while ganister was extracted from two higher horizons.

The medium-grained sandstone of Unit 1 (Fig. 6.5) is only loosely consolidated, and sedimentary structures are barely discernible. Further up, however, in Unit 2, the sandstone is finer-grained and contains abundant trough cross-sets up to 0.8 m thick, directed towards the south-west (Fig. 6.4). These are arranged either randomly, or occasionally in cosets, and small (0.1 m) sets superimposed on the stoss side of larger ones (0.5m) are sometimes preserved.

In thin section, the sandstone is seen to have been subjected

Fig.6.5

GENERALISED VERTICAL SECTION THROUGH BESSY'S BANK QUARRY (NZ076495)

(Based on Section 242 ; Appendix I)

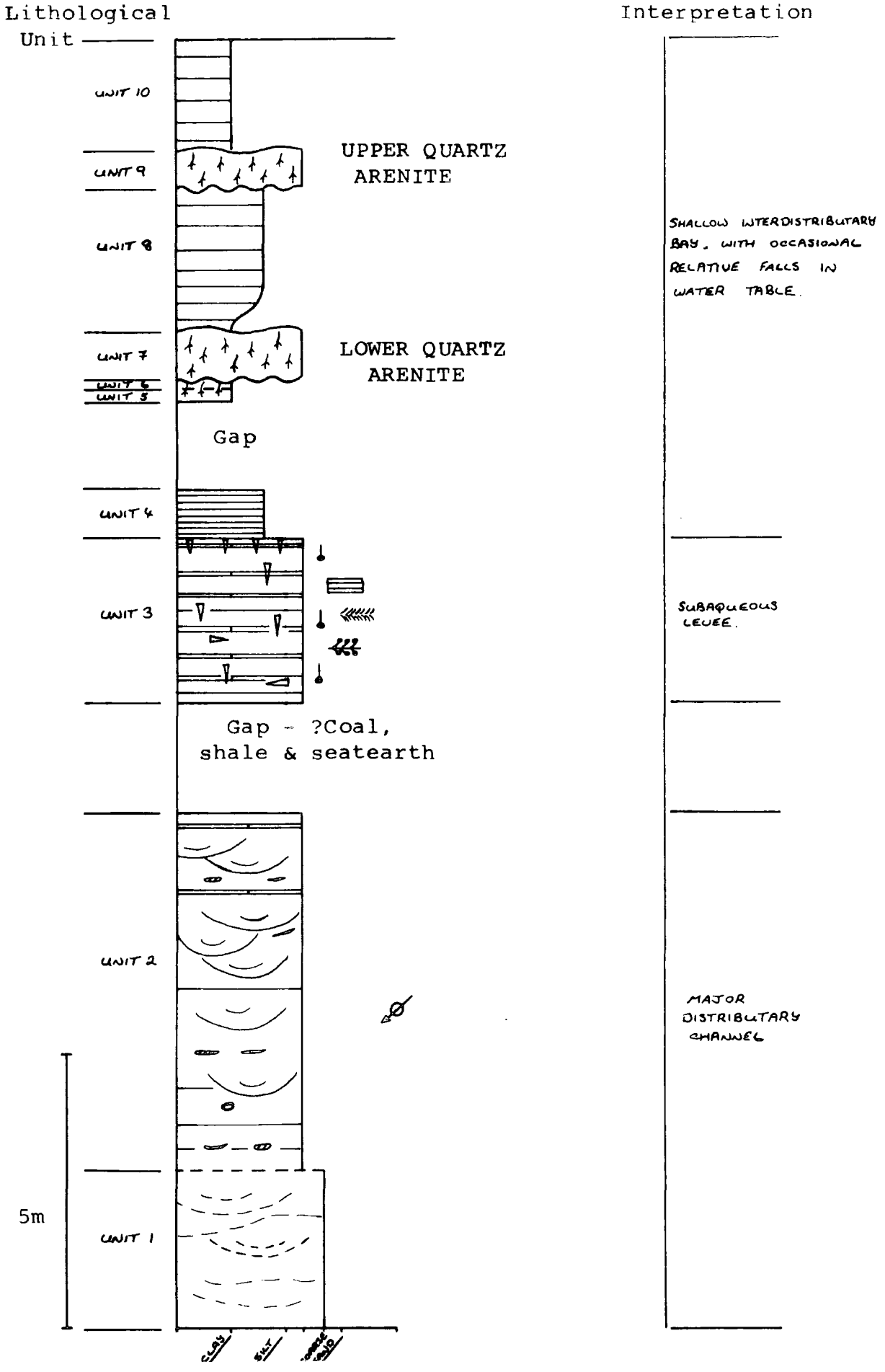




Plate 6.I - View of Bessy's Bank Quarry, showing a major sandstone of the "Third Grit".



Plate 6.2 - West Butsfield Quarry, main face, showing the "West Butsfield Ganister" and overlying coarsening-upward sequence. Head of hammer (H), 30cms long, rests on the top surface of the "Ganister".

to considerable ? Recent oxidation.

The gap in exposure above Unit 2 probably represents a seat-earth, coal and overlying shales (inferred from adjacent spoil heaps). The fine-grained sandstone of Unit 3 contains abundant claystone layers and laminae, and common trace fossils, including *Planolites*, *Pelecypodichnus* and *Cochlichnus*. The top of the Unit is very heavily bioturbated, containing abundant *Planolites* burrows.

In thin section, this sandstone comprises a mosaic of sutured, strained quartz grains with occasional areas of kaolinite/illite cement and rare accessory phases.

Above the well-laminated, silty claystones of Unit 4, and a further gap in exposure, is a soft, kaolinitic claystone which changes in colour from medium grey to cream upward, and contains Stigmarian rootlets (Units 5 and 6). This is in turn overlain by a fine-grained, well-indurated ganister sandstone (Unit 7), termed the "lower quartz arenite" by Percival (1981). The thickness of this ganister, as much as 0.88 m, varies considerably due to the irregular nature of both lower and upper contacts. Percival (*op. cit.*) noted that in thin section the quartz arenite contains 98.5%-99.5% quartz, grains of which are subrounded-to-rounded and well sorted, though the mineralogical maturity decreases at the top of the Unit. The "lower quartz arenite" passes laterally into mineralogically less mature sandstones to the east (Collins, 1925).

A further ganister horizon not observed by the author, termed the "upper quartz arenite" by Percival, occurs near the top of the exposed sequence (Unit 9). This horizon displays similar characteristics to the "lower quartz arenite" and deteriorates in quality towards the north-west.

Interpretation

The thickness, lateral continuity, internal structures and

palaeocurrent distribution of Units 1 and 2 support a fluvial or deltaic distributary channel interpretation. The channel flowed towards the south-west at this point. Information regarding the lateral extent of the sandstone body is, however, lacking.

Unit 3 is tentatively interpreted as a subaqueous levee deposit, containing frequent, irregular interlamination of fine sandstone and claystone, indicative of episodic sedimentation, and abundant trace fossils. Similar, though better-exposed sequences are described from Deborah O.C.C.S. (Ch. 6.6.4.3) and Langley O.C.C.S. (Ch. 7.8.2.1).

Above this unit, the clays and silts comprising Unit 4, 8 and 10 are interpreted as suspension deposits in shallow standing water bodies. The two siliceous sandstone horizons (Units 7 and 9) and underlying claystones (Units 5 and 6) are, however, something of an enigma.

The quartz arenites have been interpreted by Percival (1981) as the A_2 horizons of leached soil profiles (podzolic soils - see Ch. 4.3) and as such require freely drained conditions to form. This interpretation is based on the abundance of rootlets, mineralogical maturity and the sharp, noded base of the ganisters, and the clay-enriched nature of immediately underlying sediments.

The lithological contrast between the quartz arenites and their enclosing finer-grained sediments was probably a primary depositional effect, later accentuated by pedogenic and diagenetic processes. The sandstones themselves might have been laid down as crevasse splay deposits in an interdistributary area and then colonized by plants under conditons of free drainage. However, the development of free drainage in an otherwise subaqueous setting (as indicated by Units 3-6, 8 and 10) is difficult to explain. Perhaps the initially immature crevasse splay sands were reworked by waves to

become better-sorted, and/or fluctuations in water-table occurred on a local scale, due to the effects of differential subsidence, causing elevation of some areas above the level of permanent waterlogging.

Considered as a whole, the sequence exposed at Bessy's Bank Quarry indicates deposition in and adjacent to a major fluvial or deltaic distributary channel during its' active operation, and the following abandonment phase.

6.2.2.3 West Butsfield Quarry

West Butsfield Quarry (G.R. NZ 095443), (Fig. 6.2) exposes a sequence of rocks including the Kays Lea Marine Band (Fig. 6.6). The quarry was formerly worked for ganister, but is now used as a council refuse tip.

The lowest part of the sequence is exposed in Butsfield Burn at Sawmill Bridge (G.R. NZ 096446), where the interbedded fine-grained sandstones and finer sediments of Unit 1 (Fig. 6.6) are sharply overlain by the "West Butsfield Ganister" (Unit 2), a fine-grained quartz arenite. This attains a maximum thickness of 3.2m, but thins gradually to the south and west (Fig. 6.7). The quartz arenite is bedded in sharply-based units 10's of cms thick, sometimes separated by thin, shaly partings. In the uppermost part it contains burrows, Stigmarian roots and rootlets. Percival (1981) reported that this unit also has a transitional base in places, and recorded a single north-north-east-directed set of ripple cross-lamination.

In thin section, the quartz arenite is seen to comprise 95% quartz, (detrital grains and early diagenetic overgrowths) and 5% late diagenetic minerals, largely siderite and hematite (Appendix 2). Framework grains are mostly very angular-to-angular, though dust rims show many to have been originally quite well-rounded, and grain

Fig.6.6

GENERALISED VERTICAL SECTION THROUGH WEST BUTSFIELD QUARRIES (NZO95443)

(Based on Sections 345, 346, 417; Appendix I)

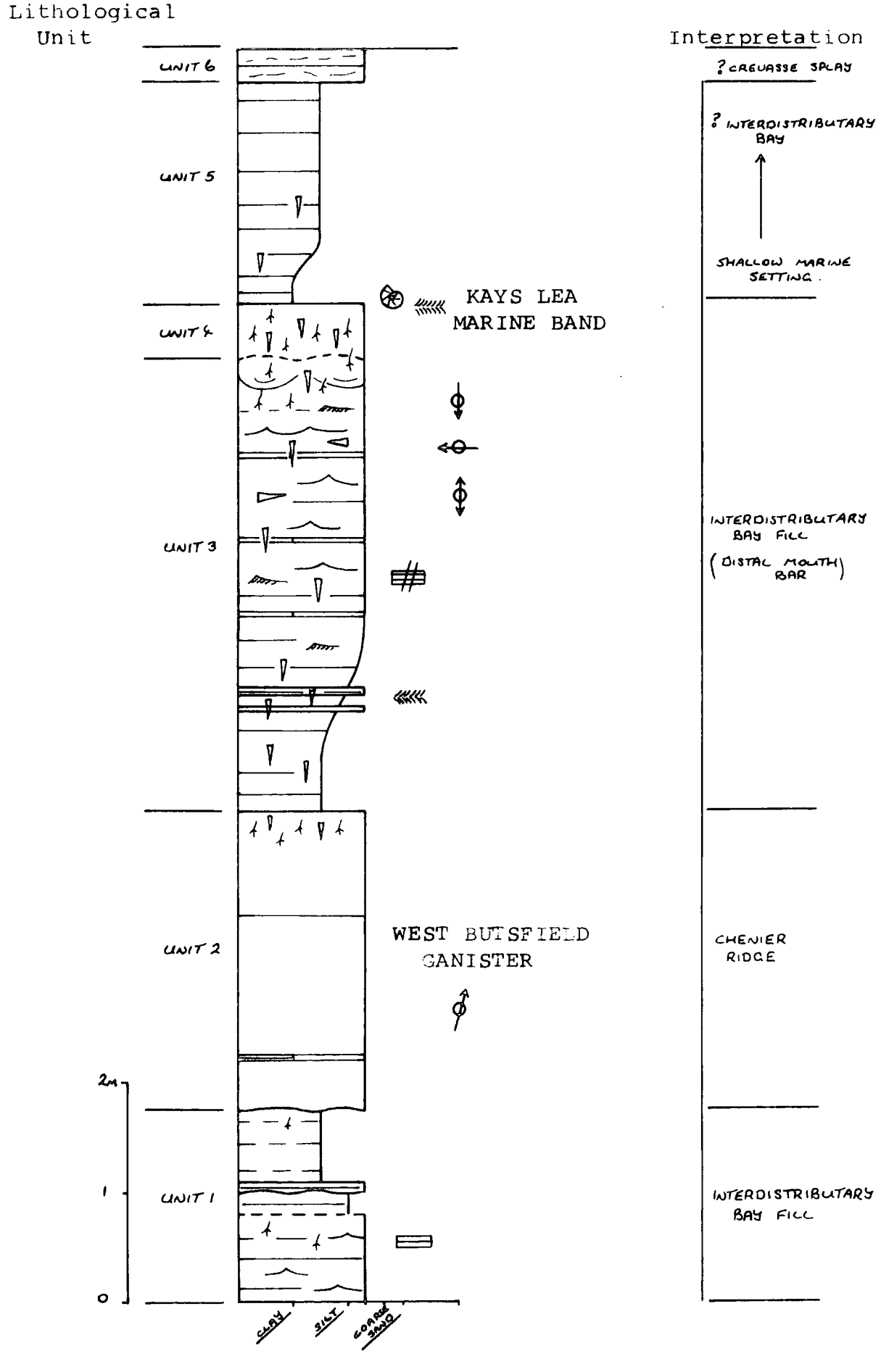
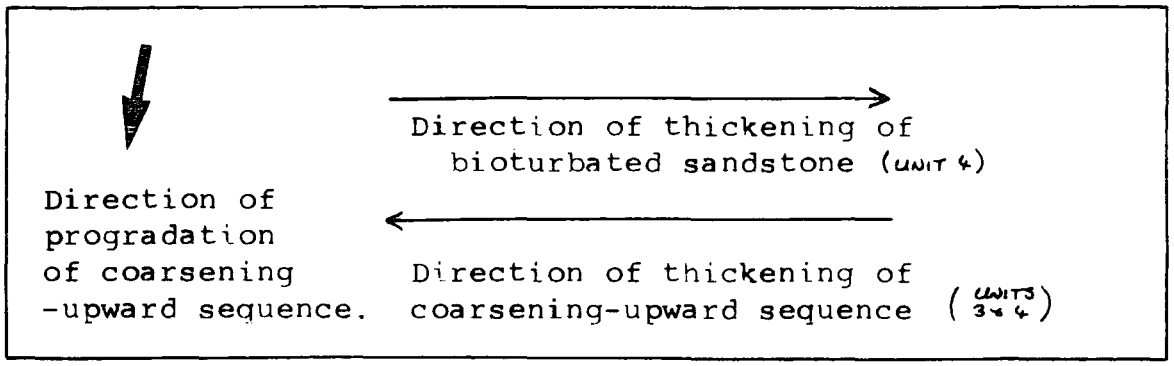
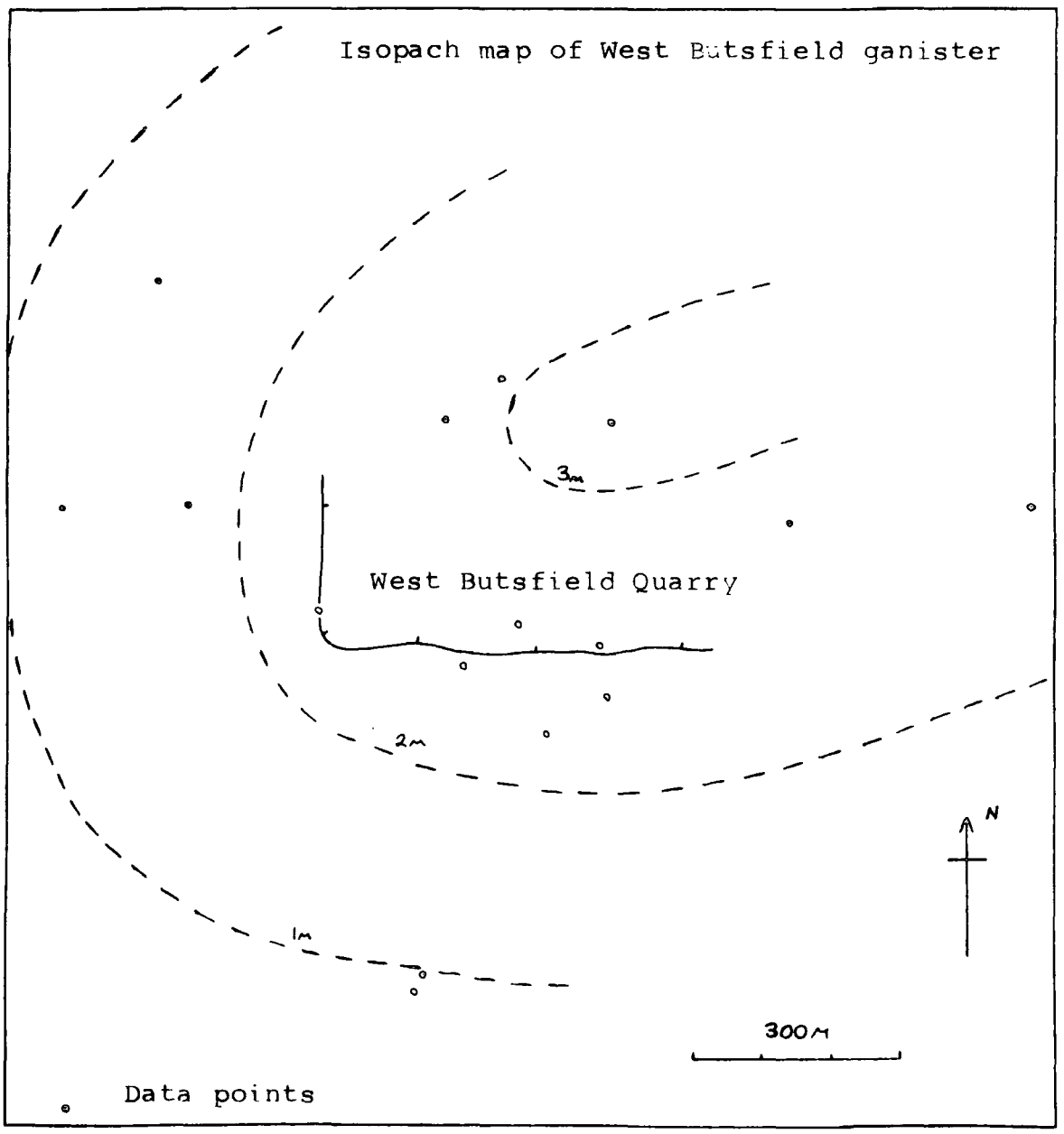


Fig.6.7

GEOMETRY OF SEDIMENTARY UNITS AT WEST BUTSFIELD QUARRIES





size sorting is good (ϕ = 2.82 $\pm$ 0.49). No evidence of pedogenesis is visible, other than the occasional rootlets in the top of the sandstone.

Above the sharp top of the ganister lies a 4.5 m thick coarsening-upward sequence (Unit 3; Fig. 6.6), best exposed in the main quarry (G.R. NZ 095443) (Plate 6.2). The central part of this sequence, consisting of interlaminated siltstone and fine sandstone, contains occasional impressions of the grazing trail *Cosmorhaphe*. Wave ripple-marks in the central and upper parts of the sequence indicate wave motion towards the north and south, small-scale (0.2 m) trough cross-sets in the upper part are directed towards the south, and a small number of ripple cross-lamination sets are inclined towards the west. The fine-grained sandstone comprising the upper part of the coarsening-upward sequence is heavily penetrated by Stigmarian rootlets, and in thin section contains a striking development of macrocrystalline vermicular kaolinite (Plate 6.3).

The uppermost 0.25-0.45 m of this sandstone (Unit 4), above an abruptly gradational or abrupt, undulating contact contains a patchy development of ? chamosite (Appendix 2), and is also rootleted and intensely bioturbated, the top surface containing abundant *Zoophycos* traces and productid brachiopods. Overlying claystones and silty claystones (Unit 5) are occasionally bioturbated and contain *Lingula*, productid brachiopods and indeterminate bivalves near their base.

Visible lateral variation in facies along the well-exposed main quarry face is limited; the development of small-scale trough cross-bedding in Unit 3 is sporadic, but not noticeably concentrated at any one point, the bioturbated sandstone of Unit 4 varies in thickness from 0.20 m at the west end of the quarry to 0.70 m in an

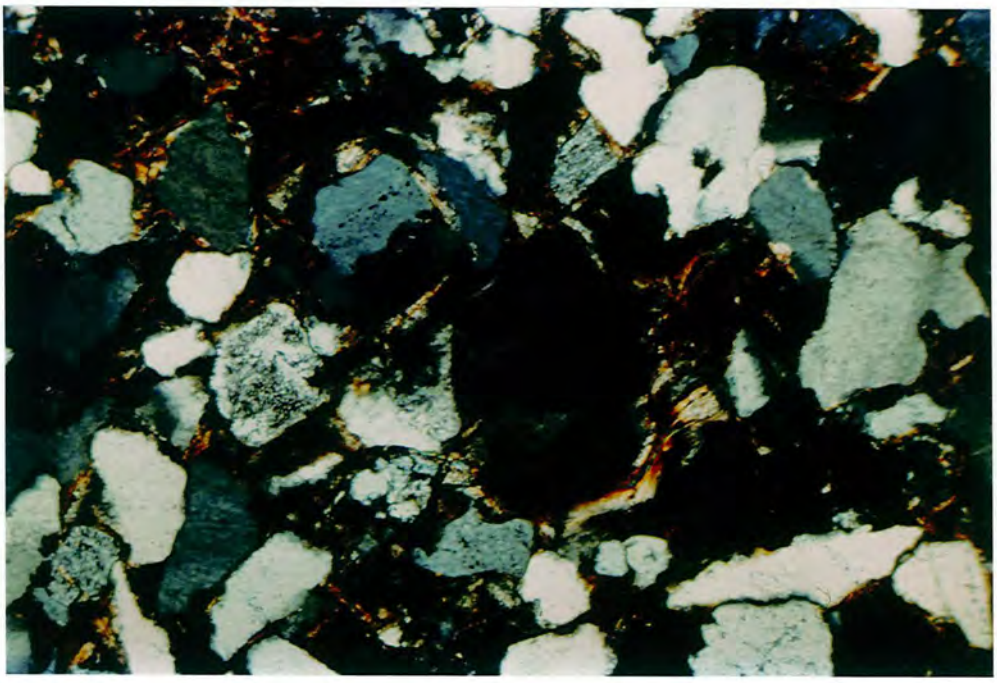


Plate 6.3 -
Photomicrograph showing development of coarsely crystalline, authigenic kaolinite (centre of photo) in sandstone immediately underlying the Kays Lea Marine Band, West Butsfield Quarry. Length of photomicrograph I.Omm. (Crossed polars).



Plate 6.4 - View of Greenfield No.I Quarry, facing east, showing a major sandstone immediately beneath the Marshall Green coal. Height of quarry face 8m.

isolated exposure 200 m east of the main quarry, and the coarsening-up sequence thickens slightly to the west (Fig. 6.7).

Interpretation

The sediments underlying the West Butsfield Ganister (Unit 1) are interpreted as the upper part of an interdistributary lake/bay fill, from similarities between this and other such described sequences (e.g., Coleman, 1966; Elliott, 1975). The ganister itself (Unit 2) is interpreted by Percival (1981) as a chenier ridge deposit, and this interpretation is supported by its' sharp and gradational basal contact, the geometry of the unit and its' petrographic characteristics.

From borehole data, the quartz arenite body appears to be lenticular in geometry (Fig. 6.7), and elongated east-north-east to west-south-west, possibly indicating a similar orientation for the palaeo-shoreline (Fig. 6.8a).

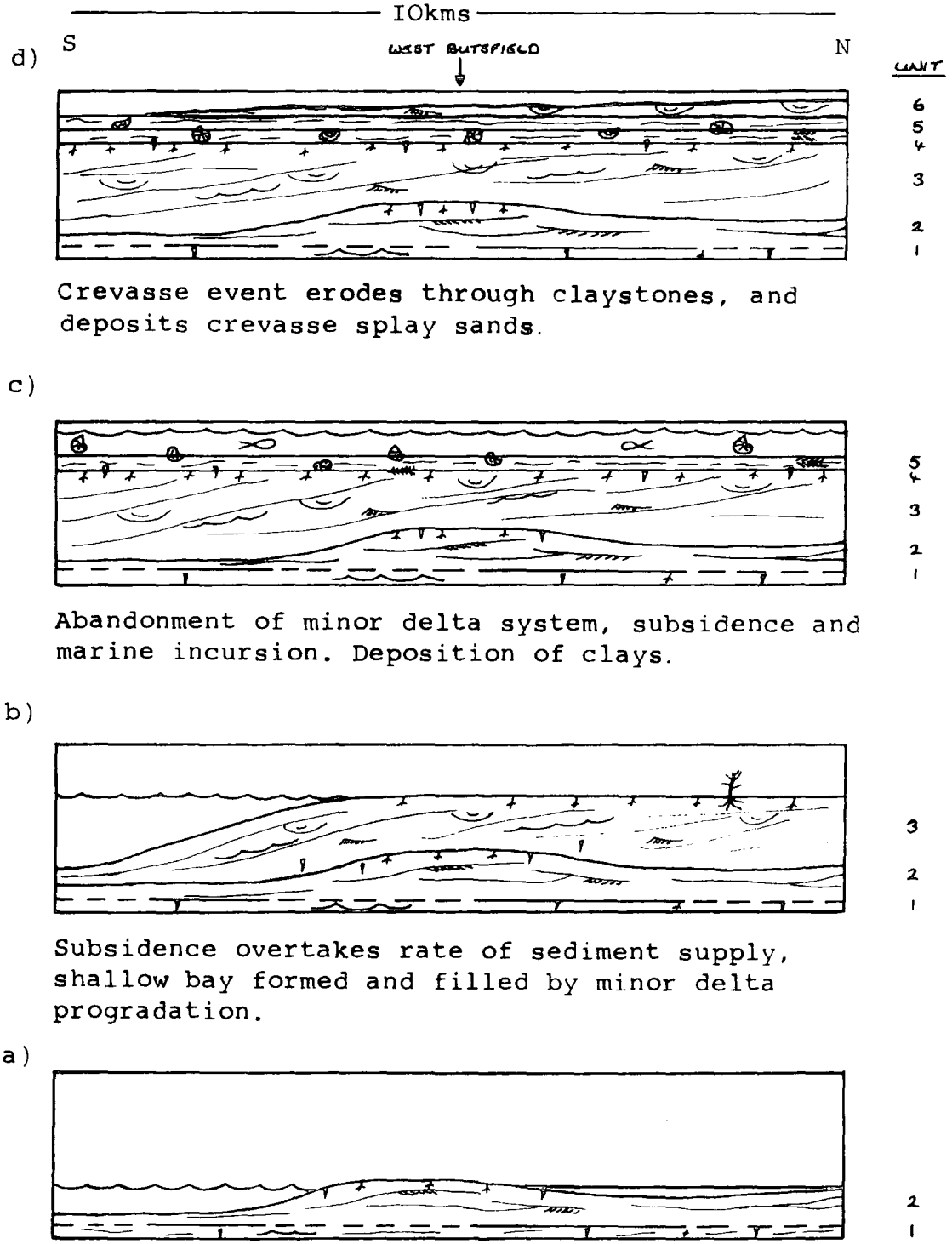
The well-sorted nature of the sediment in the ganister, relative to other stratigraphically adjacent sandstones, suggests reworking of sediment over a considerable period of time. The presence of rootlets in the uppermost part of the quartz arenite suggests that sediment supply at least kept pace with the rate of subsidence.

Chenier ridges form at the present day along prograding coastlines, alongshore from river estuaries or deltas which form the source of sediment for these features (Heward, 1981). Cheniers are thus in character with the marine-influenced basal Coal Measures, and also indicate the importance of longshore currents in reworking sediment, as well as that of waves.

Supply of coarse-grained detritus eventually failed, due perhaps to delta switching, and the sediment surface was allowed to subside several metres below the water level. During this time, fine-grained

Fig.6.8

GEOLOGICAL HISTORY OF THE WEST BUTSFIELD SEQUENCE



sediment accumulated, at first from slow suspension fallout and then more rapidly under the influence of tractional currents (from the coarsening-upward nature of Unit 3). Sedimentation terminated following virtual infilling of the body of water, at least to the level at which plants could grow (Fig. 6.8b). The poorly sorted nature of the sandstone comprising the upper part of this sequence suggests fairly rapid accumulation without significant reworking, although the presence of oscillation ripples implies the action of waves on the water surface.

From a consideration of shallow water deltaic sequences (Elliott, 1973, 1974; Heward, 1976), (Fig. 3.2), the coarsening-upward sequence culminating in a gradationally based sandstone is interpreted as the deposit of a distal mouth bar or minor mouth bar, prograding into a shallow water interdistributary bay. The environment is given the name "bay". as opposed to "lake", implying a body of water open to marine influence, as indicated by underlying shoreline deposits. The depth of water in the bay was approximately 5 m immediately before rapid infilling began, as determined by a modification of the method of Klein (1974), to be discussed in Chapter 9. Oscillation ripples in the upper part of the sequence suggest deposition in water depths of 2-10 m, with a wave fetch of at least 10-20 kms (Komar, 1974; J. Allen, 1979b; P. Allen, 1981). The environment of deposition in the West Butsfield area is considered to be "distal", that is, beyond the influence of high-energy crevasse deposition, on account of the prominence of wave-produced structures, abundant evidence of bioturbation and lack of erosively-based or channelized sandstone deposits. From the southward directed cross-sets in the upper part of the sequence, it is inferred that the source of this prograding minor mouth bar lay in a major channel to the north. The exact setting on the minor mouth bar is not

thought to be proximal/lateral, due to the lack of levee or over-bank sediments in the upper part of the sequence (Fig. 3.2). However, the presence of sparse ripple cross-lamination at the east end of the quarry, directed westward, and the possible thickening of the coarsening-upward sequence westward along the quarry face, perhaps suggest that the axis of sediment transport and deposition lay to the east of the present exposure. The source of the inferred crevasse event which produced the minor mouth bar, and the depositional axis, are unfortunately not exposed.

The minor delta lobe was eventually abandoned without causing any significant channel diversion across the area. The "abandonment phase" is preserved in the form of intense rootlet development and bioturbation in the uppermost part of the bay fill (Unit 4). Such crevasse-initiated bay fills are common in the lower delta plains of river-dominated deltas, for example, the Mississippi (Coleman, Gagliano and Webb, 1964; Elliott, 1974).

Lack of sediment supply led to the gradual subsidence of the area, once again, leading to standing water conditions which were evidently fully marine in character. The presence of productid brachiopods and *Zoophycos* trails in the intensely bioturbated sandstone of Unit 4 is evidence of fully marine conditions with little or no sedimentation (Fig. 6.8c). These fossils, along with others of marine affinity in the overlying claystones, form the record of the Kays Lea (=*LISTERI*) marine incursion, which is widespread over Central and Northern England (Calver, 1968a).

The claystones of Unit 5 were probably laid down in this quiet water environment by suspension fallout; marine fossils are found only in the basal 0.2m or so, and there is no evidence of fully marine conditions above this level.

The sharply-based sandstone of Unit 6, seen to be at least 4.5 m thick in some borehole records, truncates the claystones of Unit 6 after 2-5 m, and is tentatively interpreted as the deposit of a crevasse splay lobe, or a stacked series of lobes (Fig. 6.8d).

Considered as a whole, the succession may be thought of a series of shallow basin infills (5-10 m water depth) in a lower delta plain environment, interspersed with delta-destructive deposits. The West Butsfield exposure is particlarly significant in recording marine influence on basal Westphalain shoreline and shallow water interdistributary environments.

6.2.2.4 Knitsley Fell Lower Quarry

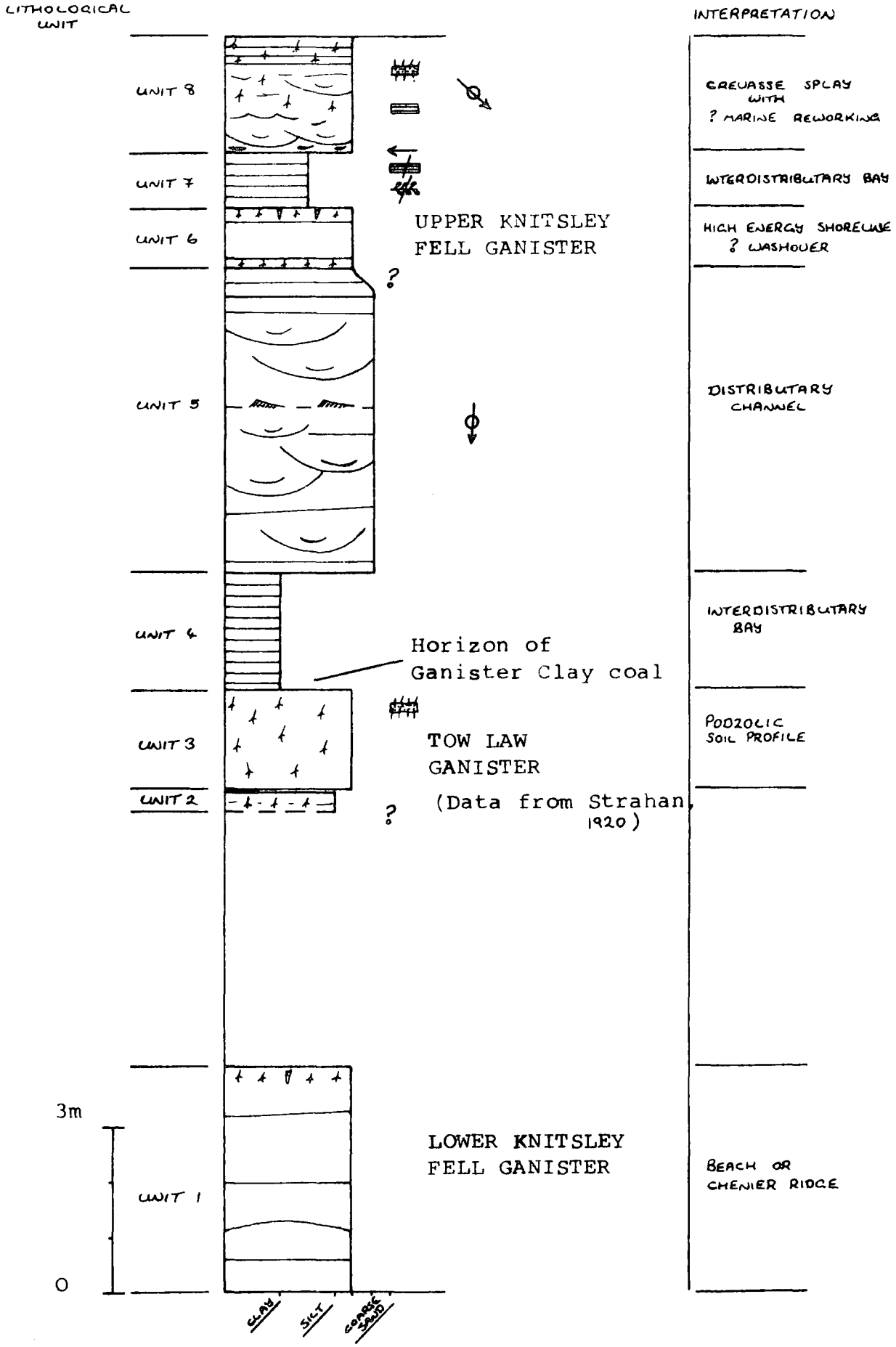
The Knitsley Fell quarries (G.R. NZ 097344), (Fig. 6.2), formerly worked for ganister, expose sequences immediately above and below the horizon of the Ganister Clay coal (Fig. 6.9).

The exact stratigraphical position of these quarries is not clear, but Strahan (1920) describes the extraction of Tow Law Ganister (stratigraphically immediately below the Ganister Clay coal) from the base of the central of three quarries. With the aid of a quarry plan (1:1250 scale, 1 m contours), a photogrammetric plot of the area and published I.G.S. information, it was ascertained that the vertical interval between the Quarterburn Marine Band, exposed a short distance to the south, and the base of the middle quarry is about 54 m. This is very close to the average interval for the area between the Quarterburn Marine Band and the Ganister Clay coal of 52 m, and so Strahan's (1920) indentification of the Tow Law Ganister is considered to be correct.

Fig.6.9

COMPOSITE VERTICAL SECTION THROUGH THE KNITSLEY FELL GANISTER QUARRIES (NZ097344)

(BASED ON SECTION 431 :- APPENDIX 1)



The middle and upper quarries, lying stratigraphically above the Ganister Clay coal, are considered in the following section (Ch. 6.3.2.1), and the lowermost quarry only is discussed here.

The lower Knitsley Fell quarry (G.R. NZ 098347) exposes up to 4.1 m of hard, grey, fine-grained quartz arenite (Fig. 6.9; Unit 1), the top 10-20 cms of which contain rootlets and ? burrows. The only other sedimentary structures exposed in the quarry are low-amplitude (up to 1.5 m)/high wavelength (about 60 m) undulations in the upper surface of the sandstone body (Fig. 117 of Percival, 1981).

Petrographically, the lower quartz arenite consists of rounded-subrounded detrital quartz grains and smaller quantities of cements (quartz overgrowths, kaolinite and ? hematite), (Percival, 1981, p. 308). The uppermost rooted levels contain substantial proportions of clay minerals.

Strata immediately above and below the quarry are not exposed, but calculations indicate a gap of 5.0 m between the top of the quartz arenite and the inferred base of the Tow Law ganister in the middle quarry.

Interpretation

The lower Knitsley Fell quartz arenite has been tentatively interpreted as a beach or chenier ridge deposit by Percival (1981) based on the sedimentary structures and the comparative maturity of the sandstone.

This author agrees with Percival's interpretation and the quartz arenite is thus thought to record shoreline reworking of previously-deposited sediment, by waves and/or longshore currents.

6.2.2.5 Major sandstones ("Third Grit")

Description

As mentioned in Chapter 4.2.1, several "major" sandstone bodies (greater than 10 m thick, and often more than 20 m) occur within the basal Coal Measures sequence. These are exposed in a number of quarries, two of which have been described (Cross's Upper Ganister quarry and Bessy's Bank quarry), and three more will now be considered.

The exposures concerned are Quarry Wood Quarry (G.R. NZ 074422), Grey's Well Quarry (NZ 111380) and Viewly Hill Quarry (NZ 101392), (Fig. 6.2) These expose up to 10m vertical sections of sandstones at varying positions within the stratigraphical sequence; the Quarry Wood exposure lies above the Quarterburn Marine Band, whereas the Viewly Hill and Grey's Well exposures are situated above the horizon of the Kays Lea Marine Band.

The sandstones are strongly trough cross-bedded, with sets preserved up to 2.0 m in thickness. Other structures include ripple cross-lamination, parallel lamination and primary current lineation. Further notable features include common shale clasts and coalified plant debris, thin micaceous and carbonaceous, laminated silt partings, some of which may be laterally extensive over at least 50 m, and occasional indeterminate trace fossils. A vertical section through a typical exposure is shown in Fig. 6.5. Grain size varies between and within individual exposures from fine to granular grade.

In the uppermost part of the exposure at Viewly Hill, the sandstone takes on an unusual mineralogically and texturally mature appearance (grain size/sorting 1.62 $\phi \pm 0.35$, as opposed to 1.78 $\phi \pm 0.83$ lower in the exposed sequence, and about 86% detrital quartz grains, as opposed to 67%), and possesses significant secondary

porosity caused by ? Recent dissolution of microcrystalline kaolinite cement (Appendix 2).

Palaeocurrent data collected from cross-bedding at the various exposures indicate a general west-to-south-directed palaeoflow with moderate spread between localities but little variation within each one (Fig. 6.4).

Interpretation

The sequences described are interpreted as the deposits of large, southerly-flowing, fluvial or distributary channel systems. There are no outcrops of channel margins, and few indications as to the internal structure of the channel sediments. Cosets of 0.1-0.5 m trough cross-sets and laterally persistent "slack-water partings" are common, and at Grey's Well a single 2.0 m cross-set is exposed over possibly 100 m in the downcurrent direction, possibly representing the migration of a single bedform over the channel floor, but these are the only discernible pointers towards channel fill structure.

In most of the exposures examined, the thicknesses of sandstone bodies (inferred from I.G.S. records) negate the alternative interpretation of crevasse-initiated, shallow basin infills, although the channels themselves probably originated by crevassing of earlier channel margins (Elliott, 1974).

The uppermost part of the Viewly Hill exposure requires an additional explanation. Despite the superficial resemblance to the quartz arenite "ganisters" (Percival, 1981), the exposed lithology contains no visible root structures or other evidence of pedogenesis. On the other hand, the greater mineralogical and textural maturity relative to the rest of the sandstone implies reworking of previously-deposited sediment, probably during the Roddymoor marine incursion.

The inferred former abundance of kaolinite/illite cement in the uppermost sandstone at Viewly Hill quarry forms a further contrast to the quartz-rich "ganisters", which contain little cement other than quartz overgrowths, and little porosity. The reworked top of the Viewly Hill sandstone evidently contained considerable primary intergranular porosity which was not cemented by early diagenetic quartz overgrowths, but was later reduced or completely plugged by kaolinite/illite precipitation.

6.2.2.6 The Tow Law Ganister

Description

The Tow Law Ganister, a highly siliceous sandstone formerly worked extensively for refractory purposes, occurs immediately beneath the horizon of the Ganister Clay coal in the Wolsingham-Tow Law area (Fig. 6.1). Two outcrops of the ganister, both small and poorly-exposed are considered:

Black Burn (G.R.NZ085457) and

Greenfield No. 2 Quarry (G.R.NZ094411),(Fig. 6.2).

In addition, the sequence formerly exposed in Knitsley Fell middle quarry is briefly mentioned.

At Black Burn, the Tow Law ganister consists of 0.57 m of fine-grained quartz arenite sandstone, containing moderately sorted, subrounded grains, (Percival, 1981, p. 311). Rootlets and large *Stigmaria* roots are present, and the basal contact of the quartz arenite is sharp and noded. Overlying the ganister is a thin (0.035 m), bioturbated, fine-grained sandstone containing *Teichichnus* burrows. The Ganister Clay coal is absent at this locality.

At Greenfield No. 2 Quarry, former ganister workings expose the lower part of the Tow Law ganister, which is fine-grained,

poorly sorted and contains a variety of grain shapes (Appendix 2). In contrast to the previous example, the ganister has a transitional base, passing down into progressively less-indurated, ripple cross-laminated and parallel laminated clay-rich sandstones. The upper part of the ganister is no longer visible, but the uppermost level exposed displays many of the characteristics of pedogenic ganisters, and is penentrated by rootlets.

Petrographically, the top part of the exposed sandstone contains about 95% quartz (detrital grains + overgrowths) with minor amounts of illite/kaolinite cement and a late-diagenetic iron phase, probably hematite and goethite (Appendix 2).

No accurate thickness estimation is available for this locality, though at Dixon's Shaft, 600m to the south-east (G.R. NZ 099408), a thickness of 1.07 m for the Tow Law ganister was recorded. At certain localities, thin units of coal or coaly shale (up to 0.05 m in thickness) occur immediately above or below the Tow Law Ganister. Thicknesses of up to 1.8 m for the Ganister have been recorded from workings (Strahan, 1920; Collins, 1925; Percival, 1981).

Interpretation

Percival (1981) has interpreted the Tow Law Ganister as a podzolic soil profile, based on the presence of rootlets, noded base and petrographic characteristics of the rock.

At Greenfield No. 2 Quarry, Knitsley Fell middle quarry and probably also at Black Burn, units of fine sand were laid down in very shallow water interdistributary environments, perhaps as crevasse splays, and then colonized by plants under conditions of free drainage.

Though exposures are few, and records poor, there does appear to be an inverse relationship between the occurrence of the Tow Law ganister and that of the overlying Ganister Clay coal. This may be explained by relative levels of topographical elevation; where freely-drained conditions predominated, allowing development of podzolic soils, the geochemical environment might not have been sufficiently reducing to allow peat to accumulate extensively, and conversely, in areas of relatively greater subsidence, poorly drained, more reducing conditions allowed accumulation and preservation of peat.

6.2.3 The Ganister Clay Coal

The Ganister Clay coal (V000 in the N.C.B. nomenclature; see Figs. 2.6, 6.1) is the lowest worked coal in the Durham coalfield, ignoring small outcrop workings of lower, minor seams.

The Ganister Clay coal varies from 0-0.79 m in thickness, and is commonly banded, particularly where of workable thickness. The seam is notable for its' irregular thickness variation, but broadly speaking has been worked sporadically in the South Durham area, and thins rapidly north of the latitude of Crook (Fig. 6.10).

Sulphur levels in the Ganister Clay coal are generally quite low, ranging from 0.5-0.75%.

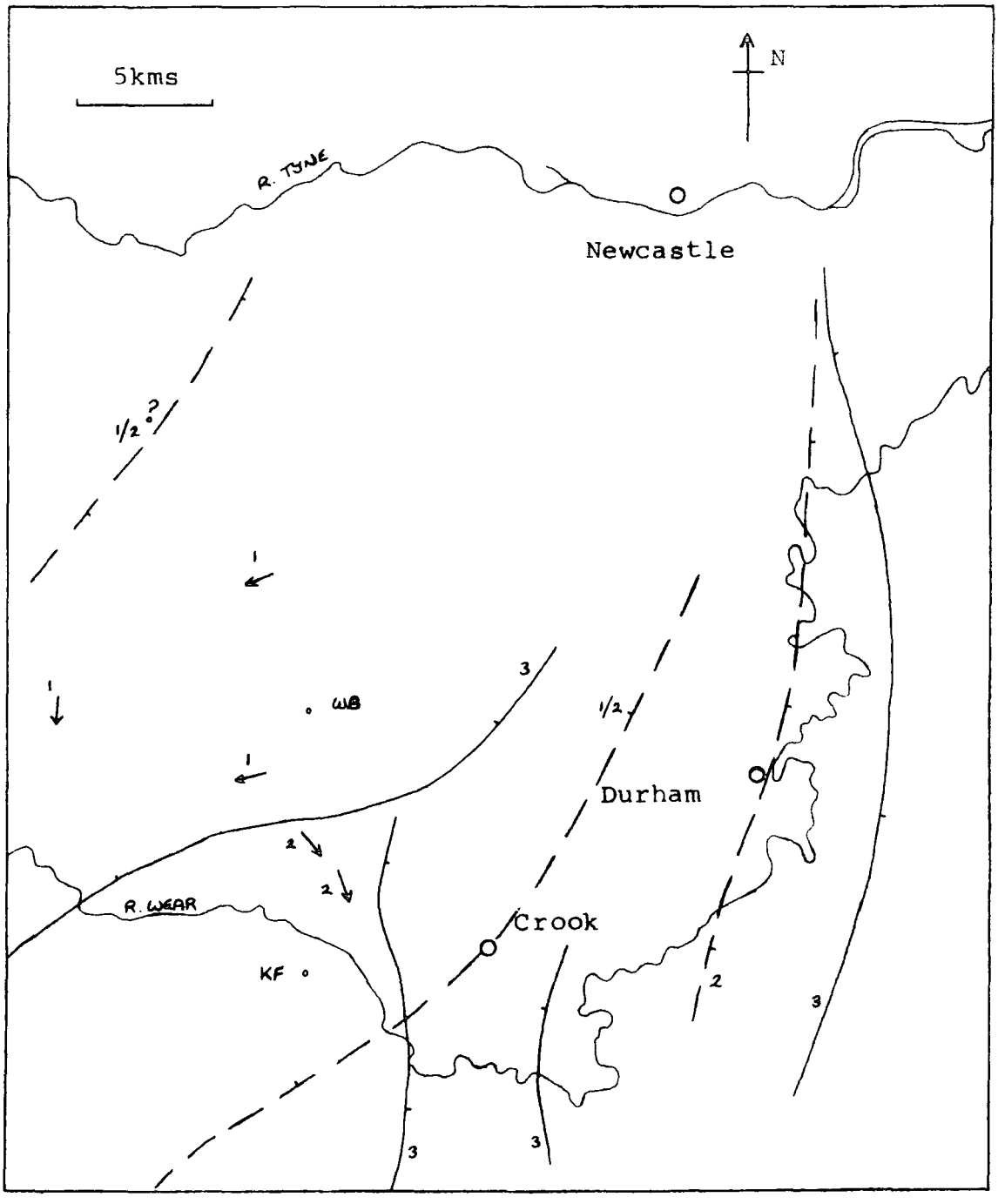
The absence of the Ganister Clay coal in the area west of Tow Law and Wolsingham may in some cases be ascribed to post-depositional erosion, but in many instances peat probably never accumulated.

6.2.4 Discussion

From the association of major channel, interdistributary bay, backswamp and shoreline deposits, the sedimentary setting of the

Fig.6.IO

SPECULATIVE CHANNEL BELT TRENDS IN THE BASAL COAL MEASURES OF THE DURHAM AREA



- Speculative channel belt margins, based on outcrop and subsurface data.

1/2/3 - Depositional "phases" (see text), as follows ;

3 - post Roddymoor marine band
2 - post Kays Lea marine band
I - post Quarterburn marine band

- Palaeocurrent vector mean (see Fig 5.5).
WB - West Butsfield. KF - Knitsley Fell.

basal Coal Measures is interpreted as the lower delta plain of a lobate or elongate, river-dominated delta, probably influenced by tides and waves (Elliott, 1978). Thus, the major sandstones interpreted in the preceding sections as channel sediments may be regarded as the deposits of deltaic distributaries.

Models of delta plain sedimentation have been proposed by Horne, Ferm and co-workers for the Upper Carboniferous coal-bearing rocks of central and eastern U.S.A. (Ferm, 1974; Horne *et al.*, 1978). According to these models, distributary channels in lower delta plain settings are widely spaced, and peat/coal seams are thin, laterally continuous and contain variable levels of sulphur (commonly greater than 2%). The basal Durham Coal Measures are conspicuous by an almost total lack of workable coal seams, most of those occurring being thin and laterally impersistent over any distance. Sulphur levels are characteristically variable, though relatively low (0.5-0.75%).

Following examination of available exposures, an attempt was made to assess the magnitude and orientation of the major sandstone-filled distributary channels, by examination of subsurface records for thick (10 m +), erosive-based, sandstone bodies. This proved difficult, due to lack of reliable, accessible information, but tentative conclusions are presented in Fig. 6.10.

The deltaic distributaries appear to be confined to broad belts 10's of kms wide, which may have contained more than one active channel at any one time. The channel belts are oriented in a general south-south-west direction, and the variable thickness of individual sandstones within the channel belt might well be due to channel "wandering" across these areas. Palaeocurrent means for each locality show a moderate dispersion, but provide no indication as to channel morphology.

Subsurface records suggest the existence of three broad "units" of sedimentation in the sub-Ganister Clay channel sandstones numbered 1-3 on Fig. 6.10. The earliest phase occupies the interval between the Quarterburn and Kays Lea Marine Bands, the second above (and commonly cutting through) the Kays Lea Marine Band and the third above (and cutting through) the Roddymoor Marine Band.

These "units" are not thought to be entirely separated in time, but rather represent a continuous history of erosion and deposition throughout earliest Westphalian A times. Thus in some areas the previously-mentioned marine bands were eroded by subsequent, down-cutting channels, and in others were never deposited, where channels were active during the period of marine incursion. (In still other areas, marine sediments were laid down during marine incursions and unaffected by contemporary or subsequent channels). Borehole evidence suggests that the easternmost "Phase 3" channel belt of Fig. 6.10 may have been active during accumulation of the Ganister Clay peat.

It is worth noting that the sub-Ganister Clay sequence in the Durham coalfield is markedly condensed in comparison with equivalent sequences in other coalfields (Plate 2 of Ramsbottom *et al.*, 1978). Indeed, the interval under consideration represents the entire *lenisulcata* bivalve zone (Fig. 2.4). This is probably due to a comparatively low rate of subsidence in the northern part of the Upper Carboniferous Pennine basin, in association with relatively low sedimentation rates.

The major distributary channels operating through this period were thus probably active over considerable periods of time, though

perhaps not continuously. Due to lack of data, it is difficult to determine whether channels were vertically stacked or offset, but from a consideration of examined vertical sequences, the latter alternative seems more likely.

Interdistributary areas were shallow water bays of the order of 10-20 kms wide, and up to at least 10 m deep, where marine processes aided reworking of abandoned distributary and crevasse/minor delta sediments to form mature, quartz arenitic shoreline sandstone bodies. The orientation of deltaic distributaries and of the West Butsfield Ganister indicate a general east-west trend to the shoreline, and wave ripples (from West Butsfield) indicate north-east and north-ward, that is, onshore-directed, winds. Interdistributary bays were filled predominantly, if not exclusively, by channel-derived overbank and crevasse splay/minor delta sediments, from a comparison with modern delta plain environments (Elliott, 1978).

Superimposed upon this "steady state" depositional system, probably characterized by slow, regular subsidence, were at least three marine incursions which, by their widespread occurrence across the British and northern European coalfields, are considered by many authors to be eustatically controlled. In the Durham area these relative rises in sea-level were probably of the order of 10-20 m, from the thicknesses of sequences overlying marine bands.

In the central Pennines and South Wales, where subsidence was greater, these marine incursions had the effect of creating a widespread, shallow and highly reducing, shelf basin environment (Demaison and Moore, 1980) in which bottom-living fauna were unable to live (Calver, 1968a). In the Durham coalfield, however, bottom conditions were sufficiently aerated to allow faunal colonization, as

evidenced by the body and trace fossils of benthonic organisms in the "marine bands". This was due probably to a reduced marine influence (in terms of salinity, nutrient levels, etc.), also indirectly implied by the abundance of the inarticulate brachiopod *Lingula* in the marine sediments.

It is worth noting at this point that the basal Westphalian marine bands, where preserved in the Durham area, almost always occur a short distance above a thin coal seam or seatearth, and this may be explained in terms of relative rates of sedimentation and subsidence; records of marine incursions were perhaps only preserved in areas where sedimentation was virtually non-existent prior to the incursion, i.e., in swamp areas where peat was accumulating. This topic will be discussed in Chapter 10.

One possible consequence of the occasional marine incursions represented in the sedimentary record of the basal Coal Measures is that of increased channel bank crevassing, perhaps represented in exposures at Cross's Upper Ganister Quarry and at West Butsfield Quarry. Following a relative rise in base level (and depending on the rate of rise relative to rates of channel aggradation) channels might adjust to the change by rapid vertical aggradation. This in turn would lead to inherent instability of channel courses and susceptibility to crevassing, particularly if base-level then dropped to its' former level. An increased incidence of crevassing and channel switching might therefore be expected to follow the marine incursions of the Westphalian, and this may explain the frequent truncation of the claystones above marine bands by erosively-based crevasse and channel sandstones. It may also help to explain the apparent sheet-like geometry of the "3rd Grit" sandstones.

The association of pedogenic ganisters with the basal Westphalian A, marine-influenced Coal Measures is unique, and it is necessary to search for a genetic relationship between the two. These ganisters, the products of leached, podzolic soil profiles, obviously required conditions of free drainage to form,a situation difficult to imagine in the waterlogged setting of a lower delta plain.

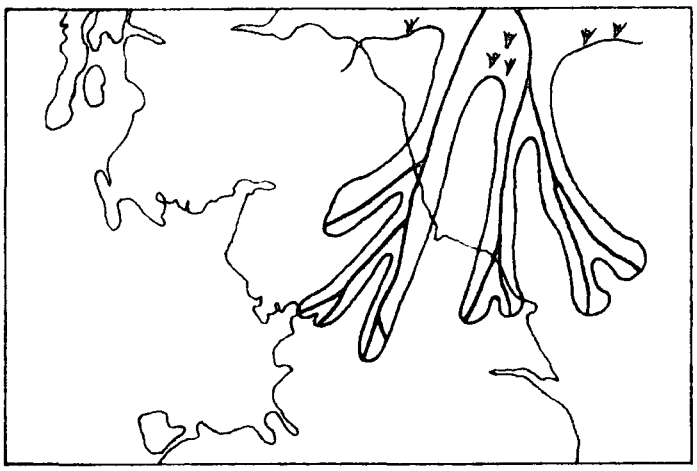
It is thus proposed that the lowermost Westphalian A ganisters were formed by wave reworking of petrographically immature deltaic sands, followed by soil formation on emergent surfaces. Emergence could have been produced temporarily and locally by differential subsidence-induced fluctuations in water-table.

There is a marked similarity between the Upper Namurian and basal Westphalian sequences of the Durham area, and it is possible to explain the two by a single sedimentary model (Fig. 6.11a). In this model, distributary channel belts 10's of kms wide supply sediment, from a distant source to the north, to a delta front in the central Pennines which is prograding into the "Pennine basin". The overall delta morphology is interpreted as elongate, marking a change in style from earlier lobate forms (Elliott, 1973; Collinson, 1968). Collinson and Banks (1975) interpreted the upper Namurian Haslingden Flags as the deposits of an elongate delta mouth "bar finger", and it may be possible to correlate the "Durham Grits" with some of the major fluvial/deltaic sandstones of the central Pennines, such as the Haslingden Flags, as suggested by Percival (1981). Such an evolution from lobate to elongate delta morphology might reflect progradation into the deeper water of the central Pennine basin,

Fig.6.II

GENERALISED SEDIMENTARY MODEL FOR THE UPPER NAMURIAN AND LOWER WESTPHALIAN OF THE NORTHERN PENNINES

a) Upper Namurian/Basal Westphalian



Lower delta plain of an elongate, river-dominated delta, influenced by waves and tides.
Occasional ?eustatic rises and falls in sea-level, superimposed on slow, ?steady subsidence.

b) Westphalian A - "productive Coal Measures"



Upper delta plain - no marine influence.
Slow, ?steady subsidence, largely unaffected by changes in sea-level.

similarly to that of the Recent Mississippi delta (Frazier, 1967).

The basal Westphalian sequence is condensed in the Durham coalfield, but the Upper Namurian succession is even more so (Fig. 9 of Ramsbottom *et al.*, 1978); this is again considered to be the result of comparatively slow subsidence with respect to the Central Pennine area.

While it seems likely that a large proportion of the sediment passing across the northern Pennines during these times was never deposited there, or was deposited and subsequently removed, inter-distributary areas eventually began to fill at a greater rate than that of subsidence, as the delta system prograded southward, and the shoreline advanced across the Northern Pennines. By the time of deposition of the Ganister Clay coal, upper delta plain conditions were more or less established, leading to incidences of widespread peat accumulation,(Fig. 6.11b). At about this time, the non-marine bivalves, so characteristic of the Coal Measures, were able to colonize the freshwater lakes of the newly-established terrestrial environment.

Above the Roddymoor Marine Band, the next marine incursion to have any effect on the area was the *VANDERBECKEI* (Harvey Marine Band) event, represented 170 m higher in the sequence. Steady-state conditions of deposition and subsidence were largely uninterrupted over the majority of the Westphalian A period.

6.3 GANISTER CLAY TO VICTORIA COALS

6.3.1 Introduction

The sequence between the Ganister Clay and Victoria Coal Seams varies from 25 m to 45 m, tending towards the latter in the southern

part of the coalfield. As with the underlying basal Coal Measures, this interval tends to be predominantly arenaceous, but differs in containing no marine bands, few quartz arenitic sandstones or ganisters, and a comparative abundance of coal seams (Fig. 6.1).

Two locally workable coals occur between the Gansiter Clay and Victoria Seams, the Stobswood, which is restricted in occurrence to the south-west part of the coalfield, and the Marshall Green, which comprises two separate leaves in some parts (Fig. 6.1). Several other thin coals occur locally within this interval.

Exposures of the Ganister Clay-Victoria interval, described in the following pages, are largely sandstone quarries and natural exposures.

6.3.2 Sediments between the Ganister Clay and Marshall Green Coals

6.3.2.1 Knitsley Fell Quarries, and other "major sandstone" exposures

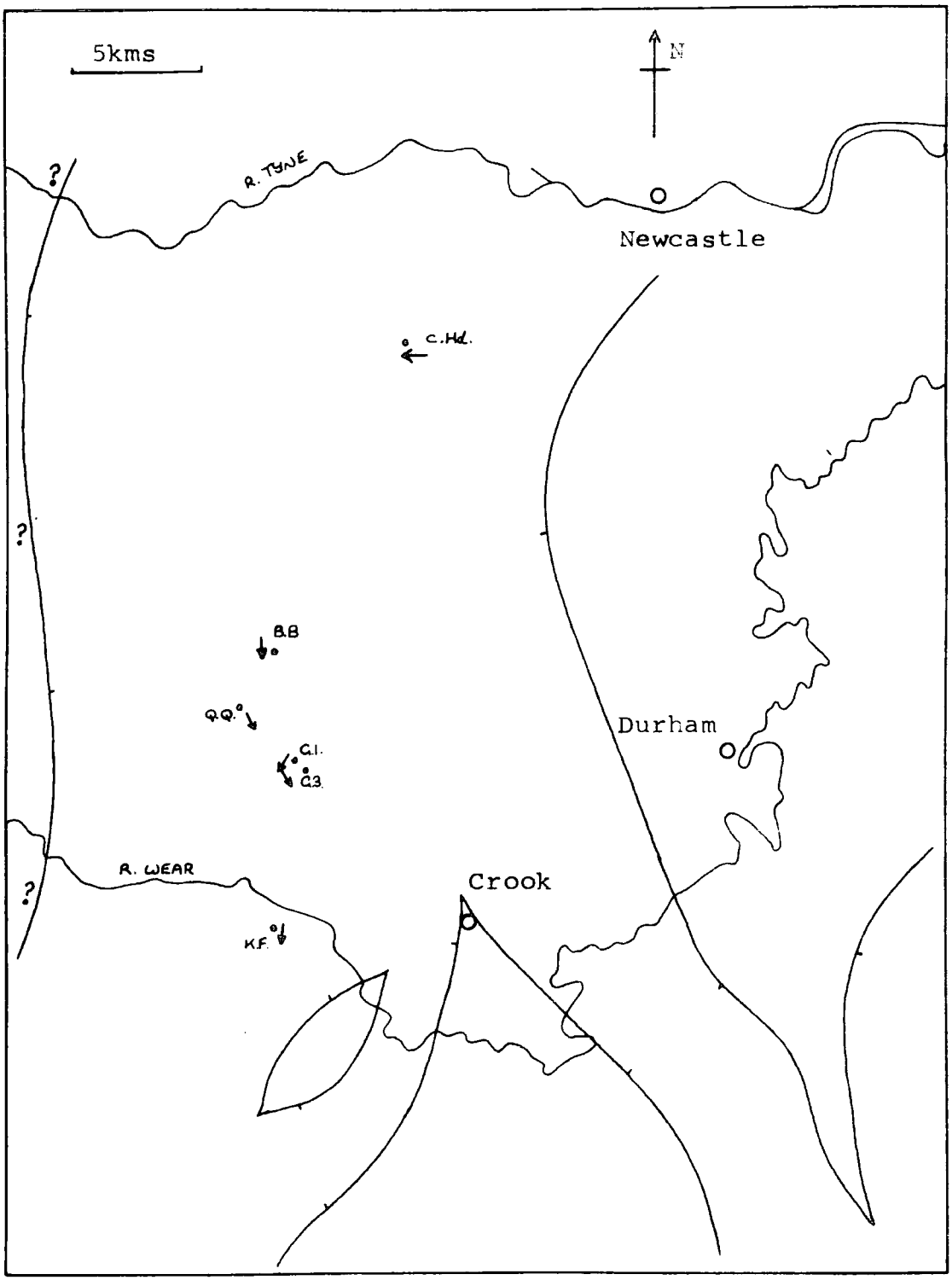
Description

The Knitsley Fell middle and upper quarries (G.R. NZ097344) expose a sequence of sediments stratigraphically above and including the Tow Law Ganister (Fig. 6.9).

The dark grey, shaly claystones of Unit 4 (Fig. 6.9) are not exposed *in situ*, but are described by Strahan (1920) and can be seen in numerous spoil heaps. The overlying trough cross-bedded sandstone (Unit 5) is, however, well-exposed and contains cross-sets up to 1.2 m thick, arranged either singly or in cosets. Trough orientations indicate palaeoflow uniformly towards the south (Fig. 6.12). The sandstone is laterally continuous over at least 275 m along the quarry wall, in a direction oblique to palaeoflow.

Fig.6.I2

SPECULATIVE POST-GANISTER CLAY CHANNEL BELT TRENDS, AND PALAEOCURRENTS



= Speculative channel belt margin.

→ = Palaeocurrent vector mean.

C.Hd. = Crag Head. (N = 8). B.B. = Black Burn (N = 5).

Q.Q. = Quickburn Quarry (N = 9) C.1. = Greenfield No. 1 (N = 47)

C.3. = Greenfield No. 3 (N = 9) K.F. = Knitsley Fell (N = 11).

Exposures of similar lithologies at an equivalent stratigraphical horizon occur at Greenfield No. 3 Quarry (G.R. NZ 098407), Black Burn (G.R. NZ 085457) and Quickburn Quarry (G.R. NZ 080427), (Fig. 6.2). Palaeocurrent measurements indicate a consistent, unidirectional flow towards the south-south-east (Fig. 6.12).

The uppermost part of the major sandstone exposed on Knitsley Fell comprises the Upper Knitsley Fell Ganister, a fine-grained moderately sorted quartz arenitic sandstone (Unit 6). Few structures are visible, other than rootlets and *Planolites* burrows in the uppermost few cms. This topmost zone thickens towards the south from 0.05 m to 0.30 m over a 20 m-long exposure.

Petrographically, the quartz arenite is similar to that exposed in the lower quarry, but the uppermost rootlet-penetrated horizon contains up to 28.5% of iron minerals (Percival, 1981, p. 313).

The fine-grained sandstones of Unit 8 overlie the silty claystones of Unit 7 with a slightly undulating, erosive contact. The base of the sandstone contains features resembling flute marks, and the lowermost few cms are chaotically bedded, containing abundant coaly plant casts. Further up the section, the sandstone is trough cross-bedded (indicating palaeoflow towards the south-east) and rootlet-penetrated. Undulatory bedding with a wavelength of 1.0 m and amplitude of 0.15 m, is exposed at one locality, striking towards the west-north-west.

Near the top of the exposed section, the sandstone takes on a hard, "flinty" appearance in two separated 20 cm bands, not unlike the quartz arenites below.

Interpretation

The major sandstone of Unit 5 is tentatively interpreted as the deposit of a distributary channel which flowed southwards, following crevassing of a former channel course. That the channel originated by sustained crevasse splay deposition in a standing body of water is inferred from the presence of an ? erosively-based sandstone directly overlying dark-coloured, well-laminated claystones.

The dimensions of this channel cannot be ascertained, but the width was at least 200 m, and the vertical thickness of the deposit about 5.6 m. The abundance of large-scale structures and lateral continuity of the sandstone support the above interpretation, and the other similar exposures mentioned above are interpreted in the same way.

The top of the sandstone comprising Unit 5 of Fig. 6.9 appears to have been reworked to some extent and ? periodically colonized by plants to form the mature, quartz arenite exposed in the upper quarry, and Percival (1981) has suggested a high energy shoreline, washover origin for this deposit (Unit 6). A tentative estimate of about 6-8 m water depth may thus be made for the post Ganister Clay basin at Knitsley Fell, prior to infilling.

Reworking of the ? abandoned distributary sands evidently took place under conditions of reduced, or even non-existent, sediment supply. As the area subsided below the influence of waves or tides, fine-grained sediments containing plant detritus were laid down, probably by very gentle traction currents, to form Unit 7 (Fig. 6.9).

The erosional base, thickness (2.0 m, or possibly slightly more), and contained structures of Unit 8 suggest a proximal and/or axial crevasse splay origin for this sandstone. Evidence for rapid

deposition is contained within the basal part of the sandstone, and it seems likely that several events deposited this Unit.

Evidently the crevasse "package" all but filled the body of water into which it poured, giving a probable water depth of about 2 m. As to the nature of the body of water into which Units 5 and 8 prograded, the inferred presence of reworked, shoreline sandstone deposits (Units 1 and 6) implies open water, probably marine-influenced conditions, and so the environment of deposition of Units 4-8 is regarded as a lower delta plain interdistributary bay. The presence of wave-like bedforms within Unit 8 is further evidence of a possible marine influence.

The ganister-like lithologies at the top of Unit 5 may be interpreted as further reworked horizons or/and as the result of pedogenic activity. Lack of exposure makes it impossible to distinguish between the two alternatives.

The sequence exposed in the Middle and Upper Knitsley Fell quarries records the diversion of a distributary channel into an interdistributary bay, its' active life and subsequent abandonment. The interdistributary area is interpreted as having been influenced by basinal processes, though not fully marine in character.

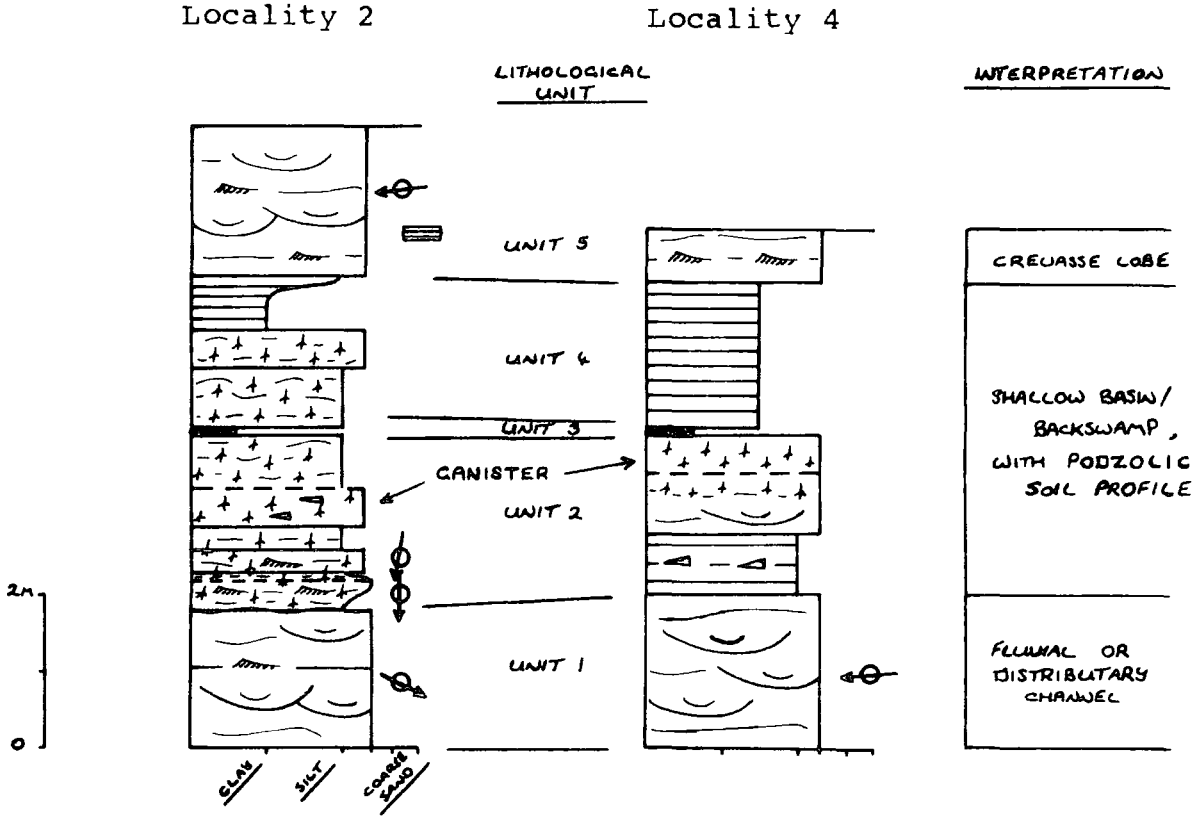
6.3.2.2 Quickburn Quarry

Description

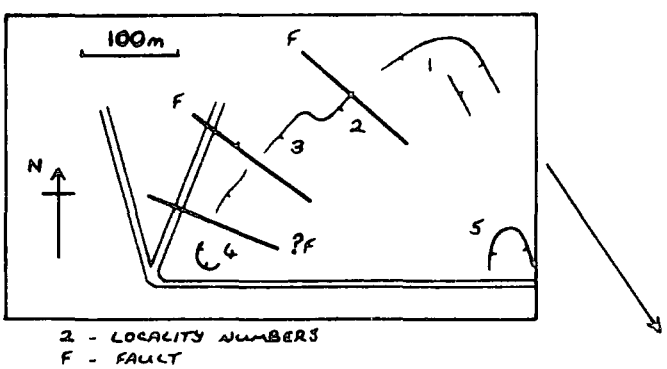
Quickburn Quarry (G.R. NZ 080427), (Fig. 6.2) exposes a sequence of rocks above the horizon of the Ganister Clay coal (Fig. 6.13). The area is crossed by a number of small faults, but these are thought to cause little vertical displacement.

Fig.6.I3

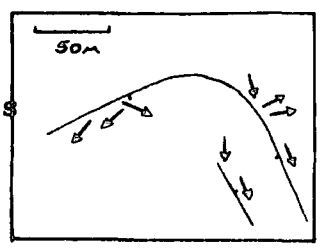
MEASURED VERTICAL SECTIONS AND PALAEOCURRENTS
FROM QUICKBURN QUARRY (G.R.NZ080427)
(Based on Sections 409 & 4IO - Appendix I)



Plan of quarry



Locality I
- palaeocurrents



The lowest unit exposed in the quarry is a major sandstone possibly more than 10 m thick (Unit 1), the main part of which is exposed in the north-east and south-east corners of the quarry (localities 1 and 5, respectively; Fig. 6.13). This sandstone is fine-to-coarse-grained, buff-coloured and strongly trough cross-bedded. Occasional horizons display chaotic bedding, with abundant coaly plant debris. Trough cross-sets are relatively wide and shallow (up to 1 m in preserved thickness), and display considerable variation in direction, within the west-south-east semicircle, both between and within individual localities (Fig. 6.13).

The uppermost part of this sandstone body is exposed in the central area of the quarry (localities 2, 3 and 4; Fig. 6.13), where it is fine-grained and has an abrupt, undulating top.

Unit 1 is overlain by a series of interbedded siltstones and fine sandstones (Unit 2), which is in part rootleted. Small-scale trough cross-bedding and ripple cross-lamination indicate transport towards the south. Within this sequence is a 0.50 m ganister horizon, containing *in situ* rootlets.

Petrographically, the ganister is variable in quality, comprising 74% quartz in the lower part, but becoming increasingly pure upward. Occasional *Planolites* burrows are found within the lithologies of Unit 2.

Above the interbedded sediments of Unit 2, and a thin (0.11 m) coal (Unit 3), lie similarly interbedded lithologies comprising Unit 4. The sandstone of Unit 5 contains abundant trough cross-sets up to 0.4 m in thickness, indicating palaeoflow consistently towards the south-west (Figs. 6.12, 6.13).

Lateral variation is common over the area of the quarry, particularly in Units 2 and 4. At locality 2, the top surface of Unit 1 undulates, causing a compensatory thickening/thinning effect in the overlying beds. At localities 2 and 3, the sediments of Units 2 and 4 are almost totally rootleted, whereas at locality 4 only the upper part of Unit 2 and none of Unit 4 is rootlet-penetrated. At localities 2 and 3, the ganister within Unit 2 occurs as a sharply based sandstone, 0.48 m thick, and is overlain by 0.70 m of rootleted silt passing up into the thin coal of Unit 3. At locality 4, however, the ganister occurs as the upper 0.5 m of a 1.3 m sandstone bed, has a transitional base and is directly overlain by the coal of Unit 3. At localities 2 and 3, Units 2 and 4 are represented by a number of thin beds whereas at locality 4, these Units are made up by fewer, comparatively thicker beds, overall thicknesses being closely comparable (Fig. 6.13).

Interpretation

From its' character and associated lithologies, the major sandstone body exposed at localities 1-5 is interpreted as the deposit of a distributary channel, flowing generally towards the south-east, though with significant local variation (Figs. 6.12, 6.13). Considerable evidence for rapid, almost catastrophic, sediment deposition and periodic slack-water conditions is shown in chaotic bedding, jumbled plant debris at all angles to bedding, and by thin micaceous/carbonaceous partings, respectively. The dimensions of the channel itself cannot be ascertained, owing to poor exposure in the surrounding area.

Channel abandonment is thought to have taken place quite rapidly, as inferred from the abrupt upper contact of the sandstone;

no fining-upward trend was observed, and at localities 2 and 4 trough cross-sets up to 0.3 m thick occur up to the top of the sandstone. Abandonment probably took place by complete avulsion, effectively ending sand transport and deposition through the old channel course.

The interbedded sediments of Unit 2 are interpreted as shallow standing water deposits, laid down as the abandoned channel gradually subsided. Much of the time, the sediment/water interface was sufficiently near the surface to allow plant colonization. Conditions must also have been at least periodically conducive to infaunal colonization, as evidenced by the presence of *Planolites* burrows. The thin (up to 1.3 m), sharp-based sandstone units were probably deposited as crevasse splays, particularly that containing the ganister horizon.

The ganister itself is interpreted as arising from pedogenic processes and ? reworking of previously-deposited sands, to produce a leached podzolic soil profile in well-drained conditions. The ganister is thus similar in origin to the Tow Law and Bessy's Bank ganisters. It is apparent, though, that the "lessivage" process had not proceeded to the extent of producing a particularly clay-enriched B-horizon. The sandstone comprising the ganister is interpreted as a crevasse splay deposit rather than as channel abandonment or overbank sediment from the overall thickness of the bed and the presence of relict trough cross-bedding.

Ripple cross-lamination in the lower part of Unit 2 indicates a southward direction of transport, and the sandstone thickens towards the south-west, from localities 3 to 4 (Fig. 6.13).

The thin coal comprising Unit 3 accumulated at a time when conditions of plant accumulation, groundwater geochemistry and subsidence were conducive to peat formation. From the overlying lithologies, particuarly at locality 4, it would seem that the peat accumulated under conditions of progressive subsidence intermediate between the freely-drained situation necessary for formation of the podzolic soil and the standing water conditions inferred for the overlying sediments. The peat was initially preserved at localities 2 and 3 by rapid burial, and at locality 4 by gradual burial beneath slowly-accumulating, organic-rich sediments, in a persistently reducing environment.

The sediments of Unit 4, as implied above, accumulated in a standing body of water, largely in depths unsuitable for plant colonization. The occurrence of sharply based siltstone and fine sandstone beds within Unit 4, up to 0.8 m thick, at locality 3, implies crevasse splay sedimentation originating possibly to the north. The presence of rootlets in these beds indicates that deposition of thin crevasse lobes all but filled the local "basin" in turn implying that water depths were probably of the order of 1-2 m.

The sandstone of Unit 5 is interpreted as a major crevasse lobe which originated to the east of the present exposure and cut down through underlying deposits as it prograded westwards. At localities 2 and 3, the uppermost part of Unit 4 coarsens upwards and is erosionally truncated by the sandstone of Unit 5, indicating progradation of the crevasse lobe across previously-deposited distal crevasse splay deposits.

In summary, the sequences exposed at Quickburn Quarry record the active life and abandonment of a major distributary channel, subsidence of the area below "rootlet-base" after termination of channel sedimentation to form a shallow body of standing water and finally the progradation of a major crevasse lobe across the area (Fig. 6.14). One interesting point to emerge from the study of this exposure is the impression that the juxtaposition of rootleted and non-rootleted sediments of shallow water environments at the same stratigraphical horizon need not imply differential subsidence, but may simply be a function of local infilling my minor crevasse events or other depositional processes.

6.3.2.3 Greenfield No. 1 Quarry

Description

Greenfield No. 1 Quarry (G.R. NZ 095413), (Fig. 6.2) exposes an 8 m vertical sequence of strongly trough cross-bedded fine-to-coarse-grained sandstone, stratigraphically immediately below the horizon of the Marshall Green coal (Plate 6.4, Enclosure 1). Though part of the exposure is inaccessible, there appears to be no consistent change in grain size or scale of sedimentary structures upwards.

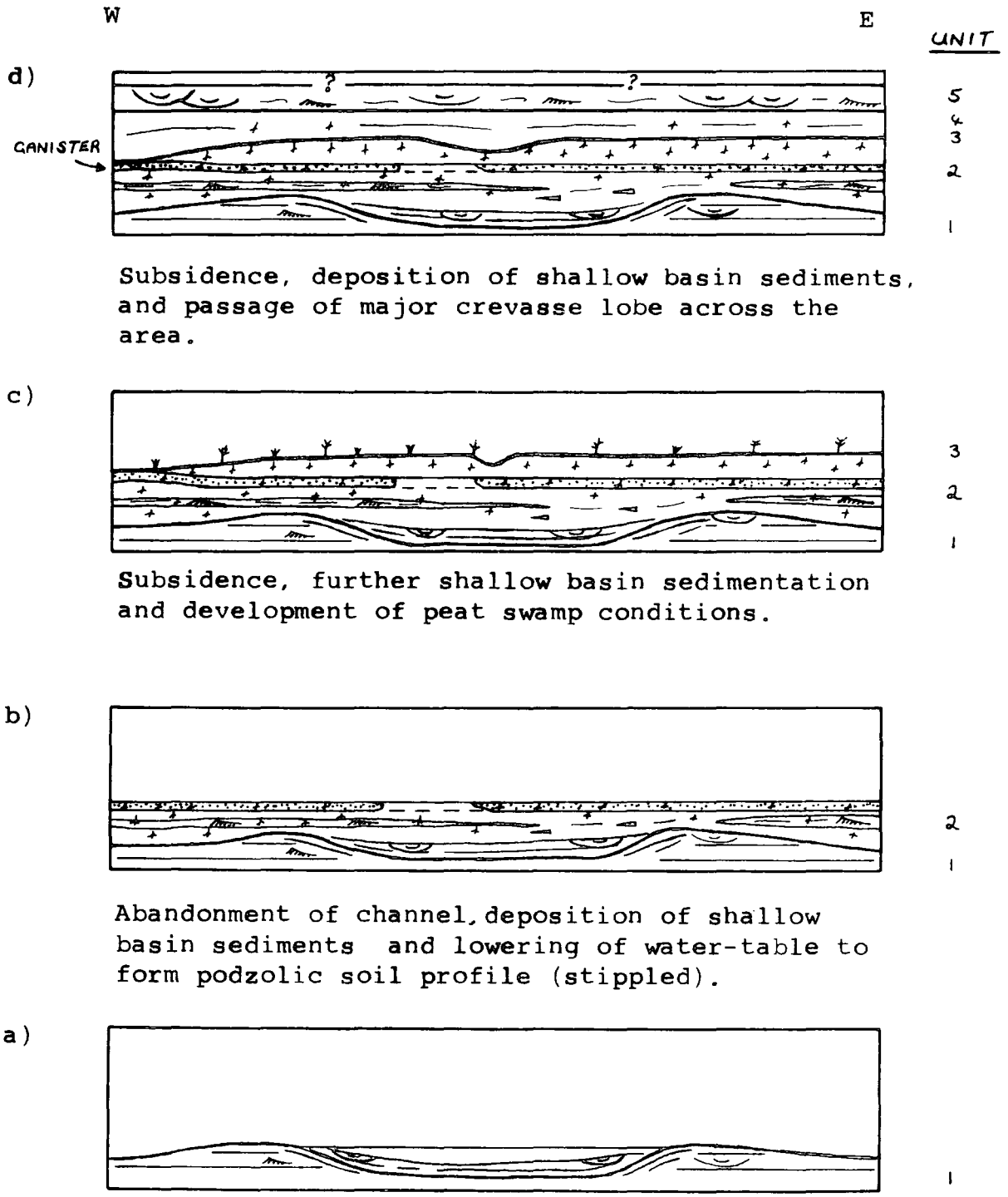
There is, however, some indication as to the internal architecture of the sandstone body. Several major bounding surfaces occur, which divide the sandstone into a number of depositional units (Enclosure 1).

The basal unit (Unit 1) is fine-to-medium-grained and characterized by abundant trough cross-sets up to 0.6 m in thickness, displaying moderate spread in palaeocurrent direction along the face, and occasional undulatory bedding. Above this is a Unit of variable

Fig.6.I4

GEOLOGICAL HISTORY OF THE QUICKBURN QUARRY SEQUENCE

(Schematic; see Fig. 6.13)



Subsidence, deposition of shallow basin sediments, and passage of major crevasse lobe across the area.

Subsidence, further shallow basin sedimentation and development of peat swamp conditions.

Abandonment of channel, deposition of shallow basin sediments and lowering of water-table to form podzolic soil profile (stippled).

Deposition of sands in a major fluvial or distributary channel.

thickness (0-0.8 m) and grain-size, characterized by a total lack of internal organization (Unit 2). Plant casts, and coalified peat and sediment rafts up to 2.5 m in length, are common in this Unit, which generally thins south-eastward along the quarry face.

Overlying this bed is a series of fine-to-medium-grained, trough cross-bedded sandstones, separated by bounding surfaces, with drapes of fine sediment which can be seen to dip at 1-3^{o} toward the south, successively overlapping and coming to rest on the "chaotic unit" (Enclosure 1; Units 3-6). Palaeoflow is consistent both within and between these sandstones and is significantly different from that of Unit 1 (Enclosure 1). The overall palaeoflow direction in the sandstone body was towards the south (Fig. 6.12, Enclosure 1).

Interpretation

The exposure is interpreted as the deposit of a major channel, the dimensions and morphology of which remain unknown. However, abundant evidence is contained within the exposure for a fluctuating, possibly even flashy, discharge regime. The chaotically bedded unit was obviously rapidly deposited under very high energy conditions, in one or more flood stage events. On the other hand, the numerous, downcurrent-dipping bounding surfaces are probably indicative of bedform erosion during falling stage, with fine-grained sediment drapes being deposited under low stage conditions (Jones and McCabe, 1980).

The cross-bedded sandstones between these bounding surfaces are interpreted as the deposits of channel floor bedforms (with a wavelength/height ratio of at least 50:1) which migrated southward

across previously-deposited units, coming to rest over the sedimentary discontinuity marked by the "chaotic unit". These bedforms are thus termed "channel-floor bars", since it is not possible to ascertain their position with respect to channel margins (Bluck, 1976).

While the cross-bedding, morphology and palaeocurrent distribution of Units 3-6 imply downcurrent migration of single bedforms, those of the basal member (Unit 1) suggest a rather more complex origin. Perhaps Unit 1 represents channel floor sedimentation over a considerable period, involving several erosional and depositional events.

The gradual rise in topographical level of the "chaotic unit" to the south-east, along the quarry face, may be due to shallowing of the channel, possibly towards a bank, to regional dip or to a combination of the two (Enclosure 1).

Similar features to those preserved at Greenfield were described by Haszeldine (1981a,b) from the Westphalian B of Durham and Northumberland, and interpreted as downcurrent-migrating, channel-floor bars in low sinuosity, braided rivers.

6.3.2.4 Crag Head

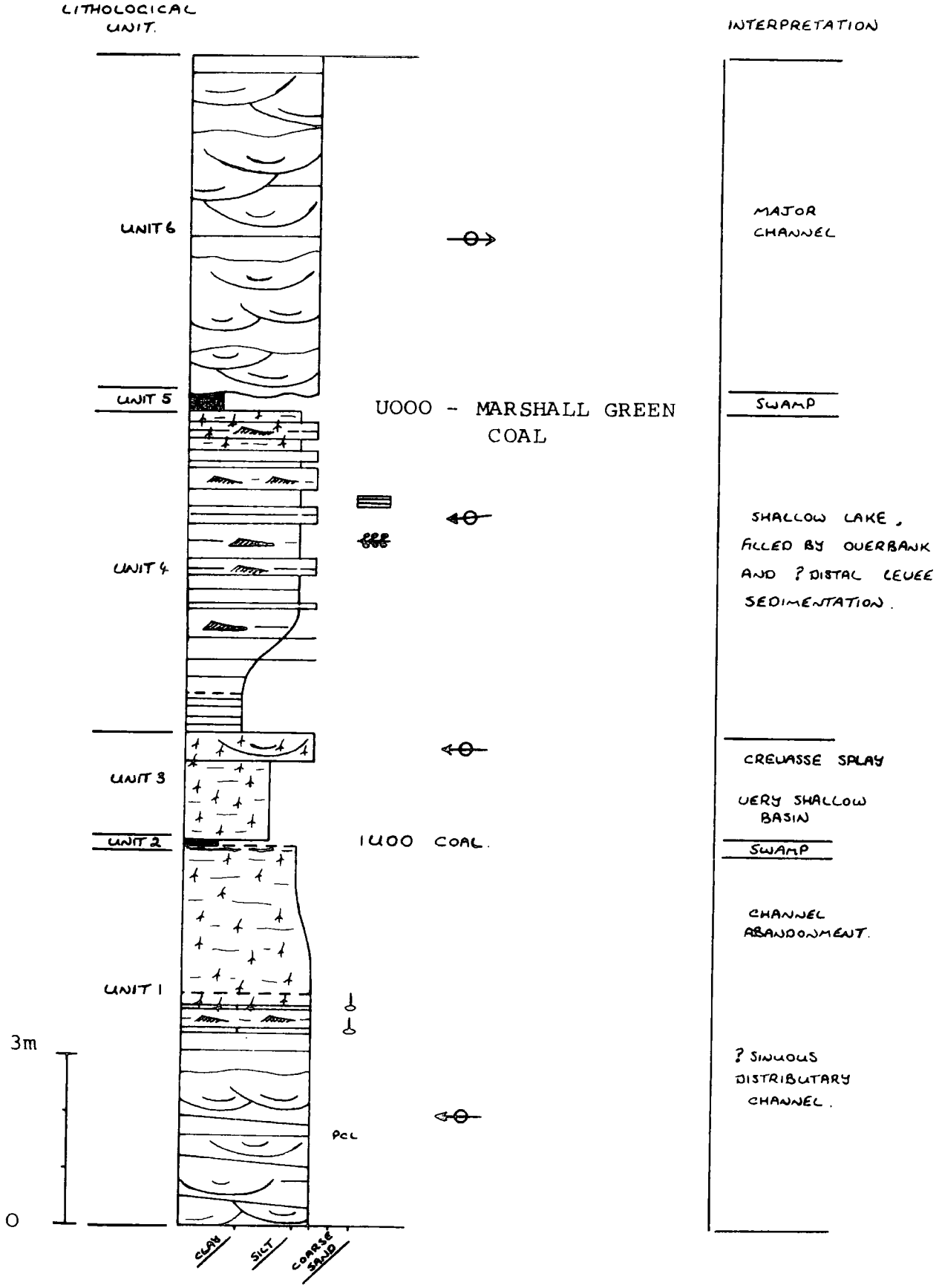
Description

At Crag Head (G.R. NZ 141574), (Fig. 6.2), steep-sided bluffs on both sides of the River Derwent expose a sequence of rocks which includes the Marshall Green coal (Fig. 6.15). The exposure on the south bank, being the most accessible and laterally extensive, was studied in detail.

Fig.6.I5

MEASURED VERTICAL SECTION AT CRAG HEAD (G.R.NZI4I574)

(BASED ON SECTION 624 ; APPENDIX I)



The very-fine-grained sandstone of Unit 1 (Fig. 6.15) contains a number of low-angle accretion surfaces inclined at 2-3° to the horizontal, and low-angle trough cross-bedding up to 0.2 m in thickness. *Pelecypodichnus* traces and dark, carbonaceous claystone partings become abundant towards the top of the sandstone, which passes upward into rootlet-penetrated siltstone. Palaeocurrent measurements from trough cross-bedding and ripple cross-lamination indicate palaeoflow towards the west, while the low-angle accretion surfaces dip towards the south-west (Fig. 6.12).

The thin, shaly coal of Unit 2 is overlain by a further sequence characterized by the abundant presence of rootlets (Unit 3), the uppermost 0.52 m of which comprises a sharp-bounded, fine-grained sandstone bed with rare relict trough cross-bedding. Rootlets within Unit 3, and the upper part of Unit 1, truncate both upwards and downwards at all levels within the host sediment.

The coarsening-upward sequence of Unit 4, in contrast, contains no evidence of rootlet penetration until the uppermost 0.50 m. Within this Unit, layers of fine sandstone increase in number and thickness upward, until the uppermost part is composed predominantly of 0.02-0.2 m sandstone units, separated by thin (up to 0.02 m), dark claystone partings. Palaeocurrent measurements from structures in Units 3 and 4 indicate a westward palaeoflow, similar to Unit 1.

The bright coal of Unit 5 is the Marshall Green seam; this coal contains thin, discontinuous claystone partings, and is laterally variable in thickness, due to differential erosion by the overlying sandstone.

The cross-bedded sandstone of Unit 6, at least 6 m thick at the locality examined, is seen to be at least 10 m thick in exposures

on the opposite side of the river. Trough cross-sets up to 1.0 m + thick are exposed, occasionally with very small (5 mm) intrasets. Directional structures indicate sediment transport towards the east (Fig. 6.16), a complete reversal of the pattern prevalent during deposition of Units 1-4.

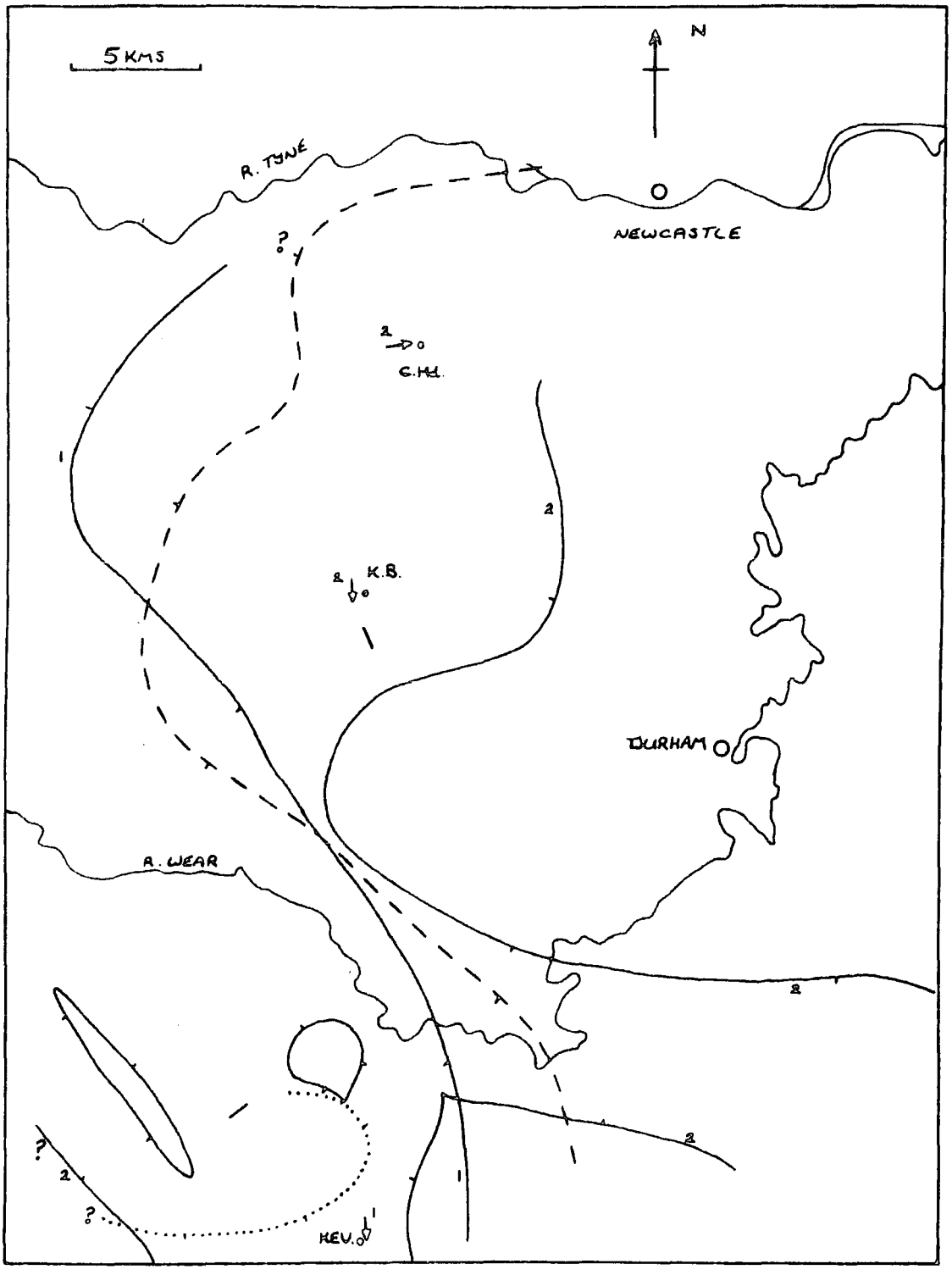
The limited extent of the exposure allows little observation of any lateral variation in facies, and the only visible variability is in the thickness of the Marshall Green seam, mentioned above.

Interpretation

The cross-bedded sandstone of Unit 1 (Fig. 6.15) is interpreted as the deposit of a channel, flowing at this point towards the west. The presence of low-angle accretion surfaces dipping in a direction 40-60 degrees oblique to that of the cross-bedding suggests lateral accretion towards the west, implying a sinuous channel morphology. Evidence of episodic deposition is abundant in the form of the ? lateral accretion surfaces, thin claystone partings and *Pelecypodichnus* escape burrows. The fining-upward and intensely rootleted nature of the upper part of Unit 1, leading up into the thin, impure coal of Unit 2, and the predominance of small-scale ripple cross-lamination in the upper part of the sandstone, possibly reflect gradual abandonment of the channel and a rate of subsidence which eventually overtook that of sediment accumulation. The observation that rootlets within the siltstone appear to terminate upward at all levels within the unit supports the interpretation of gradual subsidence and continuous plant colonization. Results of recent work by Jackson (1981) on mixed bedload channels suggests that most, if not all, of Unit 1 could have been deposited within the channel itself. Sinuous or meandering channels have been widely

Fig.6.16

POST-MARSHALL GREEN PALAEOCURRENTS, CHANNEL BELT TRENDS, AND THEIR RELATIONSHIP WITH ENCLOSING SEDIMENTS.



CHANNEL BELT MARGINS

PALAEOCURRENT VECTOR MEAN.

1/2 "DEPOSITIONAL PHASE" (SEE TEXT)

WASHOUT IN MARSHALL GREEN COAL.

"SPLIT" IN MARSHALL GREEN COAL (SEAM SPLIT ON ORNAMENTED SIDE).

LIMIT OF OCCURRENCE OF STOBSWOOD COAL (SEAM ABSENT ON ORNAMENTED SIDE).

CHd. - CRAG HEAD (n = 7). KB. - KNITSLEY BRIDGE (n = 13).
KEV. - KEVERSTONE GRANGE (n = 17).

recorded from modern (Allen, 1965b) and ancient (Stewart, 1981b; Leeder, 1981) fluvial settings and also from modern (Frazier and Osanik, 1961) and ancient (Guion, 1978; Elliott, 1976) coastal/deltaic plain environments. The sediments of Unit 1 display many features in common with these.

As subsidence of the sediment surface fell below a critical level, plant material began to accumulate, rather than be oxidized. However, fallout from suspension continued to supply fine clastic material to the swamp bottom, which evidently did not sink below the base level for plant growth, judging by the completely rootleted nature of Unit 3. The sharp-bounded fine sandstone bed forming the upper part of Unit 3 is interpreted as a minor crevasse splay deposit, which originated from a source to the east. Perhaps the channel which previously crossed this point switched its coarse to the east, and supplied sediment to the Crag Head area, at this time a backswamp, through overbank flooding and minor crevasse events. Water depth at this time cannot have been greater than 2 m, and was possibly less than 1 m.

Following the backswamp deposition of the Unit 3 peat, subsidence once again overtook accumulation, and the area became a standing water body of possibly 5 m depth. The bottom of this basin was at first stagnant and reducing, and in the absence of current activity sedimentation was restricted to slow deposition of dark grey, carbonaceous clays, now comprising the lower part of Unit 4.

After a time, however, it seems that tractional currents introduced somewhat coarser sediment to the basin, as evidenced by

the majority of Unit 4.

The finely laminated nature of the "siltstones with sandy streak" and ripple cross-lamination structures indicate periodic influxes of current-transported sediment, from a source to the east, either by overbank flooding or as distal crevasse splays. Abundant plant detritus was buried quite rapidly under probably mildly reducing conditions, as the basin was gradually filled with sediment.

The uppermost part of the Unit, composed largely of fine sandstone layers, is tentatively ascribed to the westward advance of a channel levee, perhaps laterally equivalent to a major distributary channel (Fig. 3.2), (Elliott, 1974; Heward, 1976). The channel supplying the levee presumably lay some distance to the east. This interpretation is supported by the lack of a regular coarsening-upward sequence and the assemblage of sedimentary structures present. A lack of trough cross-bedding, syndepositional deformation, wave ripples, etc., argues against alternative interpretations of proximal or distal axial settings.

The top of Unit 4 appears to mark an end to the period of levee progradation, perhaps due to channel abandonment, and as the area was once again starved of sediment and began to subside slowly, plants were able to colonize the passive levee surface. Peat accumulated, as backswamp conditions were established, and is now preserved as the Marshall Green Coal Seam (Unit 5).

It is possible that, during subsidence below "plant-colonization-base", fine-grained suspension sediments were laid down in the stagnant swamp. Whatever may have been originally deposited above the Marshall Green peat was subsequently eroded by a major channel, which cut down to lie directly over the coal and deposited the sandstone of Unit 6. Although the nature of the exposure did not

permit any elucidation of channel form or internal structure, it is clear from the thickness of the sandstone Unit (at least 10 m) and the size of trough cross-sets (up to at least 1.0 m) that this channel was a major and probably long-lived feature. The complete reversal in palaeocurrent direction between Units 1-5 and Unit 6 demonstrates that palaeoslope on this part of the Coal Measures plain was virtually zero.

The exposed sequence represents the operation and abandonment of fluvial or distributary channels, and the development of back-swamp and floodbasin conditions following their abandonment.

6.3.3 The Marshall Green Coal

The Marshall Green coal (U000 in the N.C.B. nomenclature:- see Figs. 2.6, 6.1) is probably the lowest widely worked coal seam in the Durham coalfield. The seam was worked mainly in the south-west part of the coalfield, around the Wear valley. In this region it is generally 0.3-0.6 m in thickness, though it may reach as much as 1.70 m. Like the underlying Ganister Clay seam, the Marshall Green is laterally very variable in thickness and quality, and thins rapidly towards the northern and eastern parts of the coalfield. The seam commonly occurs as two "leaves", separated by up to 12 m of sandstone. The roof of the seam, particularly in the south-west, is usually composed of thick, laterally continuous sandstone, both where the seam is "split" and where it occurs as a single leaf.

No records of an actual split in the Marshall Green coal have been encountered by the author, although such a split seems likely to occur from the convergence of the two seams in certain areas.

In the northern and eastern parts of the coalfield, the coal becomes difficult to trace, since it is often less than 0.15 m thick.

However, even in the north-east, the Marshall Green seam occasionally reaches workable thickness (Smith and Francis, 1967).

Sulphur levels in the Marshall Green coals are variable, but characteristically quite low (0.5-1.6%). Where the coal is split into two leaves, the Top Marshall Green has a consistently higher sulphur content than the Bottom Marshall Green.

6.3.4 Sediments between the Marshall Green and Victoria Coals

Description

Thick, laterally extensive sandstones overlying the Marshall Green seams are exposed in several quarries and natural outcrops, three of which were visited by the author.

These are at Crag Head (G.R. NZ 141574), described in Ch. 6.3.3, Keverstone Grange (G.R. NZ 134228) and Knitsley Bridge (G.R. NZ 121482), (Fig. 6.2). At those localities, vertical sections of up to 15 m of fine-to-medium-grained, trough cross-bedded sandstone are exposed.

Trough cross-sets up to 3.0 m in thickness are preserved, both in cosets and, more commonly, in apparent disorder. Little vertical ordering in the nature and size of preserved structures can be discerned. Small scale (0.1 m) cross-sets superimposed upon larger sets (e.g., 1.0 m) are occasionally present, as are chaotically-bedded horizons with loaded surfaces and fine-grained micaceous/carbonaceous partings.

Palaeocurrent measurements show a fiarly uniform direction of sediment transport towards the south (Fig. 6.16).

Interpretation

The major sandstones examined are interpreted as the deposits of of large fluvial or distributary channels.

6.3.5 The Victoria group of coals

The group of coal seams known as the Victoria (T000 in the N.C.B. nomenclature; Figs. 2.6, 6.1) is characterized by extreme lateral variability. In places, a single seam is present, up to 0.74 m in thickness, but more commonly the seam is banded or split into several leaves. In some areas, the various components of the Victoria group have been named Bottom Victoria, Victoria, Top Victoria and Victoria Rider seams (Smith and Francis, 1967; Mills and Hull, 1976).

Generally speaking, the Victoria Coal is most commonly of workable thickness in the central and western parts of the coalfield. However, even there it is noted for rapid lateral changes in character. The seam thins rapidly towards the eastern and northern parts of the coalfield, where it is generally less than 0.15 m thick.

Sulphur levels within the Victoria Coals are extremely variable, and occasionally high (0.4-2.8%).

Despite its lateral variability, the Victoria coal is relatively easy to trace across the coalfield, partly because of its' common occurrence as a group of coals, and partly because of a prominent fossil marker horizon in the overlying shales, the Victoria Fish Bed.

The Victoria coals and their enclosing strata are, unfortunately, poorly exposed, the only exposure examined being at Pont Burn (described in the following passage).

6.3.6 Sediments within the Victoria group of coals

6.3.6.1 Pont Burn

Description

A series of small, natural crags on the banks of the Pont Burn, (G.R. NZ 147562), (Fig. 6.2) forms the only examined exposure within the Victoria group of coals.

Here a 10 cm coal is overlain by a 5 m coarsening-upward sequence, passing upward from fissile, well-laminated claystone into fine-grained sandstone. This sequence contains abundant flattened plant debris in the lower part, and a sequence of sedimentary structures indicative of progressively higher-energy and more rapid deposition upward, from ripple form sets and cross-lamination, through cross-lamination and loading structures to small-scale (0.1 m) trough cross-bedding (Appendix 1:- Section 423). The uppermost part of the exposed sequence fines to silt grade, and is penetrated by abundant rootlets. Palaeocurrent measurements from various structures indicate sediment transport towards the west-south-west.

Interpretation

This sequence is interpreted as a minor delta infill of a shallow standing body of water, which initially developed due to drowning of a swamp environment. Water depth was no more than 5 m, and was probably somewhat less than this. Evidently, the shallow basin was all but filled by the minor delta, judging by the abundance of rootlets at the top of the exposed section.

From the abruptly gradational nature of the sandstone member basal contact, it is possible to infer a medial, possibly axial position within the crevasse-initiated lacustrine delta system responsible for depositing the exposed sequence (Elliott, 1974;

Heward, 1976), (Fig. 3.2). The channel supplying this crevasse infill lay some distance to the east, though no information is available regarding its' orientation or dimensions.

6.3.7 Discussion

The association of "major" and "minor" channel, shallow basin and extensive backswamp environments interpreted from the Ganister Clay-Victoria interval, largely free from marine influence, is in marked contrast to that characteristic of the underlying basal Coal Measures. In it, the only evidence of marine influence comes from the reworked quartz arenite and ganister sandstones exposed at Knitsley Fell and Quickburn quarries. Stratigraphically, these exposures lie a few metres above the level of the Ganister Clay coal and are the only observed remnants of the depositional style characteristic of Upper Namurian and basal Westphalian times.

No evidence of marine influence or significant base level fluctuation occurs above the horizon of the Marshall Green coal, and it is suggested that by this time, upper delta plain conditions had been fully established.

In the facies models of Horne, Ferm and co-workers, Upper Delta Plain environments are characterized by closely spaced or coalesced channel sand bodies, and thick, pod-shaped coal bodies elongate to depositional dip and with low sulphur values (around 1%).

In the Durham area, coals are variable in thickness but not noticeably elongate in any direction, and have moderate-low sulphur contents.

Major channels operating after the accumulation of the Ganister Clay and Marshall Green seams, tentatively identified from outcrop

and subsurface data, are shown on Figs. 6.12 and 6.16 respectively. These are seen to be confined to broad belts up to more than 10 kms wide.

The post-Ganister Clay channel belts are grossly similar in morphology and location to those of the underlying basal Coal Measures, though exact locations of channel margins are difficult to ascertain (Figs. 6.10, 6.12).

Post-Marshall Green channel belts (Fig. 6.16) are again similar in general location to those of underlying intervals, but within the broadly south-east directed channel tracts individual channels display evidence of possessing a degree of sinuosity, and are probably somewhat narrower (perhaps up to 3 kms wide). Two "phases" of deposition can be recognized:

(1) an early phase separating the Top and Bottom Marshall Green seams in certain areas, and

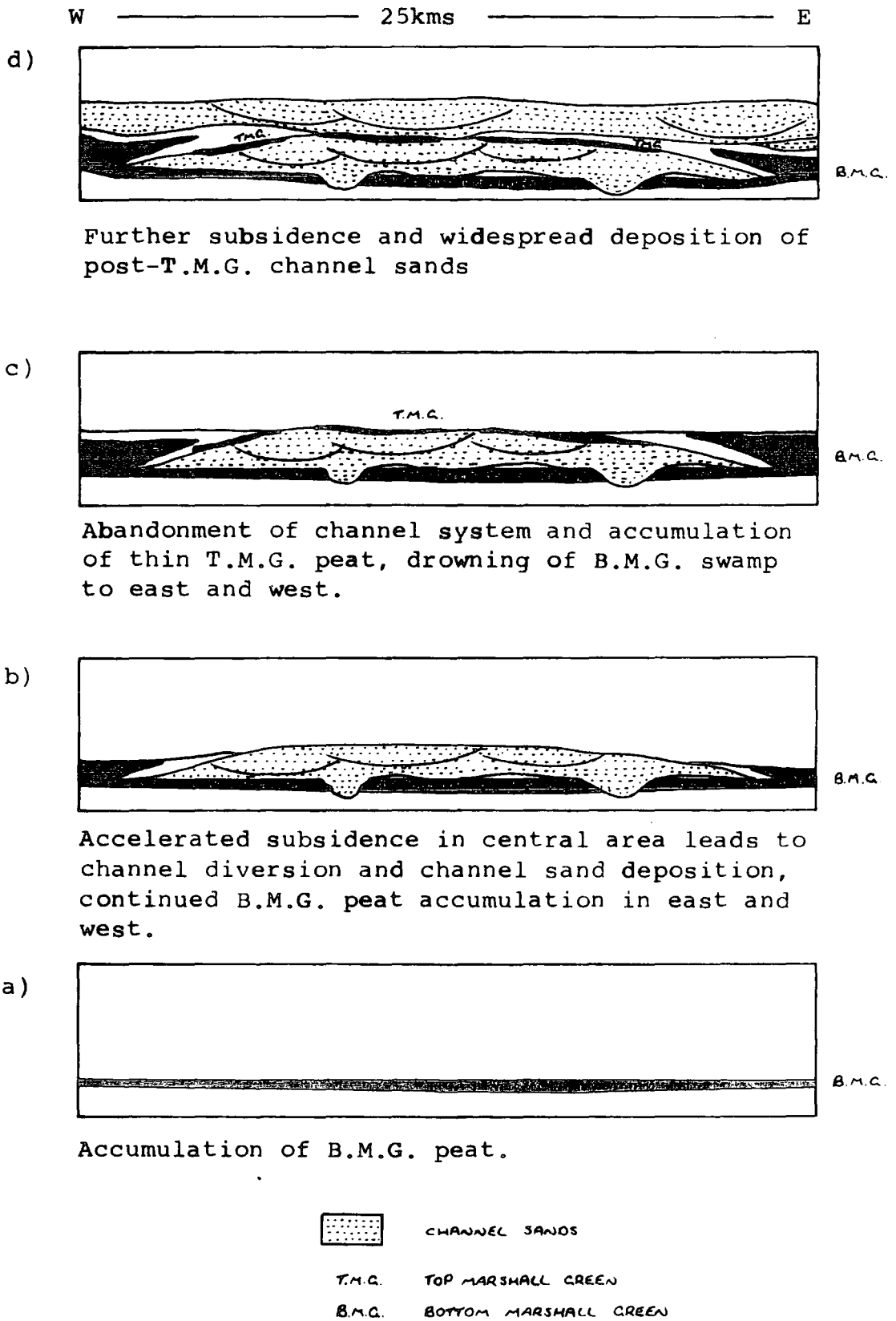
(2) a later phase which was deposited above either the Top Marshall Green seam, or the single Marshall Green, where present (Fig. 6.17).

The inferred north-eastern margin of the "Phase 1" channel belt is close to the line marking the limit of occurrence of two Marshall Green seams, as opposed to one (Fig. 6.16). It is thus suggested that the deposition of thick (up to 25 m) sand bodies in the "Phase 1" channel or channels over a thick, partly consolidated peat deposit led to accelerated subsidence of that area.

Following abandonment of the "Phase 1" channel, peat swamps developed over the rapidly subsiding channel sands, allowing the thinner Top Marshall Green peat to accumulate. This was followed by a second, more extensive "phase" of channel sand deposition, as major channels were again attracted into the topographical hollow

Fig.6.17

DEPOSITIONAL MODEL FOR THE MARSHALL GREEN COALS AND ENCLOSING STRATA IN THE SOUTH DURHAM AREA



created by accelerated subsidence. It is also worthy of note that the area of occurrence of the impersistent Stobswood seam is within the area of inferred accelerated subsidence on Fig. 6.16.

The depositional history of the Marshall Green coals and surrounding lithologies is summarized in Fig. 6.17.

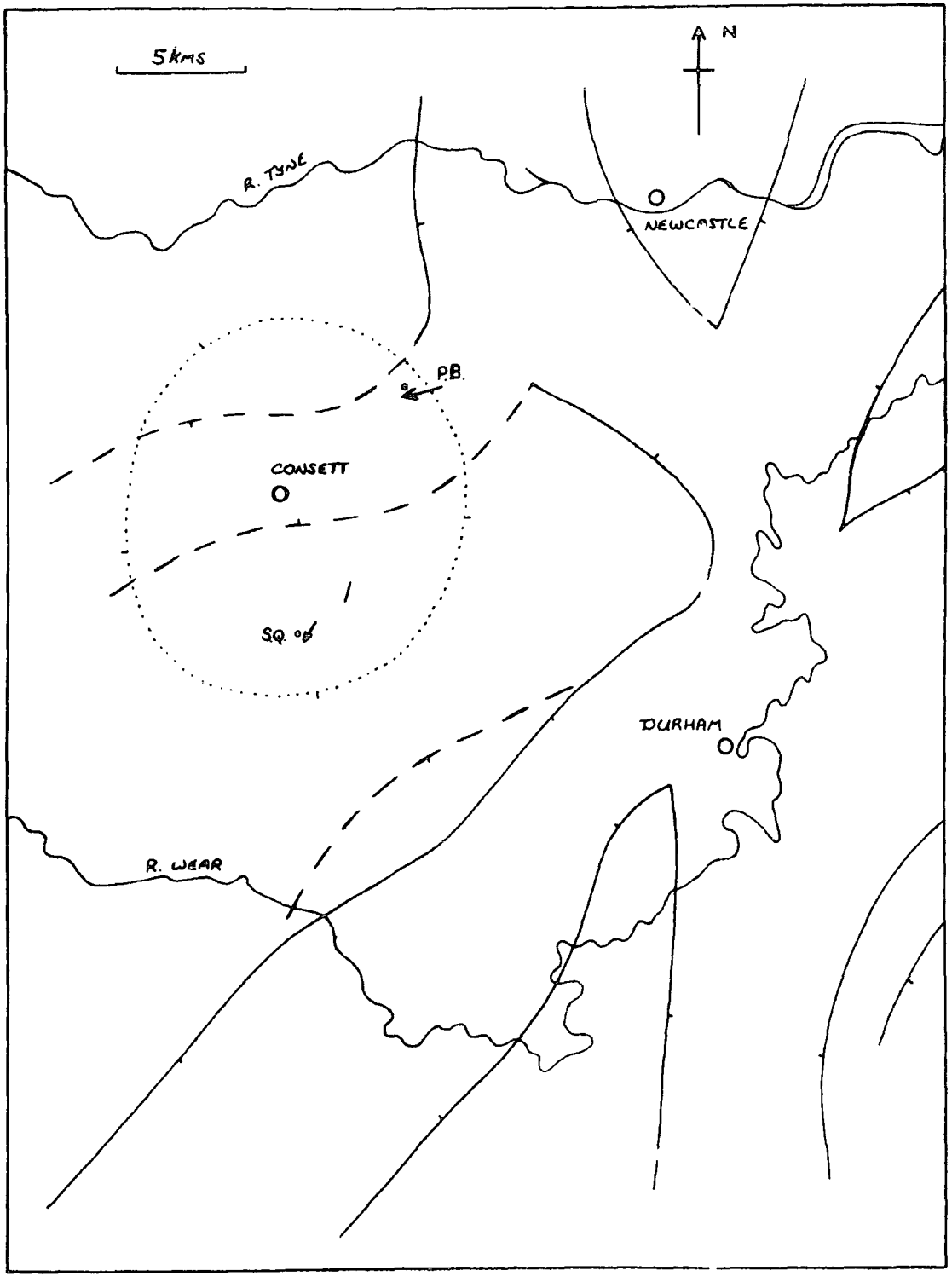
There are occasional records of a single Marshall Green seam within the area of occurrence of two leaves (Fig. 6.16), and these might be explained as "islands" of peat swamp which were unaffected by channel erosion and deposition, or by erosion of a previously-deposited Top Marshall Green seam. From a lack of channel sandstones which can be shown to record deposition during the period of accumulation of the Marshall Green peat, for example, by sandstone splays within the coal seam, no channels are thought to have been active at this time in the area of study.

However, it is possible that some channels were active across parts of the Durham coalfield during accumulation of the Victoria peat, from records of thick, erosively-based sandstones which "wash-out" the Victoria seam but which, from their position in the sequence, could have become active before its' accumulation. Sediments such as those exposed at Pont Burn must have been ultimately derived from such channels (Fig. 6.18).

Water depths in the upper delta plain lakes, estimated by a modification of the method of Klein (1974), (see Ch. 9), rarely seem to have exceeded 5 m, and lake floors were often only allowed to subside to depths of 1-2 m before being infilled, probably quite rapidly, by crevasse-initiated sedimentation and overbank deposition. The comparative shallowness of these basins probably reflects a general increase in interdistributary sedimentation rates associated with the change in environment, and from a lack of any evidence of a marine influence, lakes were probably freshwater in character.

Fig.6.I8

POST-VICTORIA PALAEOCURRENTS AND SPECULATIVE CHANNEL BELT TRENDS.



CHANNEL BELT MARGINS.

LATE-STAGE CHANNEL BELTS.

PALAEOCURRENT VECTOR MEAN.

WASHOUT IN VICTORIA COAL.

LIMIT OF GERMAN BANDS IRONSTONE (IRONSTONE ABSENT ON ORNAMENTED SIDE)

S.Q. - SHEEPWALKS QUARRY ($n = 5$) P.B. - PUNT BURN ($n = 9$)

Deposition was controlled by slow, probably steady subsidence, accelerated in places due to compaction of fine-grained clastic sequences and peat deposits. Widespread development of compaction-induced differential subsidence was probably the result of a general increase in sedimentation rates associated with the transition to an upper delta plain environment. Peat swamps developed over lake infills and abandoned channel sediments and the thickness of resultant coal seams can, in certain cases, be related to relative rates of subsidence (Fig. 6.17).

As for regional subsidence rates, it is worth noting that the Marshall Green and Victoria coals thicken towards the west and south, and that the Ganister Clay - Victoria interval as a whole thickens towards the south, possibly indicating greater subsidence towards the inferred Pennine basin depocentre.

Two types of channel sequences appear to be preserved within the interval under consideration:

(1) straight to ? moderate sinuosity major "trunk" channels, possibly several kms wide which deposit sequences up to 20 m or more in thickness, and

(2) high sinuosity minor distributaries of uncertain dimensions which produce sedimentary sequences less than 10 m thick.

The large channels were probably major avenues of sediment transport across the Coal Measures plain, serving a similar function as those preserved in the stratigraphically lower "Durham Grits". A possible increase in major channel sinuosity could be interpreted as the result of the transition from lower to upper delta plain conditions, and the inferred decrease in channel size may be a result of avulsion

of the early Westphalian trunk distributary system (i.e. delta switching), associated with this environmental change.

The smaller, meandering distributaries probably supplied sediment from the major channels to crevasse-initiated lacustrine delta systems (Elliott, 1974). The apparent lack of such meandering channels in the basal Coal Measures and Upper Namurian sequences is probably due to lack of exposure. Indeed, meandering distributary channels have been described from the lower Namurian of the northern Pennines (Elliott, 1976).

The association of major and minor distributaries is characteristic of most modern delta plains (Elliott, 1978), and an association of straight-to-meandering major fluvial and distributary channels and minor distributary channels has been described from the Westphalian B Coal Measures of the East Midlands by Guion (1978).

The two types of distributary channel have noticeably different abandonment characteristics; the relatively abrupt tops to the major channel sandstones (exposed at Quickburn Quarry and at Knitsley Fell) indicate quite rapid abandonment, due probably to complete channel avulsion, whereas the minor, meandering channels display evidence of typically more gradual abandonment, caused by a progressive decrease in stream competence with the infilling of the body of water into which they flowed. It is evident, however, that this relationship may not persist throughout the succession.

With the onset of upper delta plain conditions seems to have come the bewildering complexity of sediment transport directions so characteristic of the Coal Measures. Simple southward progradation

is replaced by movement in virtually all directions, due partly to the increase in sinuosity of channels, and partly to the almost random direction of infilling of shallow lacustrine basins.

One further point worthy of mention is the quite subtle variety of lake fill sequences exposed in the interval described above, representing some of the various possible depositional sequences within a crevasse-initiated lake delta setting (Elliott, 1973; Heward, 1976), (Fig. 3.2).

6.4 VICTORIA TO BROCKWELL COALS

6.4.1 Introduction

The Victoria to Brockwell sequence varies between 12 and 27 m in thickness over the Durham coalfield. There seem to be few regular trends in interval thickness and lithology, but generally speaking, thicker sequences occur where major sandstone bodies are present.

Several distinctive, laterally persistent lithologies occur in this interval, and serve as useful marker horizons. Above the Victoria Rider (or uppermost coal of the Victoria group) lies a fissile claystone containing abundant non-marine bivalves, fish remains and *Planolites opthalmoides* burrows. In some areas, particularly in the southern part of the coalfield, this fossiliferous claystone is up to 5m thick and is separated into a "Victoria Shell Bed" overlying a "Victoria fish-bed" (Mills and Hull, 1976). A few metres higher in the sequence in the northern and eastern parts of the coalfield lies a further claystone rich in non-marine bivalve remains (the "Upper Victoria Shell Band", Smith and Francis, 1967).

Also in the lower part of the sequence, across the western part of the Durham coalfield, there occurs a unit of sideritic ironstone, named the "German Bands Ironstone", which was once extensively worked around Consett (Fig. 6.18).

Several thin (up to 0.3 m thick) coals occur locally at various levels within the interval, and a seam which is commonly found a few metres below the Brockwell is named the Bottom Brockwell (ISOO).

Exposures of the sequence between the Victoria and Brockwell coals are rare; only one locality was visited, in addition to two temporary opencast exposures of the Brockwell coal itself.

6.4.2 Sediments between the Victoria and Brockwell coals

6.4.2.1 Sheepwalks Quarry

Description

Sheepwalks Quarry (G.R. NZ 107464), (Fig. 6.2) exposes a 5 m vertical section of fine-and-medium-grained, trough cross-bedded and parallel-laminated sandstone. Trough cross-sets up to 0.4 m in thickness are preserved, commonly with irregular, scoured bases. Palaeocurrent measurements from trough orientations indicate a palaeoflow towards the south-south-west (Fig. 6.18).

Interpretation

It is impossible to attach a unique interpretation to this small outcrop since the contacts of the sandstone body are not exposed. The sandstone could represent part of a crevasse-lobe/lake fill sequence, or could equally be a channel deposit (but see Ch. 6.4.4).

6.4.3 The Brockwell coal

The Brockwell coal (SOOO in the N.C.B. nomenclature; see Fig. 6.1) is the lowest major coal seam in the Durham coalfield. In the south-west, where the seam is thickest, it is commonly unbanded and of consistently good quality. However, the Brockwell coal thins to the north and east, and at the same time becomes banded and split into two or more leaves. The maximum recorded thickness is 2.08 m, near Butterknowle, and in that region the seam is rarely less than 1.50 m thick. In the Tyne valley, however, the Brockwell coal disappears altogether (Fig. 6.19).

The coal often contains layers of cannel (spore-rich coal), particularly in the uppermost part. "Bands" within the Brockwell seam are mostly shaly or "flinty" rootlet-penetrated claystones, though a greater variety of lithologies become involved as parting thickness increases. While the incidence of banding and seam splitting generally increases to the east and north, exceptions are fairly common. Around Woodland, where the seam is some 2.0 m thick, a hard, flinty claystone parting is present near the top of the seam (Fig. 6.20).

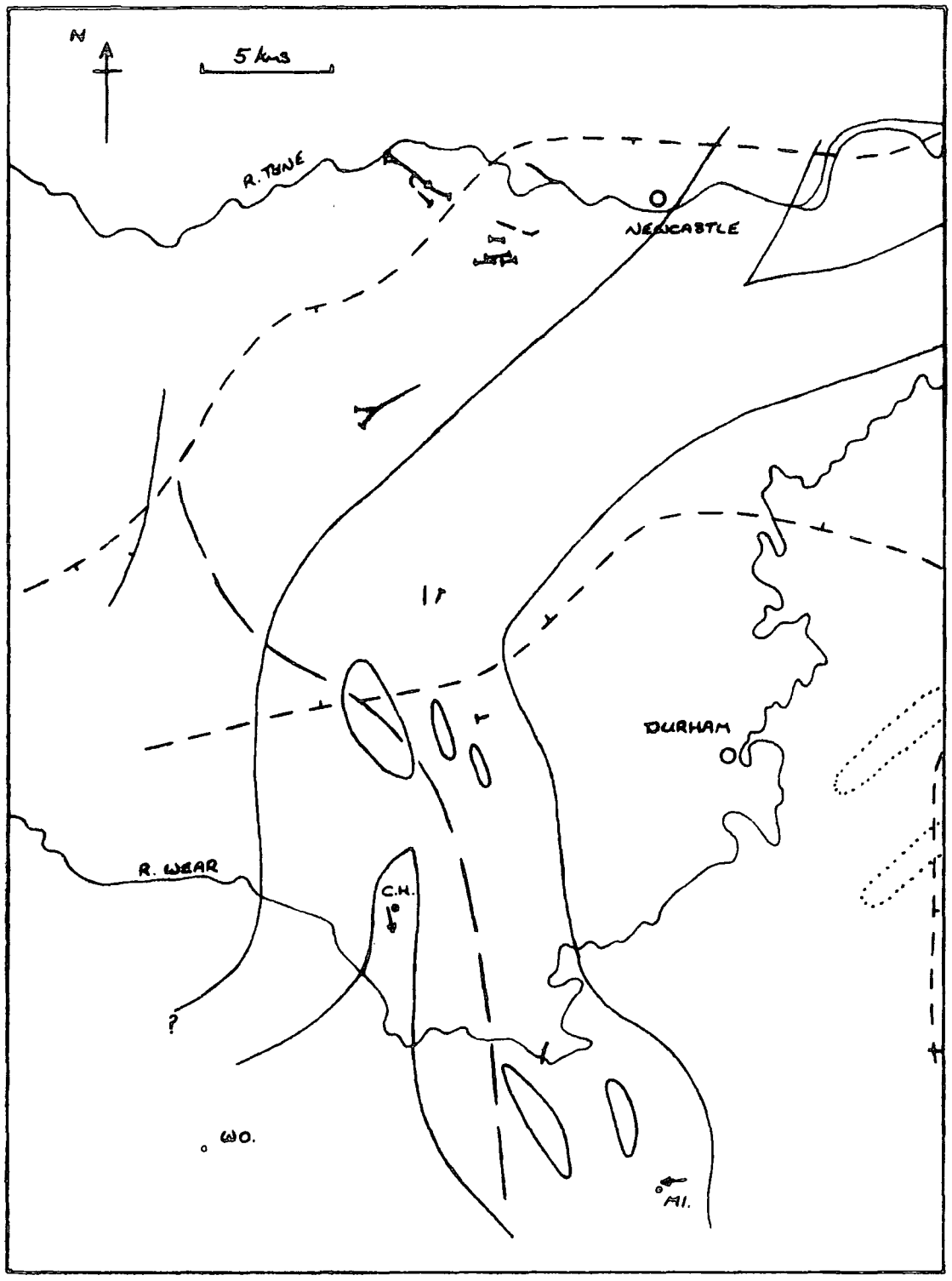
In the western part of the coalfield, the Brockwell seam is united with the Bottom Threequarter (R1OO) the latter gradually splitting from the former to merge with the true Threequarter seam (ROOO) east of that region (Fig. 6.19). This feature will be considered further in Ch. 6.5.4.

Sulphur levels in the Brockwell coal are variable, but generally quite low (0.3% - 1.1%).

Two exposures of the Brockwell coal were visited, firstly at

Fig.6.19

THE BROCKWELL COAL, POST-BROCKWELL PALAEOCURRENTS AND SPECULATIVE CHANNEL BELT TRENDS.



CHANNEL BELT MARGINS

PALAEOCURRENT VECTOR MEAN

BELTS OF IMPOVERISHMENT IN THE BROCKWELL COAL.

WASHOUTS IN BROCKWELL COAL.

APPROXIMATE EASTWARD LIMIT OF COMBINED BROCKWELL/ BOTTOM THREEQUARTER COAL.

C.H. - CABIN HOUSE O.C.C.S. (n=1)
WO. - WOODLAND O.C.C.S.
MI. - MIDDRIDGE QUARRY. (n=4)

Fig.6.20

MEASURED VERTICAL SECTION AT WOODLAND O.C.C.S.
(G.R.NZ065265) (BASED ON SECTION 422 ; APPENDIX I)

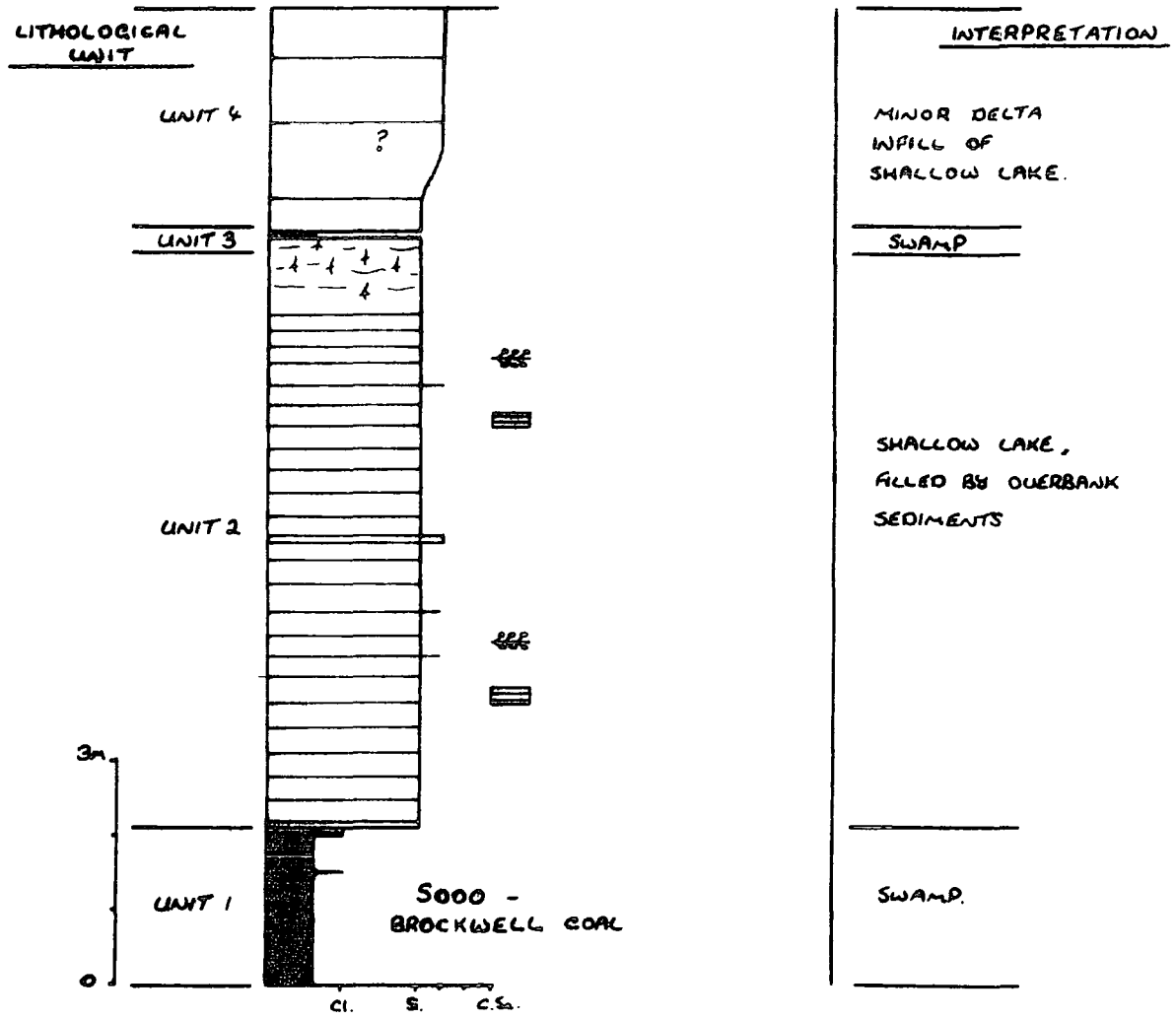
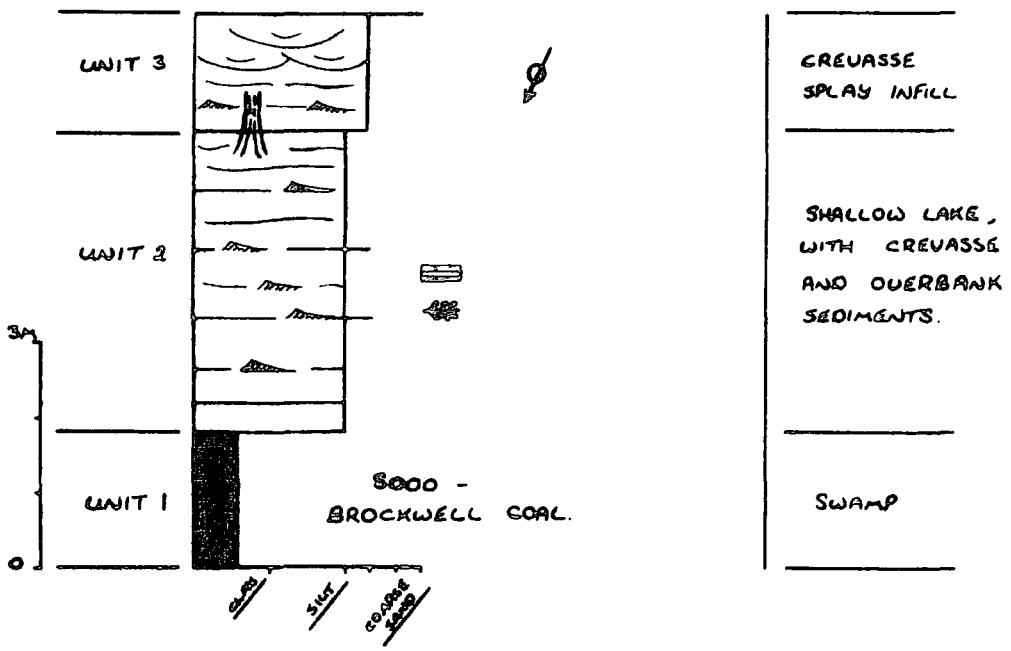


Fig.6.2I

MEASURED VERTICAL SECTION OVER THE BROCKWELL COAL AT CABIN HOUSE O.C.C.S. (G.R.NZI36356)
(BASED ON SECTION 179 ; APPENDIX I)



Woodland O.C.C.S. (G.R. NZ 065265), (Fig. 6.20), and secondly at Cabin House O.C.C.S. (G.R. NZ 136356), where the principal seam represented the combined Brockwell and Bottom Threequarter coals (Fig. 6.21), (Fig. 6.2).

6.4.4 Discussion

Lack of exposures within the Victoria-Brockwell interval preclude a detailed discussion of the depositional setting. However, following examinations of subsurface data, an attempt has been made to delimit major channel sandstones.

Fig. 6.18 shows a series of major channel belts up to 10 kms wide operative through this period, crossing largely the eastern part of the coalfield. It is possible that some of these, for example, the one crossing square NZ 15 SW, are single channels, the exact margins of which are difficult to ascertain. Probably not all of the channels or channel belts shown on Fig. 6.18 were operative at the same time; new channel courses would come into operation via major crevasse events. From a comparison with subsequent intervals it seems likely that individual channels were up to about 3 kms wide (see for example, Ch. 6.5.4).

Another interesting feature of post-Victoria channel systems is their eastward shift in position, relative to those of the underlying interval (compare Figs. 6.16 and 6.18). This may be explained by younger channels seeking courses with the maximum available gradient, that is, avoiding areas previously occupied by channels and their deposits, which, being relatively uncompactable, would subside very slowly and form relative topographical highs. Such a palaeo-

topographical control on channel location has been described from Upper Carboniferous deltaic deposits in the U.S.A. (Brown, 1969, 1979) and from modern delta plain environments (Fisk, 1955).

From the environmental setting shown on Fig. 6.18, the exposure at Sheepwalks Quarry is tentatively interpreted as a south-south-west flowing minor delta system, produced by crevassing of a major channel to the north.

In the north-west, major channel sandstones rarely occur in the Victoria-Brockwell interval, and sediments there are dominated by fine-grained, mainly lacustrine facies. It is in this region that the German Bands Ironstone occurs (Fig. 6.18).

Similar, nodular, sideritic ironstones have been described from modern delta-top swamp environments, for example the Atchafalaya basin (Coleman, 1966) and in a study of such nodules in the Upper Carboniferous Francis Creek Shale of Illinois, (a delta top deposit), Woodland and Stenstrom (1979) ascribe their formation to very early diagenetic precipitation of siderite under reducing conditons in microenvironments created by bacterial decomposition of organic remains.

The lateral variability of the Brockwell coal is well-illustrated in Fig. 7 of Smith and Francis (1967). Of particular interest are the north-east-to-south-west-trending tracts to the east of Durham City, some 8 kms wide, within which the Brockwell coal is impoverished with respect to seam thickness. A possible explanation for this thinning lies in the sequence immediately below the coal. Inspection of Figs. 6.18 and 6.19 shows that the orientation and dimensions of the thinned coal area correspond quite closely to those of an inferred major channel sandstone belt in the Victoria-Brockwell interval. It is therefore suggested that

reduced subsidence of this area following deposition of thick (up to 25 m) sand bodies caused the Brockwell peat to be thinner than in the surrounding area.

The splitting (and concomitant thinning) of the Brockwell coal in the northern part of the coalfield can be ascribed to accelerated subsidence, creating a relative palaeotopographical hollow, which prevented peat from accumulating continuously. This belt of impoverishment may have been initiated by rapid compaction of peats and clays, but is also aligned parallel to a major structural grain of the coalfield, and may thus be structurally controlled. Structural control on topography and sedimentation has been demonstrated for several modern delta plains (Morgan, 1970), and for Upper Carboniferous deltaic deposits in the U.S.A. (Brown, 1969, 1979).

From subsurface records, it is apparent that any channels operative during accumulation of the Brockwell peat were situated at least some tens of kms to the east of the area of study, indicating almost complete "abandonment" of the Durham area at that time (but see Ch. 6.5.4). The development of thick coal in the Brockwell may be ascribed partly to time available for peat accumulation, and partly to subsidence rates (Ch. 6.5.4).

6.5 Brockwell to Threequarter coals

6.5.1 Introduction

The sequence between the Brockwell and Threequarter coal seams in the Durham coalfield generally varies between 10 and 28 m. In the west, however, where the Threequarter seam is commonly split

into two separate leaves, the Bottom Threequarter coal unites with the underlying Brockwell seam.

The interval thickness does not vary systematically in any one direction, but is directly proportional to the total thickness of major sandstone bodies present.

As with the underlying Victoria seam, the roof measures of the Brockwell coal contain a prominent faunal marker horizon, the Brockwell Ostracod Band. This is present mainly in the eastern part of the coalfield and contains a varied fauna of non-marine bivalves, ostracods, *Spirorbis* and trace fossils (Smith and Francis, 1967; Mills and Hull, 1976).

Thin coals are common in the Brockwell-Threequarter parting, but rarely reach workable thickness.

Three exposures of the Brockwell-Threequarter interval were visited, two of which were Opencast Coal Sites.

6.5.2 Sediments between the Brockwell and Threequarter Coals

6.5.2.1 Middridge Quarry

Description

At Middridge Quarry (G.R. NZ 248253), (Fig. 6.2), a 2.5 m vertical section of sandstone is exposed in the basal part of a disused limestone quarry. The sandstone is fine-grained, buff-coloured, and contains trough cross-bedding and discontinuous micaceous partings. Trough cross-sets up to 1.7 m thick and at least 5.0 m wide are preserved (Section 367; Appendix 1).

The base of the sandstone body is not exposed, and the upper part is erosionally truncated by the overlying Permian sequence (Bell *et al.*, 1979). However, from nearby borings, the sandstone is known to be at least 13 m thick.

Palaeocurrent measurements from trough axes indicate a palaeoflow towards the west (Fig. 6.19).

Petrographically, this sandstone is unusual in containing a very early opaque (? haematite) cementing phase (Plate 6.5), and also contains less evidence of primary recrystallization than stratigraphically lower sandstones. This trend of decreasing diagenetic modification is continued as successively higher levels are considered.

Interpretation

The sandstone body exposed at Middridge quarry is interpreted as the deposit of a westerly-flowing major distributary channel.

The presence of early diagenetic ?haematite cementis possibly a result of fluid movements along the nearby Butterknowle fault system during the Hercynian period of earth movements (Ch. 2.2).

6.5.2.2 Woodland O.C.C.S.

Description

At Woodland O.C.C.S. (G.R. NZ 065265), (Figs. 6.2, 6.20), the Brockwell coal (Unit 1: Fig. 6.20) is succeeded by an 8 m sequence of alternating 10-20 cm medium grey laminated siltstone, and 0.5 cm dark grey, clayey mudstone units, with abundant, flattened plant debris and occasional,fine-grained sandstone layers up to 2 cms thick (Unit 2). This is succeeded by a thin, shaly coal (Unit 3) and a poorly-accessible coarsening-upward sequence (Unit 4).

Interpretation

The lithologies of Unit 2 are interpreted as the sediments of a shallow lake, deposited by an alternation of rapid and rather slower fallout from suspension,from the complete lack of traction-derived sedimentary structures. The regular, almost rhythmic, alternation

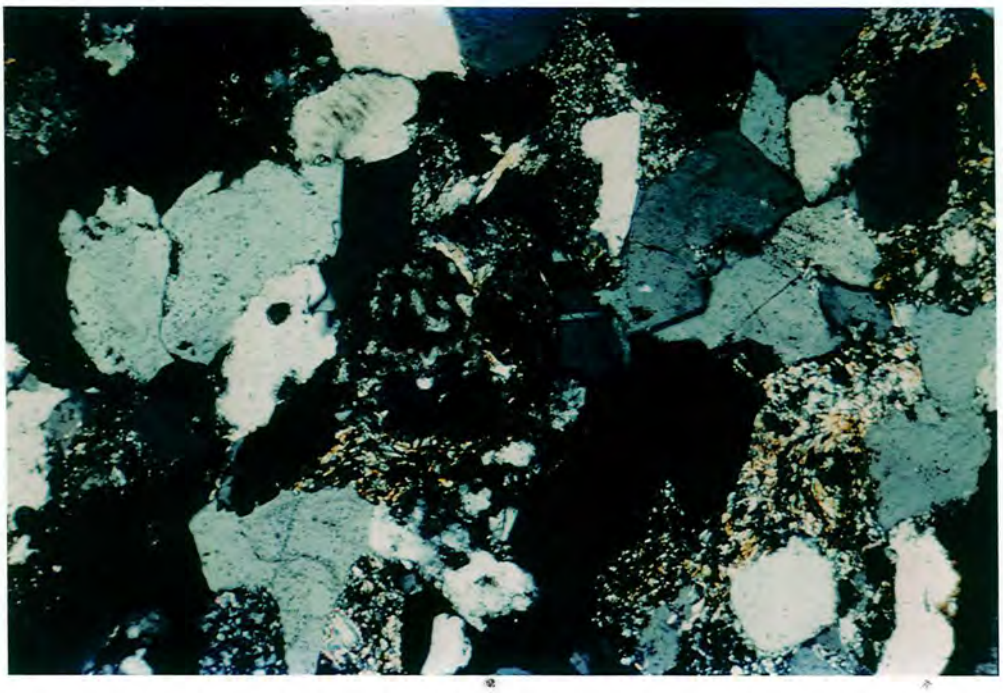


Plate 6.5 - Kaolinite/illite and opaque ?haematite cements in sandstone above Brockwell coal, Middridge Quarry. Length of photomicrograph I.2mm. (Crossed polars).



Plate 6.6 - The Bottom Busty coal and overlying sediments at Deborah O.C.C.S. (Area D - Section I52), showing shallow channel features. (C).

of siltstone and claystone in beds of reasonably consistent thickness leads to the hypothesis of a possibly seasonal pattern of sedimentation, in which coarser layers were produced by overbank sedimentation from a distant channel during flood events, and the finer layers deposited as "background" sediments. Overbank-, rather than crevasse-derived material, is considered to be the most likely source of such regularly interlaminated sediment, since influxes of sediment from channel bank overtopping are likely to be more discrete and well-defined than those from the more continuous, though erratic, style characteristic of cresse-derived minor delta progradation (see also Ch. 7.9.2.4).

The fact that the thin, autochthonous coal of Unit 3 overlies the lake sediments without any intervening coarse-grained lake-fill sediments suggests that the lake was probably only of the order of 2-3 m deep. This in turn implies a long history of comparatively low-energy sedimentation ending with the passive infilling of the lake and thus allowing plant colonization to take place.

Following this period of near-emergent conditons, the area subsided once again to form another shallow lake, which was filled by a crevasse-initiated minor delta, although this upper part of the exposed sequence was not easily accessible.

6.5.2.3 Cabin House O.C.C.S.

Description

At Cabin House O.C.C.S. (G.R. NZ 136356),(Fig. 6.2) the combined Brockwell/Bottom Threequarter coal is overlain by a similar sequence of sediments to that exposed at Woodland O.C.C.S. (Fig. 6.21).

In this case, however, siltstones are interlaminated with streaks and layers of fine sandstone, contianing ripple cross-lamination and ripple form sets in addition to parallel lamination (Unit 2; Fig. 6.21). The overlying very-fine-grained sandstone of Unit 3 contains trough cross-bedding up to 0.2 m in preserved thickness and other structures indicating palaeoflow towards the south-south-east. Preserved in the uppermost part of the siltstone and the basal part of the sandstone, at one locality, was an upright, *in situ* tree stump.

Closely similar vertical sequences were observed across the worked area in Cabin House O.C.C.S. (Enclosure 2), although lack of access and exposure did not always allow detailed observations to be made.

Interpretation

This sequence is again interpreted as the deposits of a shallow lake environment, possibly influenced by channel-derived overbank sedimentation, and finally ? filled by a crevasse splay event. Alternatively, the sequence could represent the distal portion of a shallow basin crevasse infill, cut into and finally filled by a later-stage crevasse channel or splay. Lack of palaeocurrent measurements from the lower part of the sequence precludes a unique interpretation.

The *in situ* tree stump was evidently preserved by rapid burial in sand, completed before the wood tissue of the tree had time to decompose significantly.

From a comparison of the sequences exposed at Woodland and Cabin House, attention is drawn to the possibility of distinguishing between shallow lake deposits controlled or influenced by levee/ overbank sedimentation and those resulting largely from crevasse

splay/minor delta activity, where overbank processes do not play an important role. It is suggested that the "rhythmites" exposed at Woodland O.C.C.S. are a distal equivalent to some of the sequences of alternating fine sandstone and silty claystone/claystone ascribed to levee and "proximal" overbank sedimentation later in this thesis (see Chs. 7.8.2.1 and 7.9.2.4).

Similar sequences to these, and the one described above from Woodland, have been recorded from the Westphalian A of Lancashire (Broadhurst, Simpson and Hardy, 1980), the Westphalian B of Northumberland (Haszeldine, 1981a) and of Warwickshire (I.M. Fulton, pers. comm., 1982).

6.5.3 The Threequarter coal

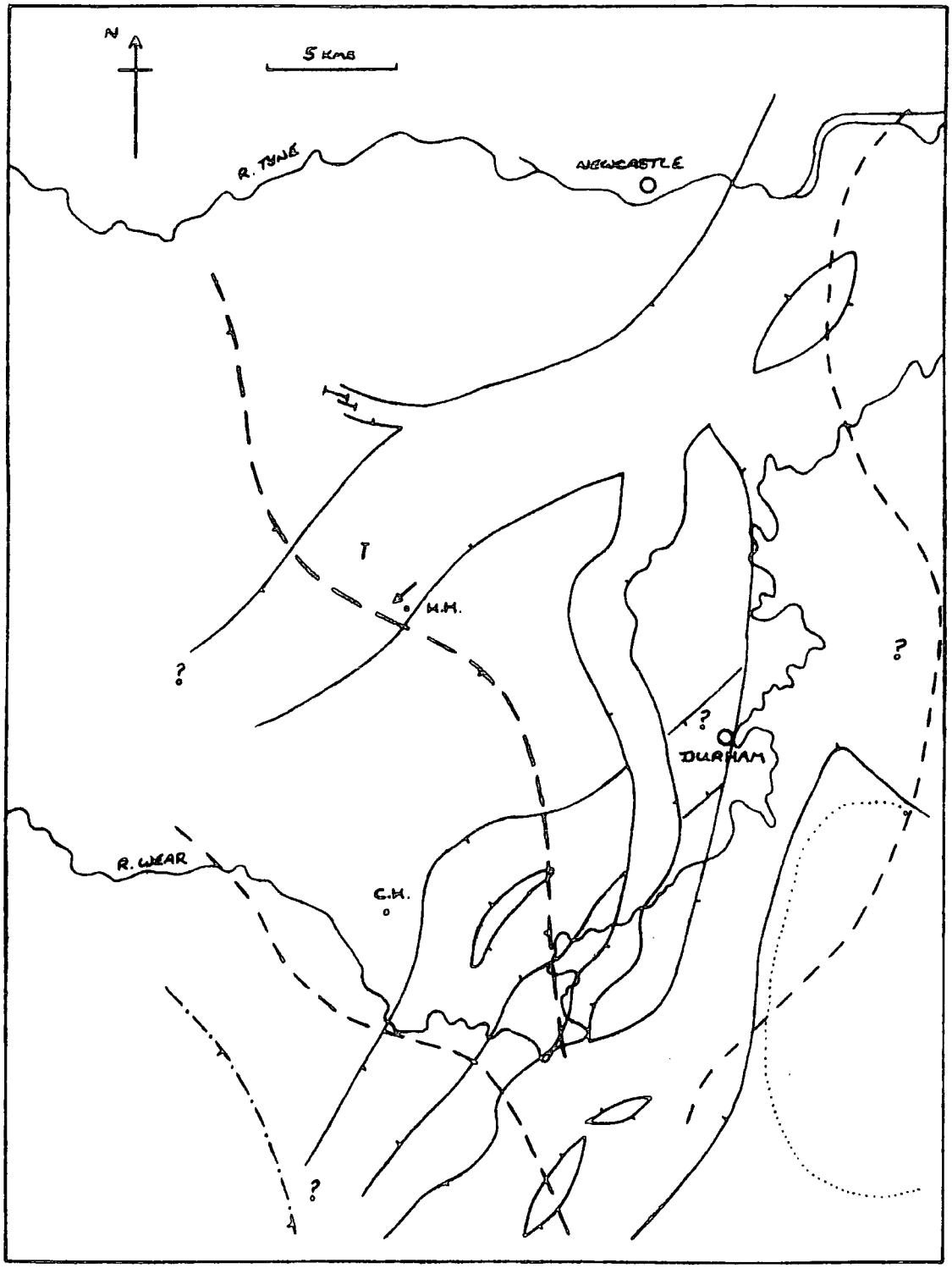
The Threequarter coal (R000 in the N.C.B. nomenclature; see Fig. 6.1) is a relatively unimportant seam in the Durham coalfield, attaining a maximum thickness of only 1.00 m. The seam is thickest in a roughly north-south-trending belt across the central part of the coalfield, thins both to the east and west and is entirely absent from the south-west (Fig. 6.22).

In places, the coal splits into two or more leaves, notably in the west, where the Bottom Threequarter coal descends the sedimentary succession to join the Brockwell, as mentioned previously. Offshore, to the east of the area of study, the Threequarter coal is known to increase to workable thickness and quality in some areas (Smith and Francis, 1967; Jones and Cooper, 1972).

Sulphur levels in the Threequarter coal are variable, though generally quite low (0.57-1.92%). No consistent pattern of variation across the coalfield is discernible from the limited available data.

Fig.6.22

THE THREEQUARTER COAL, POST-THREEQUARTER PALAEOCURRENTS AND SPECULATIVE CHANNEL BELT TRENDS.



CHANNEL BELT MARGINS

BELT OF MAXIMUM THREEQUARTER DEVELOPMENT

LINE OF SPLIT IN THREEQUARTER COAL (BEAM SPLIT ON ORNAMENTED SIDE)

"0" ISOPACH OF THREEQUARTER COAL. (COAL ABSENT ON ORNAMENTED SIDE)

WESTERN LIMIT OF FISHBURN ESTHERIA BAND.

PALAEOCURRENT VECTOR MEAN

WASHOUTS IN THREEQUARTER COAL.

H.H. - HUMBER HILL QUARRY (n=6)

C.H. - CABIN HOUSE O.C.C.S.

Only one exposure of the Threequarter coal was examined by the author, that at Cabin House O.C.C.S. (Appendix 1:- Section 156), strictly speaking the Top Threequarter, where the seam was 0.46 m in thickness.

6.5.4 Discussion

The Brockwell to Threequarter interval is characterized by complex patterns of sedimentation. Detailed examination of outcrop and subsurface information has revealed the probable courses of major channel belts, 3-10 kms wide, which cross the area of study (Fig. 6.19). From the distribution of sediment islands, individual channels were probably up to 3 kms wide. The channel belts are characterized by moderately low sinuosity, but within these, channels are possibly more sinuous. The position of the major channel belts indicates a westward shift from the position occupied during the previous stratigraphical interval, and this is explained by the "avoidance" mechanism discussed in Ch. 6.4.4. From Fig. 6.19, it is evident that the positioning of the major active channel belt in the area was probably influenced firstly by the belt of increased subsidence in the north and secondly by compaction of thick Brockwell peat deposits in the south.

The courses of "washouts" in the Brockwell seam are also plotted on Fig. 6.19 and most of these probably represent minor distributary channels, which cut across subsiding peat swamps.

The pattern of splitting in the Brockwell and Threequarter seams, and the distribution of fossil marker horizons, highlights an interesting complication in the sedimentary record. As first mentioned in Ch. 6.4.3, the Threequarter seam splits into two leaves

in the western part of the coalfield, and the Bottom Threequarter seam apparently descends the succession to unite with the underlying Brockwell coal. Clearly this indicates that the development of the Brockwell and Threequarter peats was strongly diachronous, and probably involved a very long period of time.

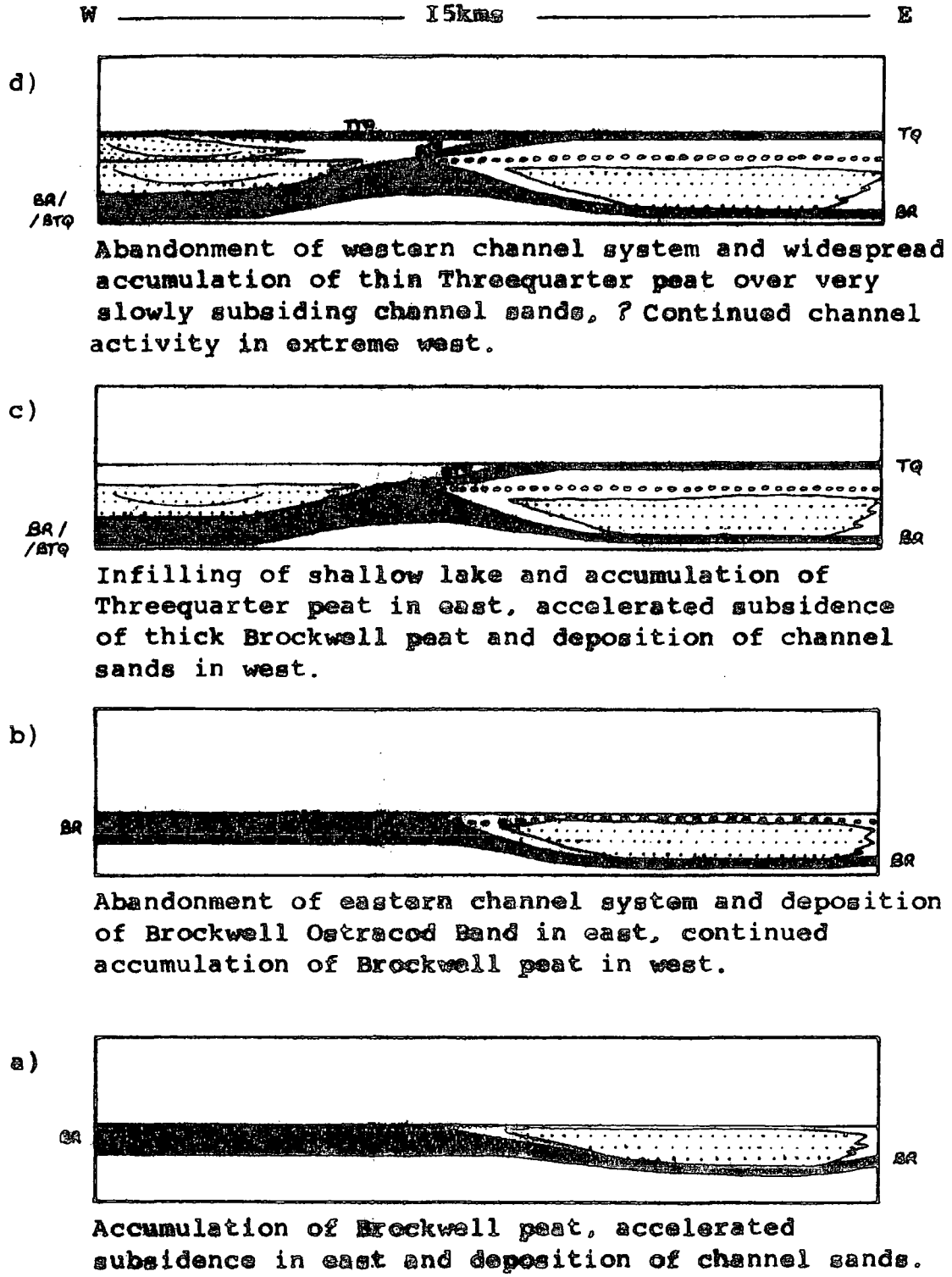
The Brockwell Ostracod Band is absent in the south-west and then rises from a position immediately above the Brockwell seam in the south-central part of the coalfield to as much as 20 m above it in the east.

The distribution of coals and fossil marker bands may be explained by differential subsidence, induced by the autocompaction of thick peat deposits (Fig. 6.23). Thus, major channels shown in the south-central part of the coalfield on Fig. 6.19 probably operated immediately following Brockwell peat accumulation in that area, while peat continued to form further west. Following abandonment of these early channels, slow subsidence led to extensive development of standing water conditions, and deposition of the Brockwell Ostracod Band. After infilling of these shallow lake environments, the Brockwell peat swamp, still active in the west, expanded eastward to form the Bottom Threequarter peat seam, and due probably to an avulsion event, encouraged by compaction of the thick Brockwell peat, a channel or channel system began depositing large quantities of sand in the south-west.

This in turn gave rise to a "see-saw" effect, with channel sand deposition in the west, and continued peat accumulation in the east forming the Threequarter seam. Eventually, the Threequarter peat swamp spread westward over the finally-abandoned later channel system, to form the Top Threequarter seam.

Fig.6.23

GEOLOGICAL HISTORY OF THE BROCKWELL AND THREEQUARTER COALS IN THE SOUTH DURHAM AREA.



This model explains the geometry of the Brockwell/Threequarter split, and possibly also the pattern of thickness variation in the Brockwell and Threequarter seams. The Brockwell is thickest in the south-west, where, according to Fig. 6.23, accumulation of peat continued for the greatest amount of time.

The north-south-trending belt representing maximum development of the Threequarter coal is closely parallel to, but offset from, the area occupied by major channels of the underlying interval (Figs. 6.19, 6.22). The location of this belt is probably partly controlled by the presence of adjacent, very slowly subsiding, post-Brockwell channel sands, which prohibited thick seams of peat from accumulating. The Threequarter coal is nowhere particularly thick, and in the south-west part of the coalfield is largely absent; this is possibly due to the operation of major channels in the area of study during the period of accumulation of the Threequarter peat; the "later channel system" of Fig. 6.23 was probably still active in the extreme west, while "Top Threequarter" peat accumulated in the east.

Compaction-induced subsidence as a mechanism for the development of "roof splits" (seam splits where detachment occurs near the roof of the parent seam) was favoured by Elliott (1969), and such subsidence was invoked by Guion (1978) to explain seam splits in the Westphalian B of the East Midlands. In the latter study, the enhanced subsidence of thick peat seams was shown to have encouraged the diversion of distributary channels across rapidly subsiding swamps.

6.6 THREEQUARTER TO BUSTY COALS

6.6.1 Introduction

The succession between the Threequarter and Busty coals varies between 6 and 30 m. Lithologies are similar to those at underlying levels, and the same general relationship exists between interval thickness and the proportion of sandstone present. No regional trends in thickness variation are apparent.

In the eastern part of the coalfield, particularly around Fishburn and Trimdon, a dark-coloured shale horizon rich in mussel and ostracod remains occurs immediately above the Threequarter coal (Pollard, 1962). This has been named the Fishburn Estheria Band (Smith and Francis, 1967), and tentatively correlated with the low Estheria Band of the East Pennines coalfield.

The Busty coal is one of the most widely-extracted seams in the Durham coalfield, ranging up to 2.44 m in thickness. Commonly the seam is split into the Top and Bottom Busty coals, both of which have been extensively worked, and which may be separated by as much as 17 m of clastic sediments.

The Busty coal in the Durham and Northumberland area is taken as the junction between the *communis* and *modiolaris* non-marine bivalve zones.

Two localities exposing the Threequarter-Busty interval were examined by the author, along with a further five exposures of the Busty coals and the sediments between the Top and Bottom Busty seams.

6.6.2 Sediments between the Threequarter and Busty/Bottom Busty coals

6.6.2.1 Cabin House O.C.C.S.

Description

At Cabin House O.C.C.S., the (Top) Threequarter coal is overlain by a 7 m sequence of interbedded clastic sediments ranging in grain-size from silty claystone to fine sandstone (Sections 156, 198:- Appendix 1). A 2 m coarsening-upward sequence in the lower half of the section is overlain by a fine-grained interval and then a further sandstone body which displays both sharp and transitional (coarsening-upward) basal contacts. Overlying this sandstone is a rootlet-penetrated, silty claystone of variable thickness, which represents the seatearth to the Bottom Busty coal.

A low-angle accretion surface dipping towards the north-east represents the only palaeocurrent measurement in this locality.

Interpretation

The sequence at Cabin House is interpreted as having been laid down in a shallow standing body of water under the alternate influence of overbank and crevasse activity.

The channel belt map for the Threequarter-Busty interval (Fig. 6.22: see Ch. 6.6.5) indicates that a major south-westward-flowing channel or channel belt was active a short distance to the east of Cabin House O.C.C.S. atthis time, and was the probable source of sediment to the Cabin House area.

The difference in the nature of sequences in Sections 156 and 198 (Appendix 1) may be explained in terms of different positions within a crevasse lobe (Fig. 3.2); assuming that sediment was being transported westward into the area, the transitional basal contact to the upper coarse-grained unit of Section 156 can be interpreted as resulting from a "lateral position on the lobe, whereas the abrupt basal contact in Section 198 probably results from a more axial location (Enclosure 2). The low-angle accretion surface

observed at this locality may have been produced by an axial crevasse channel, and this possibility is lent support by the orientation of the inclined surface.

By the same reasoning, the lower coarsening-upward sequence may tentatively be interpreted in a similar way.

6.6.2.2 Humber Hill

Description

At Humber Hill (G.R. NZ 139475),(Fig. 6.2), a number of small, disused quarries expose a sandstone which lies stratigraphically not far above the Threequarter coal. The sandstone is very fine-to-coarse-grained, with little apparent upward trend in grain size, and contains ripple cross-lamination, trough cross-bedding (in sets up to 0.7 m thick), plant casts and at least one raft of black coaly shale some 0.8 m in length. A laterally persistent dark shale horizon is also present, compactionally deformed by the enclosing sandstone.

Palaeocurrent measurements from trough cross-bedding indicate palaeoflow towards the south-west.

Interpretation

The sandstone body exposed at Humber Hill Quarry is interpreted as a channel deposit. Unfortunately, the size of the exposure does not allow a more detailed interpretation, and the channel could be either a major distributary or minor channel (see Ch. 6.6.5).

6.6.3 The Busty coals

The Busty coal (QOOO in the N.C.B. nomenclature; see Fig. 6.1), is one of the most heavily worked seams in the coalfield, reaching

a thickness of at least 2.44 m. In the west, the Busty is usually of workable thickness, but deteriorates both in thickness and quality to the east.

Commonly the Busty is divided into the Top Busty (Q200) and Bottom Busty (Q100), both of which have been extensively worked (Fig. 6.24). The Top Busty seam is usually thinner than the Bottom Busty, and is absent altogether in certain areas of the south-west, but is often thicker than the Bottom Busty in the north (N.C.B., 1959).

The Busty seam is commonly "banded", containing thin partings of fine-grained clastic sediment, and these partings are best developed in areas where the seam is split into the Bottom and Top Busty. The ash content of the Busty coals is usually between 2.5 and 7.5%, increasing gradually towards the east (N.C.B., 1959).

The interval between the Bottom and Top Busty seams, where present, is generally between 2 and 7 m, but may be as much as 17 m.

Sulphur levels in the Busty coals are moderate, but characteristically quite variable. This is particularly so of the Bottom Busty seam, where the sulphur content varies from 0.5% to as much as 7.1%. Values for the Top Busty are generally from 0.5 to 1.5%, and in the united Busty seam from 0.7-1.4%.

Localities exposing the Busty seams visited were:

(1) Deborah O.C.C.S. (G.R. NZ 175273),

(2) Cabin House O.C.C.S. (G.R. NZ 136256),

(3) Mown Meadows O.C.C.S. (G.R. NZ 137359),

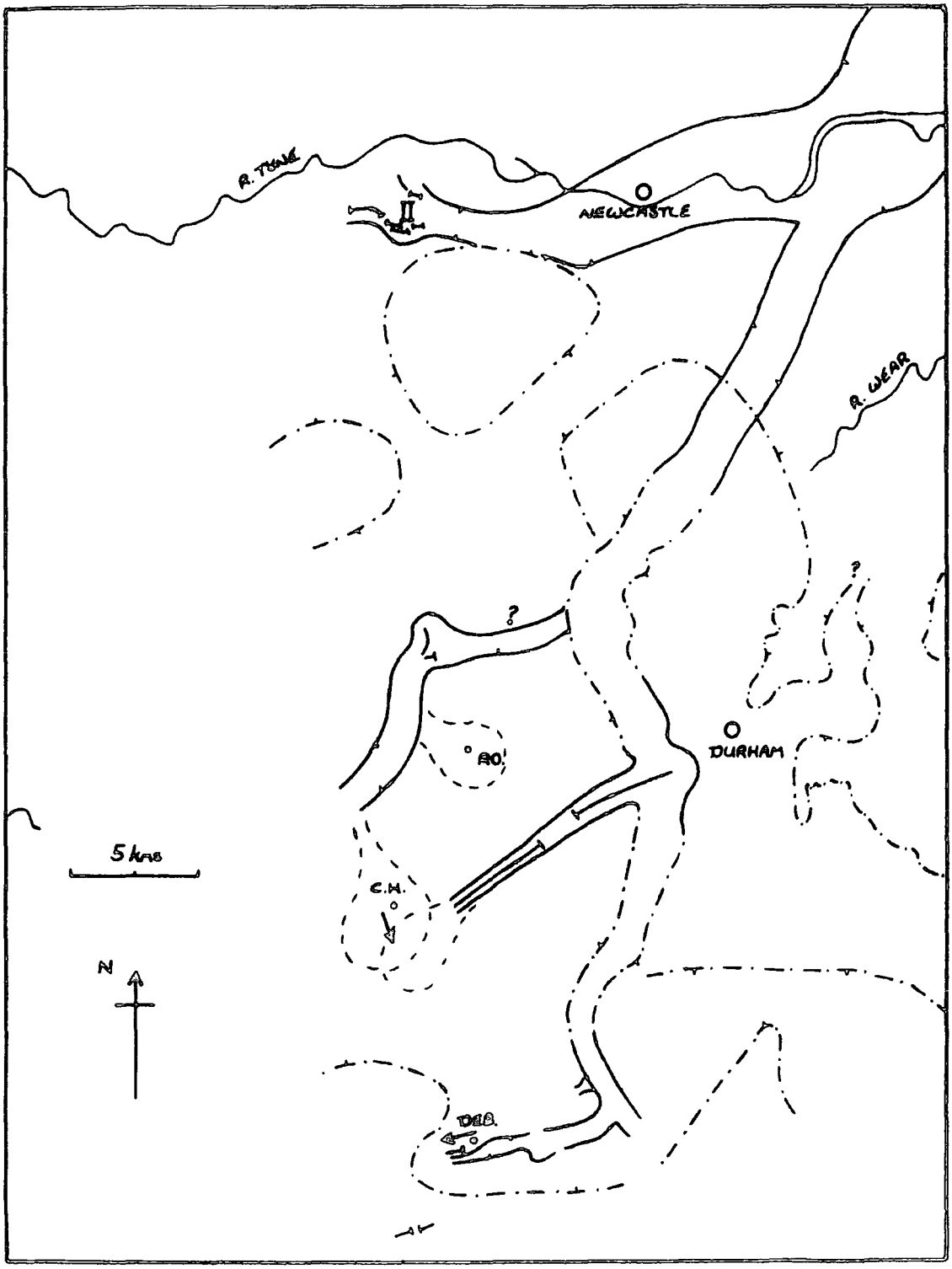
(4) Cobey Carr Quarry (C.G. NZ 209340), and

(5) Rowley O.C.C.S. (G.R. NZ 165422),

(Fig. 6.2) (Appendix 1:- Sections 137, 074, 308, 241, 035/048).

Fig.6.24

THE BUSTY COALS, POST-BOTTOM BUSTY PALAEOCURRENTS AND SPECULATIVE POST-BOTTOM BUSTY CHANNEL TRENDS.



CHANNEL MARGINS

LINE OF SPLIT IN BUSTY COAL (SEAM SPLIT ON ORNAMENTED SIDE)

WASHOUTS IN BOTTOM BUSTY COAL.

MINOR DELTA LOBE (SCHEMATIC)

PALAEOCURRENT VECTOR MEAN

Ro. ROWLEY O.C.C.S.

C.H. CABIN HOUSE O.C.C.S. ($\wedge$ = 52)

DEB. DEBORAH O.C.C.S. ($\wedge$ = 37)

6.6.4 Sediments between the Bottom and Top Busty coals

Strata representing the interval between the two Busty seams were examined at Cabin House O.C.C.S; Rowley O.C.C.S. and Deborah O.C.C.S.

6.6.4.1 Cabin House O.C.C.S.

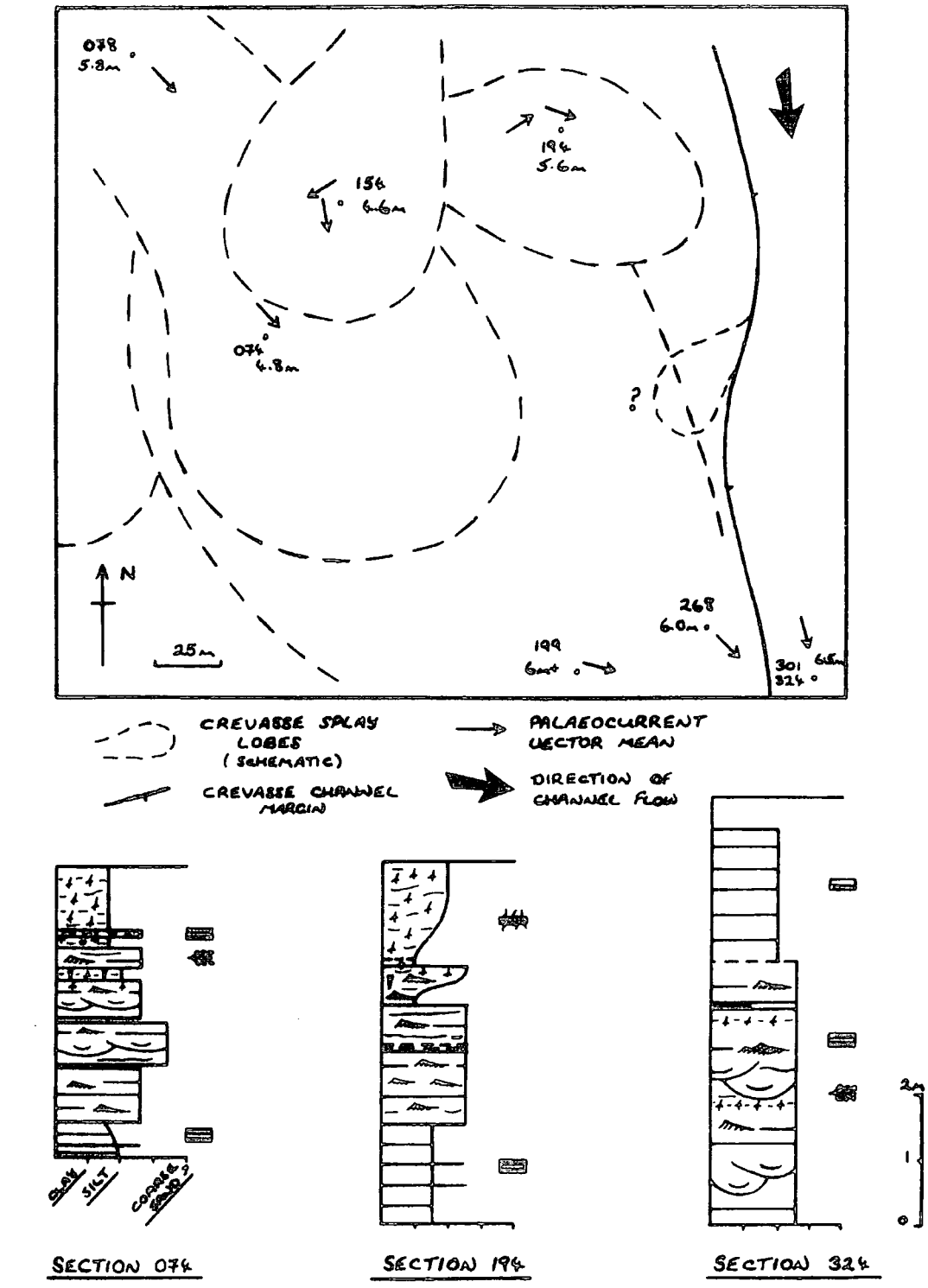
Description

At Cabin House O.C.C.S., the inter-Busty parting varies between 4.5 and 6.5 m, and consists of interbedded claystones, siltstones and sandstones up to medium sand grain-size (Fig. 6.25). Fine-grained sediments are rich in plant debris, and commonly contain burrows and shell casts of non-marine bivalves, while the sandstone units, which may be either sharply or transitionally-based, show abundant ripple cross-lamination, climbing ripple cross-lamination and small-scale trough cross-bedding. Sandstones, which are generally up to 1.5 m in thickness, vary with little apparent regularity along exposed opencast faces. Individual beds are occasionally penetrated by rootlets. Representative vertical sections are shown on Fig. 6.25 (Sections 074 and 194; Enclosure 2).

In the south-eastern part of the site, the interval is different, being composed solely of fine-grained sandstones up to 1 m thick, stacked vertically to a total thickness of 4-5 m, and overlain by a variable thickness of siltstone (Fig. 6.25; Section 324). Ripple cross-lamination of several types is abundant, as is trough cross-bedding in sets up to 0.4 m thick and at least 2.0 m wide. Occasional siltstone partings between individual sandstone units are commonly rootleted, and a thin coal is present at one locality (Section 324; see Fig. 6.25).

Fig.6.25

CREVASSE SPLAY AND CREVASSE CHANNEL SEDIMENTATION AT CABIN HOUSE O.C.C.S. (BOTTOM-TOP BUSTY INTERVAL)



The exposed sediments are interpreted as deposits of crevasse splays (074 & 194) and a crevasse channel (324) which prograded southeastward across a shallow lacustrine basin as part of a major crevasse lobe.

The uppermost 1-2 m of exposed sequences contain abundant rootlets and *Stigmaria* roots, representing the seatearth of the Top Busty coal.

Palaeocurrent measurements from ripple cross-lamination and trough cross-stratification indicate a general south-eastward sediment transport, with minor components of movement towards the south-west and north-east (Fig. 6.25). The thickness of the interval varies across the few hundred square metres of the site, but does not change systematically in any direction (Fig. 6.25). Individual sandstones are difficult to correlate between exposures, and so no attempt has been made to assess thickness variation within sandstone beds. Sandstone units do, however, tend to amalgamate and thicken towards the east.

Petrographically, the sandstones are characterized by a high proportion of finely crystalline siderite cement which appears to have replaced original carbonaceous, clay-rich laminae (Appendix 2).

Interpretation

The sediments at Cabin House O.C.C.S. were deposited by intermittent, high energy tractional and/or density currents, interspersed with less energetic flows and "quiet" periods characterized by suspension fallout sedimentation, from the nature of the sequence.

These sediments, exposed over much of the site, are interpreted as the result of repeated crevasse splay deposition in a shallow-water lake setting. The rapid changes in character and inferred lateral impersistence of individual units implies a complex sedimentation history, with numerous depositional episodes involved in the construction of the preserved sequence. The lake was infilled primarily from the north-west; other palaeocurrent directions may

indicate either separate sources or, more likely, local variations in current direction (Fig. 6.25).

The more sandstone-dominated sequence exposed in the south-east part of the area of study was deposited by more continuous, or more frequent, high-energy flows, and is interpreted as the deposit of a crevasse channel which flowed over previously-deposited crevasse splay sediments to transport sediment to a lacustrine delta some distance to the south-south-east, and also laterally (i.e., eastward and westward) into the shallow lake across which it travelled (Fig. 6.25). Evidently, from the continuous vertical repetition of sandstone units, the crevasse cannel began life as an axis of crevasse splay deposition which developed into a channel as the more proximal regions of the lake (those areas close to the channel source of sediment) were infilled by early sedimentation.

The final stage in the infilling of the lake, which cannot initially have been more than about 6 m deep, was achieved by relatively quiet-water sedimentation, due probably to abandonment of the crevasse system after elimination of its' initial high-gradient pathway. The sediments exposed were probably quite close to their immediate source, from the abundance of rootlets and sharply-based sandstones within the sequence and scarcity of siderite nodules.

The process of shallow lake infilling by crevasse systems has been described from modern delta plains, though the data base is not substantial (Elliott, 1974), the details of sedimentary processes poorly-known and those of resultant sedimentary sequences largely speculative. Similar depositional sequences and settings have been described from the British Coal Measures by Heward (1976) and Guion (1978), amongst others. Guion (*op. cit.*) provided detailed

descriptions of crevasse-initiated "minor" channels from the Westphalian B of the East Midlands, which often operated as quite long-lived distributaries, comparable channels to which have already been described earlier in this Chaper, for example from Crag Head (Ch. 6.3.2.4). The inferred crevasse channel from Cabin House may have operated in the same way, though this seems unlikely from the absence of a well-defined overbank sequence and the lack of any clearly-defined channel margins and associated features.

6.6.4.2 Rowley O.C.C.S.

Description

At Rowley O.C.C.S. (Enclosure 3), the Bottom-Top Busty parting comprises 4-5 m of sediments, although borehole data suggests considerable variation in the surrounding area.

The sequence is closely comparable with that at Cabin House, comprising interbedded laminated claystones and sharply-based, fine-grained sandstones up to 1.0 m in thickness (Fig. 6.26). Structures in the sandstones include primary current lineation and small-scale trough cross-bedding in the lower parts of individual beds, and ripple cross-lamination higher up. No palaeocurrent measurements were made on these rocks, due to limited access and exposure.

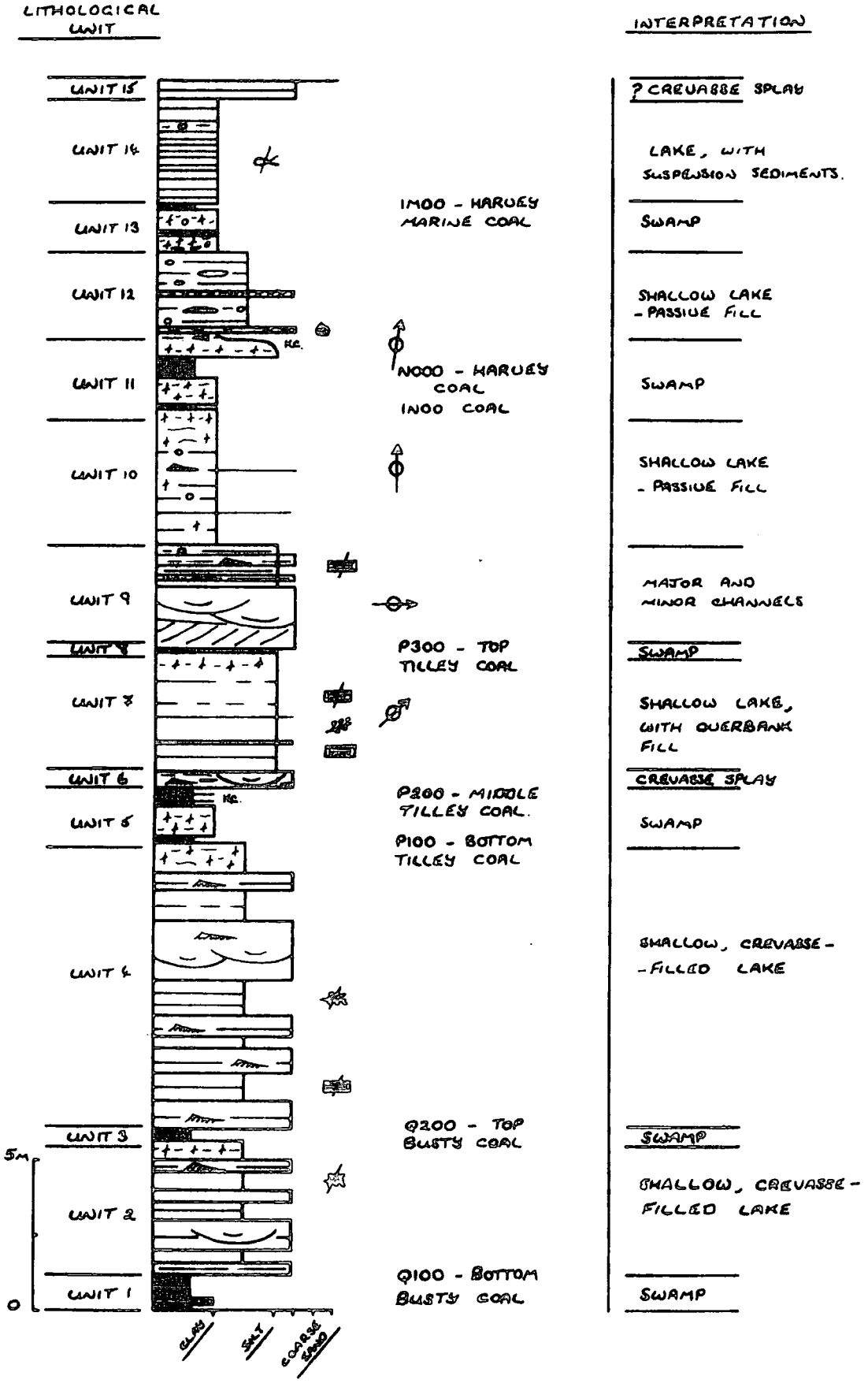
Interpretation

The sediments exposed at Rowley are interpreted similarly to those at Cabin House, that is, as a shallow lake infill composed at least partly of crevasse splay sediments. The lack of lateral control and of palaeocurrent data preclude more detailed interpretation, but borehole information indicates that individual

Fig.6.26

COMPOSITE VERTICAL SECTION - ROWLEY O.C.C.S. (G.R. NZ 165622)

(BASED ON SECTIONS 035, 109, 279, 289 AND 296)
:- APPENDIX I



sandstones are difficult to trace laterally over any distance, as at Cabin House. The vertical sequence of sedimentary structures in these sandstones is indicative of decelerating currents, as might be expected from crevasse splays prograding into a shallow basin (Arndorfer, 1973).

6.6.4.3 Deborah O.C.C.S.

Description

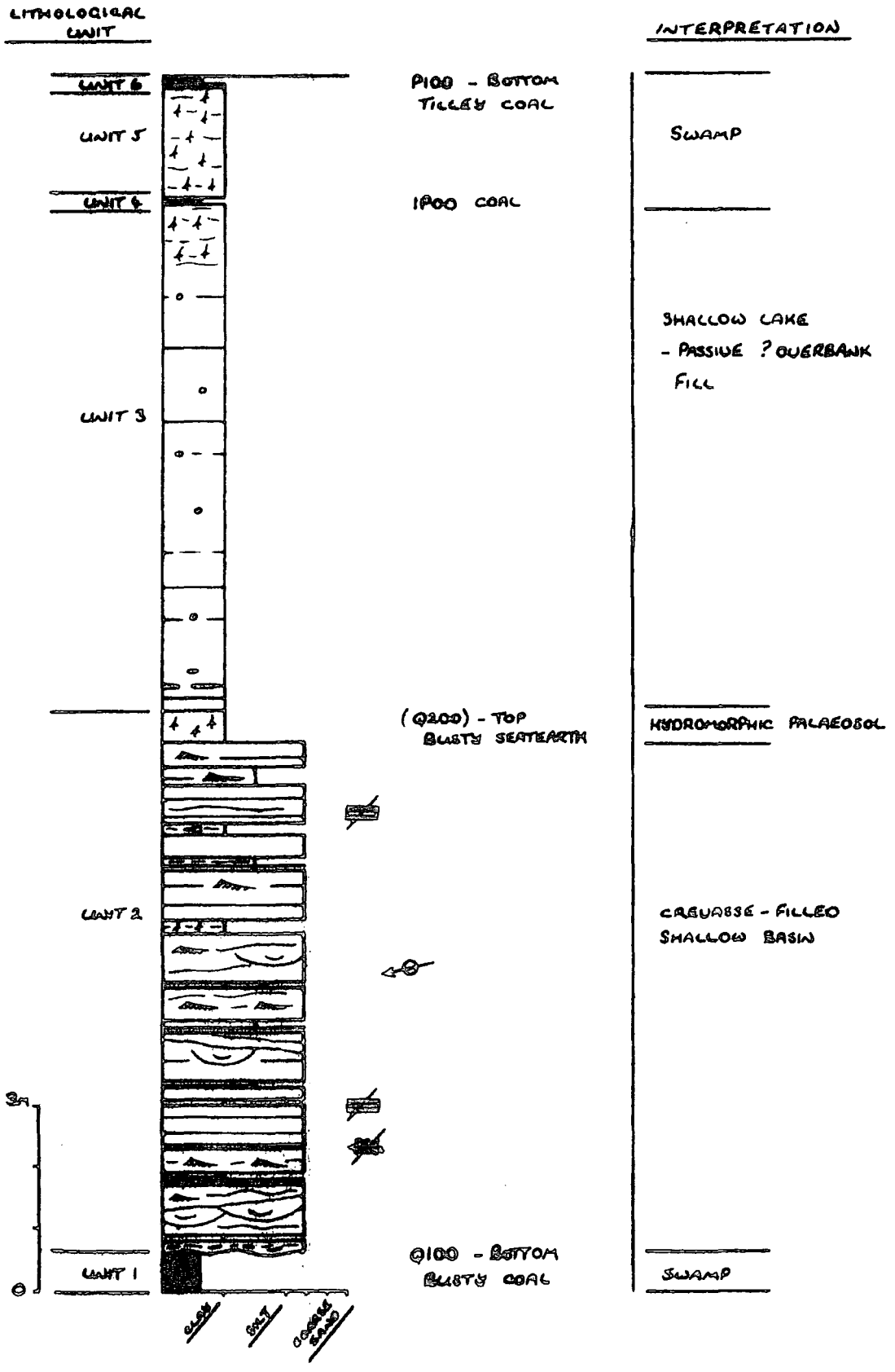
At Deborah O.C.C.S., only one Busty seam is present, and this is assumed to be the Bottom Busty since the Top Busty coal is known to be thin and laterally impersistent in the surrounding area (see also Interpretation). Thus the lower part of the sequence above the existing Busty seam is referable to the Bottom-Top Busty interval, and considered at this stage.

Over most of the area examined (Area D, see Enclosures 4, 5) the sequence overlying the (Bottom) Busty seam consists of a series of interbedded fine-to-medium-grained sandstones, siltstones and claystones some 4-11 m thick, overlain by a similar thickness of uniform, poorly-laminated, silty claystones (Fig. 6.27, Units 2 and 3), (Plate 6.6). Individual sandstones within Unit 2 vary up to about 1.0 m thick, though amalgamation may result in beds up to 3.0 m thick. Trough cross-bedding is common in the sandstones, in sets up to 0.8 m thick (though more commonly 0.3-0.4 m) as is ripple cross-lamination. Parallel lamination and primary current lineation also occur, as do scattered plant debris, occasional burrows, and, especially near the base of the section, coaly "scares". Most of the sandstone beds are sharply-, even erosively-based, though some are gradational, and internal erosion surfaces are common.

Fig.6.27

MEASURED VERTICAL SECTION BETWEEN THE BOTTOM BUSTY AND BOTTOM TILLEY COAL SEAMS AT DEBORAH O.C.C.S.

(AREA D) (BASED ON SECTION 096, WITH OTHER DATA)



The sandstone beds are characterized by moderate lateral persistence in all directions, but become difficult to trace over distances greater than 200 m. Erosive bases to some units occasionally show a channel morphology, particularly around the centre of the opencast (Enclosure 5, Longitudinal section), (Plate 6.6). Lithologies in the upper part of the Unit occasionally contain evidence of rootlet penetration.

Sandstones from the above-described settings possess variable quartz contents (62-71%), moderately sorted and display a variable development of patchy calcite or siderite cement (Appendix 2).

Interbedded with these sandstone beds are thinner (generally up to 0.30 m thick) partings of poorly-to-well-laminated claystone, silty claystone, and siltstone, containing abundant, often comminuted, plant debris, and *Planolites* burrows. Many of the coarser lithologies show a "sandy streak" (or "linsen bedding"), and rarely contain ripple form sets and ripple cross-lamination.

The proportion of fine-grained sediments generally increases up the succession, though not according to any regular pattern (Enclosure 5: Section 137). Palaeocurrent measurements from trough cross-bedding and other structures indicate sediment transport in a west-south-westerly direction (Enclosure 5).

In the southernmost part of opencast site, the sequence above the (Bottom) Busty is different, in that in an elongate, east-west-trending belt some 40 m wide, the Bottom Busty coal is "washed out" and the horizon of the coal is occupied and overlain by 9.0 m of fine-grained sandstone, with occasional siltstone partings (Enclosure 5, Section 15 m S.W. of 292).

Immediately to the north and south of this belt, the equivalent sequence contains a greater proportion of fine-grained sediments, and beds are inclined in a direction away from the "washout" belt.

On the southern side of the washout, two or more additional coals are present above the Bottom Busty. These "riders" are ? erosionally truncated to the north, and pinch out 75 m to the south of the washout belt. In the same area, the Bottom Busty seam is commonly increased from 0.75 m to as much as 1.80 m in thickness (Enclosure 5:- plan and longitudinal section). Between and above the coal "riders" are shales and silts interbedded with fine-grained sandstone beds which often downcut towards the south.

In the roof of the second coal rider at one locality three straight, aligned scours ("gutter marks") up to 1.0 m in width were observed. These were sandstone-filled, and elongated in a north-east/south-west direction (Appendix 1:- Section 151; Enclosures 4,5).

Immediately to the north of the washout belt, directly above the erosionally-reduced Bottom Busty coal, lies a sequence of thinly interbedded, fine-grained sandstones and massive siltstones. This sequence has an arched profile when seen in cross-section (Enclosure 5:- Longitudinal section), increasing and then decreasing in thickness orthogonally away from the washout belt, and attaining a maximum thickness of about 1.0 m. The northward extent of this facies (that is, away from the washout belt) is probably no more than about 40 m.

The sandstones in this sequence are well-indurated and commonly appear massive, though some have been thoroughly bioturbated. The siltstones contain chaotically arranged plant fragments, abundant evidence of bioturbation and occasional ripple form sets and ripple cross-lamination (Enclosure 5:- Section 292). Palaeocurrent measurements from ripple cross-lamination and occasional, small-scale trough cross-bedding show a general northwestward direction of flow, although a great diversity of directions is represented further away from the washout belt (Enclosure 5:- Plan).

Petrographically, the sandstones are moderately sorted ($3.04\ \phi \pm 0.54$), and contain a high proportion (up to 20%) of siderite cement (Appendix 2).

An interesting association of trace fossils occurs in this finely interbedded sequence, including *Planolites*, *Arenicolites* of various types and single "pipe-like" burrows referable to *Skolithos/Monocraterion*. These occur almost exclusively on the crest of the arch structure, with the exception of *Planolites*, which is ubiquitous (Fig. 6.28, Plate 6.7).

At a locality about 70 m north of the washout margin, (Section 231; Enclosures 4, 5, Appendix 1), a 0.24m thick, "laminated", dark grey, kaolinitic claystone occurs immediately above the Bottom Busty coal. This lithology is unusual in being composed largely of organic matter and elongate "graupen" of micro-crystalline kaolinite, with occasional silt-grade quartz particles (Appendix 2), (Plate 6.8). Similarly, the top of the Bottom Busty seam at several other localities (e.g., Sections 036, 130:- Appendix 1) is composed of a highly carbonaceous, micaceous, well-laminated claystone.

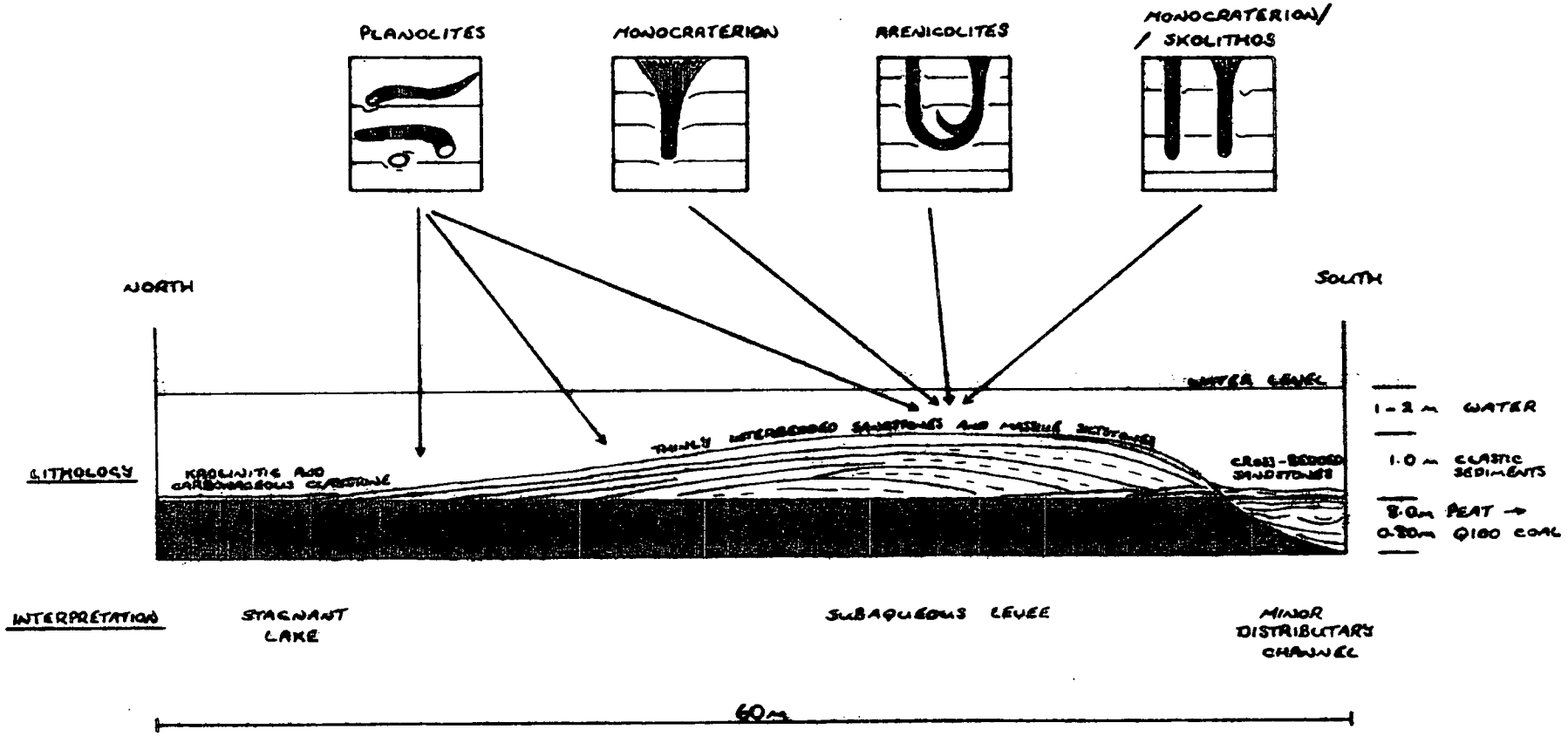
Above the finely interbedded sequence, immediately to the north of the washout belt, the succession is composed largely of massive, ? structureless siltstone displaying a subtle "draping" towards the north, and containing abundant plant fragments inclined at all angles to the horizontal (Enclosure 5:- Section 292). Occasional fine-grained sandstones, up to 2.0 thick, with sharp basal and upper contacts, occur within this sequence.

Further away from the washout belt, towards the north, more sandstone units wedge in, and the sequence takes on the "coarsely

Fig.6.28

TRACE FOSSILS IN CHANNEL LEVEE SEDIMENTS DEBORAH O.C.C.S.

(AREA D). (SEE ENCLOSURE 5, AND CH. 6.6.4.3)



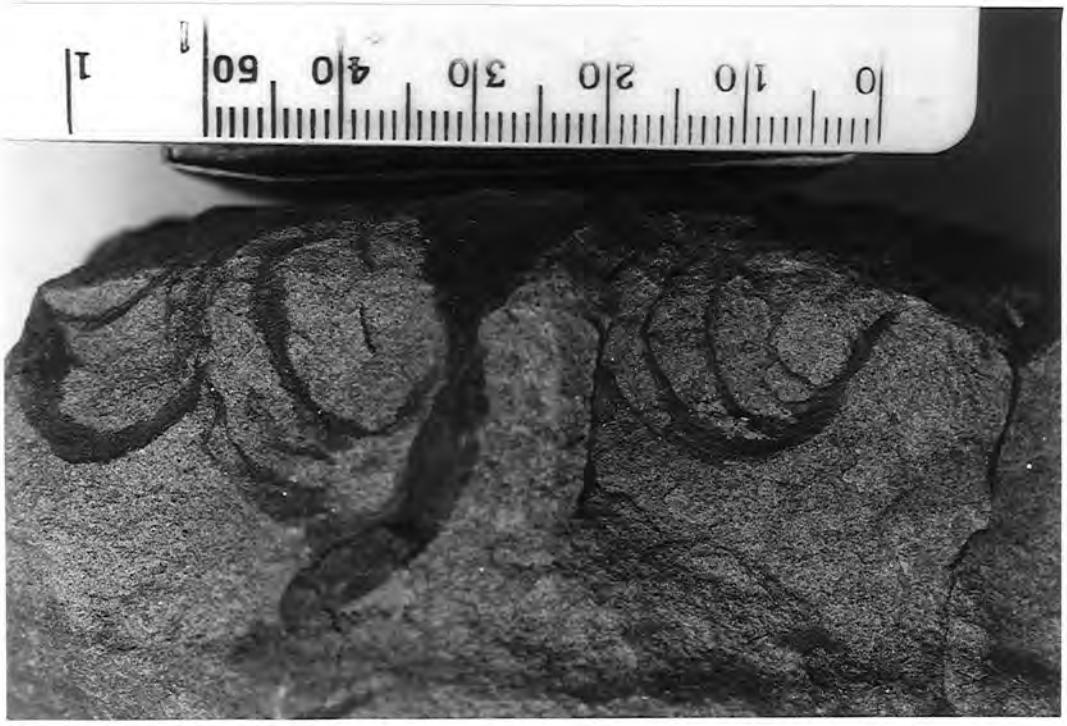


Plate 6.7 - Compound Arenicolites burrows from levee crest sediments overlying the Bottom Busty coal, Deborah O.C.C.S. (Area D). Scale divisions in mm.

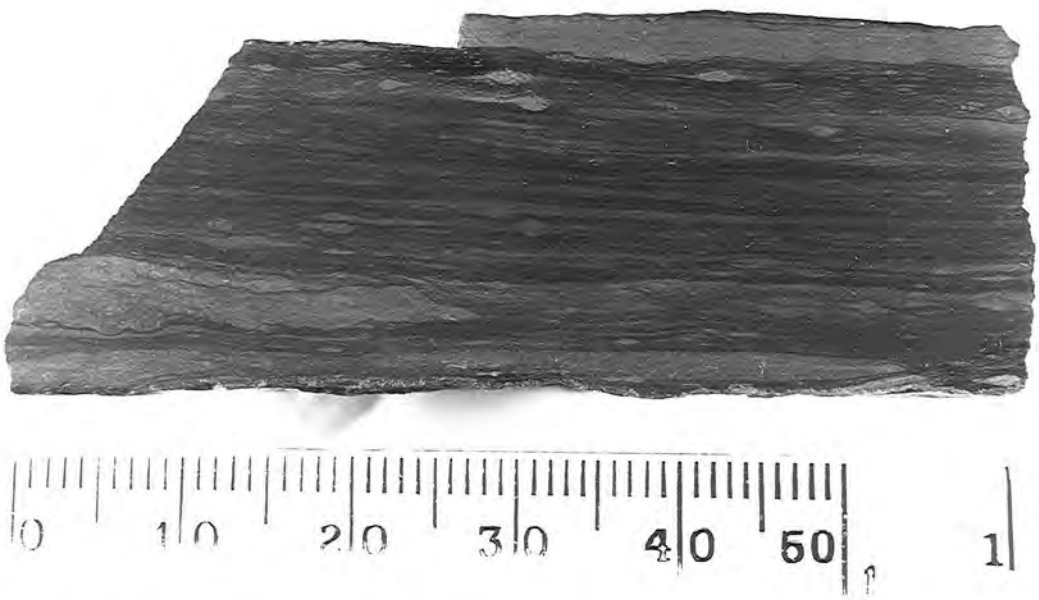


Plate 6.8 - "Laminated" kaolinitic claystone from above the Bottom Busty coal, Deborah O.C.C.S. (Area D), showing large, compound, and small, isolated, kaolinite "graupen". Scale divisions in mm.

interbedded" aspect characteristic of the majority of the site.

Interpretation

The sediments exposed over much of Deborah O.C.C.S., typified by Section 137 on Enclosure 5, are interpreted as having been deposited by a combination of high energy tractional currents, gentler currents and suspension fallout, in a shallow lake setting.

The more energetic traction currents were associated with crevasse splay activity.

The sandstones of the washout belt in the southern part of the area were deposited by intermittent, rapid, confined, traction current activity and this belt is interpreted as a minor distributary channel.

The finely interbedded sediments immediately to the north of the washout belt accumulated by periodic overtopping of the channel bank during high flow stage, and are interpreted as a levee deposit, which accumulated at an early stage of channel activity (Enclosure 5:- Plan and Longitudinal Section).

However, from a consideration of the palaeocurrent distribution and of the proportion of sandstone, as discrete units, within the sequence, it is apparent that the crevasse sediments and the distributary channel are not directly genetically related. Palaeocurrents in crevasse sandstones were directed predominantly towards the west-south-west, and the proportion of sandstone in the succession increases away from the channel deposit, hardly the situation to be expected were the former derived from the latter.

The proportion of sandstone in the sequence reaches a maximum (70 to 90%) at between about 200 m and 400 m from the inferred channel margin, decreasing both to the north and south (Enclosure 5:- Plan). This area is also characterized by an abundance of internal erosion surfaces and channel forms within sandstones, and by the

frequent occurrence of amalgamated sandstone units. It is thus interpreted as the axis of crevasse sedimentation containing the deposits of several, irregularly stacked crevasse channels which flowed towards the west-south-west. Sandstones from this depositional axis display rather better sorting than crevasse sandstones from elsewhere on the site (Appendix 2).

Evidently the depth of water in the crevasse basin was often minimal (1-3 m) as implied by the presence of *in situ* rootlets within the sequence at a number of localities.

The minor distributary channel, as inferred from the distribution of channel-related palaeocurrents, is interpreted as having flowed towards the west (Enclosure 5:- Plan). The channel fill was probably an active fill, being composed predominantly of fine-grained sandstone. Evidently the channel formed shortly after accumulation of the Bottom Busty peat, as the inferred levee sediments rest directly on the coal.

The thickened Bottom Busty coal in the vicinity of the washout belt provides an explanation for the location of the distributary channel. As the Bottom Busty swamp began to subside under its own weight, accelerated subsidence in the area of thickest peat produced a topographical hollow. When the distributary channel was initiated, presumably by a crevasse event in the bank of another channel, it sought a course with maximum available gradient, and flowed across this topographically subdued area. The "riders" on the south side of the washout are interpreted as rafts of peat eroded by the channel as it passed across the subsiding swamp, and deposited further downstream on the channel bank. Guion (1978) explained similar coal "riders" around channel washouts in the Westphalian B of the East Midlands in the same manner.

The presence of an area of incomplete coal erosion within the washout belt and the position of levee sediments limits the age of the channel to immediately after the accumulation of Bottom Busty peat (Enclosure 5). Thin partings of sandstone within the Bottom Busty coal in the vicinity of the channel may be interpreted as injection features.

Immediately to the south of the distributary channel, the equivalent sequence is dominated by crevasse splay sandstones, set in a background of structureless overbank siltsones. The crevasse units are seen to downcut to the south, and also thin in that direction.

The aligned, sandstone-filled "gutter marks" of this area are interpreted as erosional scours developed by flood-generated overtopping of the channel bank, early in the history of the channel. Similar features were described from the Silurian of the Welsh Borderland and Norway by Bridges (1972) and Whitaker (1973) respectively, and interpreted as the products of erosive scouring in shallow marine settings.

The finely interbedded sediments immediately to the north of the distributary channel, interpreted as a subaqueous levee deposit, evidently accumulated at an early stage in the active life of the channel, probably on the outer bank of a bend in the channel (Enclosure 5:- Plan). At the time of accumulation of the levee, stagnant swamp conditions must still have prevailed over the area to the north, as shown by the following features:-

(1) trace fossils are abundant on the levee crest, but uncommon elsewhere, and

(2) the Bottom Busty coal is directly overlain, to the north of the levee deposit, by a kaolinitic claystone lithology, interpreted as the result of ? subsurface

precipitation of kaolinite in sediments beneath a stagnant, reducing, shall water environment (see Ch. 6.7.4 for more detailed description and interpretation of kaolinitic claystone lithologies).

Levee sedimentation to the north of the distributary channel evidently was not allowed to develop fully, since the deposit attains a width of only about 40 m and a maximum height of 1.0 m, despite a 9 m vertical succession of channel sediments. Overlying the levee sediments is a sequence of overbank siltstones, with occasional crevasse sandstones, similar to that on the south side of the channel. Channel abandonment sediments are unfortunately cut out by Pleistocene drift deposits.

From the depth of scour of the minor distributary, and the height of the early levee deposits, the early-stage instantaneous depth of the channel is estimated to be about 18 m (allowing for decompaction of the Bottom Busty seam). The extent of the channel sandstone fill suggests a total width for the channel of 60 m, and a width/depth ratio of 3.3:1.

The channel is considered to have aggraded with time, retaining the capability to deposit overbank sediments at flood stage.

The area of study thus reflects the interaction between a west-south-west-directed crevasse system and a westward-flowing minor distributary channel with north- and southward-directed overbank and crevasse sedimentation.

Guion (1978) described a number of very similar minor distributary channels from the Westphalian B of the East Midlands, many of which displayed moderate sinuosity and evidence of lateral accretion. No direct evidence of lateral accretion was observed in the Deborah channel, though the presence of a levee on the northern bank is suggestive of a sinuous channel morphology.

One of Guion's (*op cit.*) case studies, concerning the strata surrounding the Top Hard, Lower Coombe and Upper Coombe coals at Shipley Lake O.C.C.S., Derbyshire, shows a strikingly similar setting to that exposed at Deborah (see his Chapter 10). Guion's interpretation of the Shipley Lake sequence bears considerable resemblance to the author's explanation of the Deborah exposures.

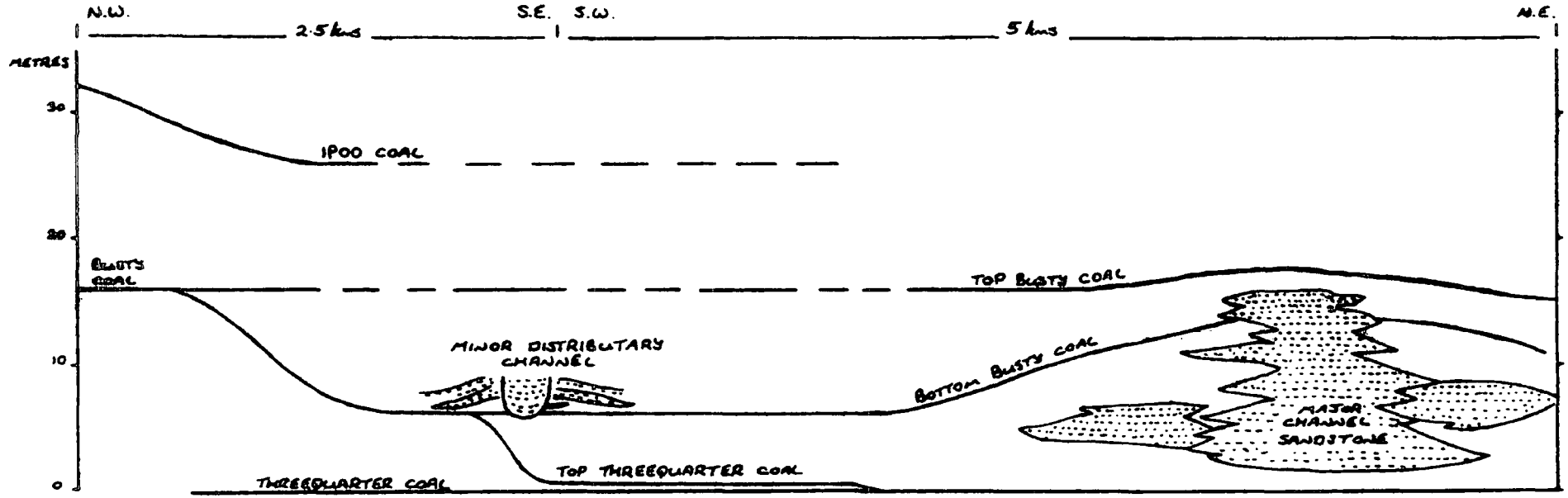
The width/depth ratios of channels in Guion's study are comparable to that of the Deborah distributary (7 - 8, as opposed to 3.3), as might be expected from the similarity in form and setting. The extremely low width/depth ratio, and channel stability with time, is ascribed to the cohesive nature of the channel banks, which must initially have been entirely composed of partly-compacted peat.

Regarding the origin of the distributary channel and crevasse system exposed at Deborah, subsurface data to the north-east of the area has shown a possible source.

In an elongate north-south belt at around longitude NZ22, the Busty seams are shown as united on I.G.S."6 inch"plans (Fig. 6.24). On closer inspection, borehole data reveals that a major, erosive-based channel sandstone, up to 30 m thick, occurs in this area above the level of the Threequarter coal. This channel system began operating some time after the accumulation of the Threequarter peat, and continued intermittently until after the time of Bottom Busty peat accumulation, causing the two Busty seams to converge, and probably causing the Bottom Busty to have been "washed out" along the channel axis (Figs. 6.22, 6.24, 6.29). It is considered unlikely that the channel system operated throughout the time of accumulation of the Bottom Busty, since no records of sandstone splays in the coal have been found by the author.

Fig.6.29

SCHEMATIC PROFILE SHOWING GEOMETRY OF THE BUSTY COALS AND ENCLOSING STRATA IN THE SOUTH DURHAM AREA.



Toft Hill Deborah O.C.C.S. Binchester Blocks

While the post-Bottom Busty channel course is not entirely clear in South Durham, it seems likely that an avulsion event caused the channel to change course and flow westward across the area now comprising Deborah O.C.C.S. (Fig. 6.24). The westward-directed crevasse palaeocurrents at Deborah may then be explained as resulting from channel bank breaching along the north-south stretch of the channel (at the point of major breaching, from further upstream or possibly from a combination of sources).

Since the (northern) channel system can be said to have ceased operating before the accumulation of the Top Busty peat along this north-south stretch, and assuming that this channel did supply the Deborah distributary, then the entire history of channel operation at Deborah may be accepted as "pre-Top Busty".

In the western part of Deborah O.C.C.S., the post-Bottom Busty sequence changes dramatically in character. In Area A (Enclosures 4, 5), a thin coal, identified as the Top Busty seam, occurs above the Bottom Busty, thickening progressively to the west, as does the Bottom Busty coal (Enclosures 4, 5). In this area, the Bottom-Top Busty parting decreases towards the west from 8-11 m to as little as 0.62 m, and is composed entirely of laminated claystone. Some 600 m further to the west-north-west, in the area south of Toft Hill (G.R. NZ 158282), the Busty coal occurs as a single, combined seam up to 1.32 m in thickness (Fig. 6.29), (see also Plate 9 of Mills and Hull, 1976). It is worth noting at this point that where the parting between Bottom and Top Busty seams decreases, that between the Top Busty and the overlying Bottom Tilley increases substantially from around 10 m to more than 20 m (see Chs. 6.7.2 and 6.7.4).

The thin Top Busty coal, identified in Area A, dies out eastward towards Area D (Enclosure 5), but is traceable as a 0.5 m thick seatearth horizon some 8-11 m above the Bottom Busty coal. Therefore, the entire minor distributary/crevasse-filled basin sequence described above is confirmed as "pre-top Busty" in age. The thickening and convergence of the Busty seams towards the west is interpreted as the record of an area of moderate subsidence which formed the fringe of the more rapidly subsiding, post Bottom Busty "Deborah basin" (Fig. 6.29).

Also of interest are the occurrences of additional coal seams immediately beneath the Bottom Busty seam in Area D (recorded in Section 041:- see Appendix 1, and Enclosures 4, 5). These "stringers" are almost united with the Bottom Busty in one area, but diverge rapidly to the east and north-east, and are thought to represent the Top Threequarter coal. If this is the case, a similar mechanism to that thought to be responsible for the Brockwell/Bottom Threequarter relationship (see Ch. 6.5.4) may have again operated in the area (Figs. 6.23, 6.29).

6.6.5 Discussion

As with the underlying interval, the Threequarter-Top Busty interval is characterized by considerable complexity in sedimentation patterns.

The areas occupied by channels, for the post-Threequarter seam and post-Bottom Busty seam intervals, are plotted on Figs. 6.22 and 6.24 respectively, and for the first time directly indicate the operation of relatively narrow (1-2.5 kms wide), ? moderate sinuosity channels, some of which must have been stable for considerable periods of time.

In particular, the channel system described previously was intermittently active from some time after accumulation of Three-quarter peat to some considerable time after the accumulation of the Bottom Busty. While it seems that the earlier activity of this channel system involved possibly more than one channel, in a belt up to 5 kms wide (apparent from borehole information), later activity became confined to probably a single channel 1-2.5 kms wide which remained positionally stable for a long time.

Some of the other "channel belts" shown on Fig. 6.22 may represent single major distributaries, or belts of smaller channels. The Humber Hill exposure may be interpreted as part of a channel deposit, from its' position with respect to the inferred channel belts.

On Fig. 6.24, most of those channels plotted were detected from "washouts" in the Bottom Busty seam, and are likely to be single ? distributary channels, up to 2.5 kms wide.

One possible explanation for the predominance of single, relatively narrow channels may lie in the observation that many of these channels eroded into the Bottom Busty peat, which then acted as a stable bank material and prevented any significant channel migration.

From the distribution of these channels, however, it seems likely that a major "trunk" distributary channel belt passed across the north of the coalfield (Fig. 6.24).

Comparison of Figs. 6.19 and 6.22 shows an eastward shift in the positions of channel courses after deposition of the Threequarter coal, to a position corresponding roughly to the belt representing maximum development of Threequarter coal. This highlights another hereditary control on sedimentation; the post-Threequarter channel belts are in such a position as to avoid the pathways taken by the earlier (post-Brockwell) channels, and are also situated above the

area of likely maximum subsidence in the Threequarter peat (in turn controlled by the position of earlier channels; see Ch. 6.5.4).

The development of the Fishburn Estheria Band in the roof of the Threequarter seam is related to quiet, possibly stagnant conditions in a standing body of water located to the east of the major avenues of contemporary channel activity (Fig. 6.22). The band is only present in the south-eastern part of the coalfield, (Pollard, 1962), but non-marine bivalves are abundant at the same level, in a peripheral belt to the south and west (Mills and Hull, 1976). This is interpreted as a response to increased levels of suspended sediment in the water column close to the post-Threequarter channel systems. The ostracods were evidently not tolerant of high suspended sediment levels, unlike bivalves which are filter- and suspension-feeders.

Pollard (1962) explains the lack of bivalve remains in the basal part of the true "ostracod-facies" faunal horizon as being due to a low Eh associated with low turbulence, and a very inhospitable environment for bottom-living organisms, later ameliorated by increased turbulence in the water column.

It is not entirely clear what has most influenced accumulation of the Bottom Busty peat, though it seems likely that a similar pattern to that of underlying levels would be followed (Figs. 6.22, 6.24). The greater thickness of the Bottom Busty in the south of the coalfield may be due to regional differences in subsidence rates. It is interesting in this respect that the thickness of the Bottom Busty seam itself is also closely related to the lines of splitting; in certain areas, notably around Durham City, the isopachs of the

Bottom Busty are shown to closely parallel the lines of splitting in the Busty Seam, although the relationship is a complex one (Fig. 8 of Smith and Francis, 1967).

The Bottom-Top Busty sequences exposed at Cabin House, Rowley and Deborah are put into a regional perspective on Fig. 6.24; the crevasse-filled basins around Cabin House and Rowley were probably supplied with sediment from the same southwesterly-flowing channel system. Lacustrine basins had wave fetches of 5-20 kms between prograding minor distributaries, though it is evident that the total width of these basins was considerably greater.

It is apparent from a study of Deborah O.C.C.S. exposures that localized, accelerated subsidence over thick peat seams may, through forming topographical hollows conducive to occupation by channels, have led to the formation of local, almost self-contained sedimentary basins. The basin which formed and filled between the time of accumulation of the Bottom and Top Busty seams in the Deborah area was no more than 10 m deep in total, and probably considerably less than this at any one time.

Tracing this small basin to its' westward termination, it is apparent that the entire 10 m basin fill is represented by about 3.0 m of peat (the total thickness of coal in the united single Busty seam, minus the combined total for the Top and Bottom Busty seams, immediately to the east, and multiplied by a factor of 10). Using available figures for modern rates of peat accumulation, this means that the small sedimentary basin around Deborah O.C.C.S. took of the order of 5,000 years to fill (see Fig. 4.2).

The underlying controls on the thickness of the Top Busty coal are, again, not readily apparent from available data. The seam is consistently thickest in the northern part of the coalfield, and this is

possibly due to regional differences in subsidence rates, as with the Bottom Busty.

6.7 BUSTY TO TILLEY COALS

6.7.1 Introduction

The interval between the Busty or Top Busty and Tilley seams varies between 8 and 20 m, and is characterized by extreme lateral variability in thickness and lithology, as are the Tilley coals themselves, and the sediments between them (see, for example, Scott, 1976, p. 49). As with underlying intervals, greater overall sequence thicknesses are associated with the presence of major sandstones.

Six localities exposing the interval between the Busty/Top Busty and Bottom Tilley seams and eight exposing the sediments between the Tilley seams were visited. Most of these were Opencast Coal Sites.

6.7.2 Sediments between the Busty/Top Busty and Bottom Tilley coals

6.7.2.1 Cockfield Reeves

Description

On the south-west edge of Cockfield Fell (G.R. NZ 119243), (Fig. 6.2), a disused quarry exposes 8 m of medium-grained, trough cross-bedded sandstone (Plate 6.9). Subsurface records indicate that this sandstone is commonly 20 m or more thick, rests directly on the Busty coal and occupies almost the entire Busty-Bottom Tilley parting (Mills and Hull, 1976).

The lower half of the exposure consists of a complex mosaic of trough cross-sets up to 0.3 m thick. The upper half comprises a series of cosets 2-2.5 m thick, containing sets 0.3-0.7 m thick, and



Plate 6.9 - Exposure of major sandstone above Busty coal at Cockfield Reeves, showing cosets of cross-strata in the upper part. Height of exposure 6m.

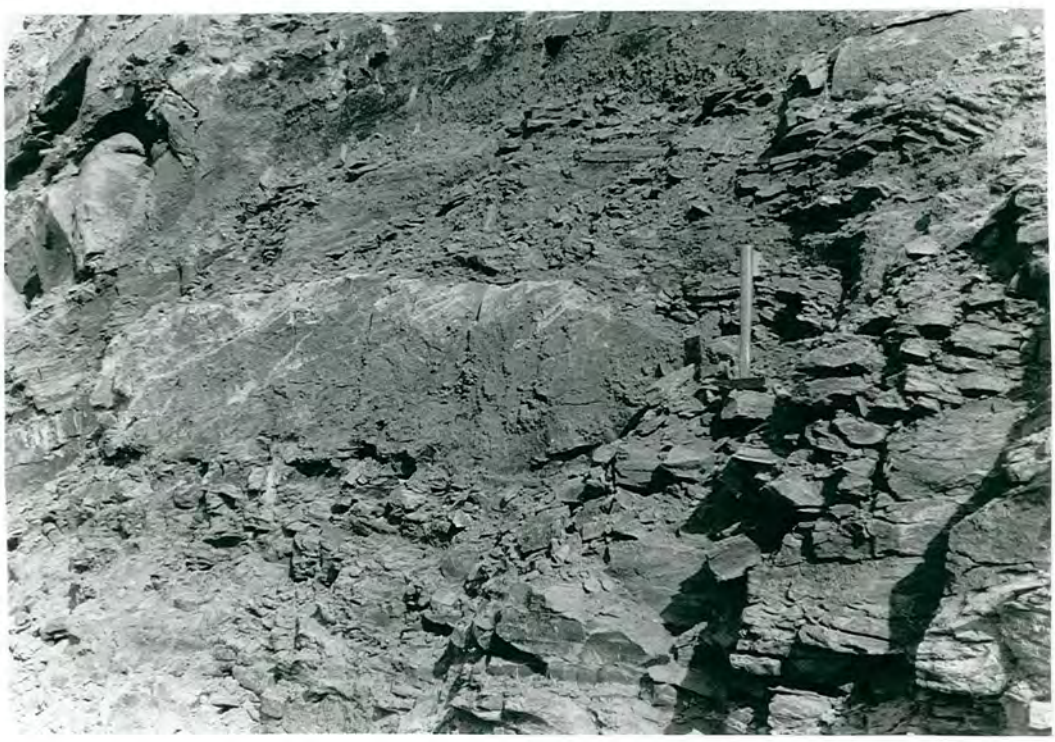


Plate 6.IO - Lens-shaped sandstone in interbedded sediments overlying the Top Busty coal, Cabin House O.C.C.S. (Section II5). Hammer is 30cms long.

individual sets, many of which are traceable for at least 75 m in the downcurrent direction (Plate 6.9). Most sets within cosets are consistent in thickness downcurrent, but some show erosive bases and thicken downcurrent. Troughs are typically shallow and wide (e.g., 0.4 m thick and 8 m wide), and trough orientations indicate palaeoflow towards the south-south-east. Occasional bounding surfaces are present which delimit cosets, but are difficult to trace laterally.

Interpretation

The sandstone exposed at Cockfield is interpreted as the deposit of a south-south-westward-flowing, major distributary channel, based on its' thickness and current-formed sedimentary structures. Channel margins are not exposed, but subsurface records indicate that the sandstone body is about 4 kms wide in an east-west direction.

The lower half of the section is interpreted as channel floor deposits, with little internal organization preserved other than a random stacking of troughs. The cosets and downcurrent-persistent sets in the upper part of the quarry are interpreted as the deposits of migrating, low amplitude/high wavelength, channel floor bedforms (*cf.* Bluck, 1976). Occasional bounding surfaces indicate a variable flow regime within the channel.

6.7.2.2 Rowley O.C.C.S.

Description

At Rowley O.C.C.S. (G.R. NZ 165422), (Fig. 6.2), the parting between the Top Busty and Bottom Tilley seams varies between 7 and 11 m and is seem from outcrop and borehole evidence to comprise interbedded sandstones and finer-grained lithologies (Fig. 4.26; Unit 4, Enclosure 3).

Interpretation

No interpretation was possible, owing to the small and disturbed nature of the outcrop, and the ambiguous nature of borehole records.

6.7.2.3 Cabin House/Mown Meadows O.C.C.S.

Description

At Cabin House O.C.C.S. and Mown Meadows O.C.C.S., the Top Busty-Bottom Tilley parting comprises 5-8 m of interbedded fine-grained sandstones, siltstones and claystones (Enclosure 2, Appendix 1, Fig. 6.30).

The sequence is similar in all aspects to the underlying Bottom-Top Busty interval at this locality. Sandstones, which may have coarsening-upward, transitional, sharp or erosive lower contacts, vary up to 1.0 m thick, and contain abundant ripple cross-lamination (Fig. 6.30). Some sandstones are lenticular in cross-section, enclosed within finer-grained sediments (Plate 6.10).

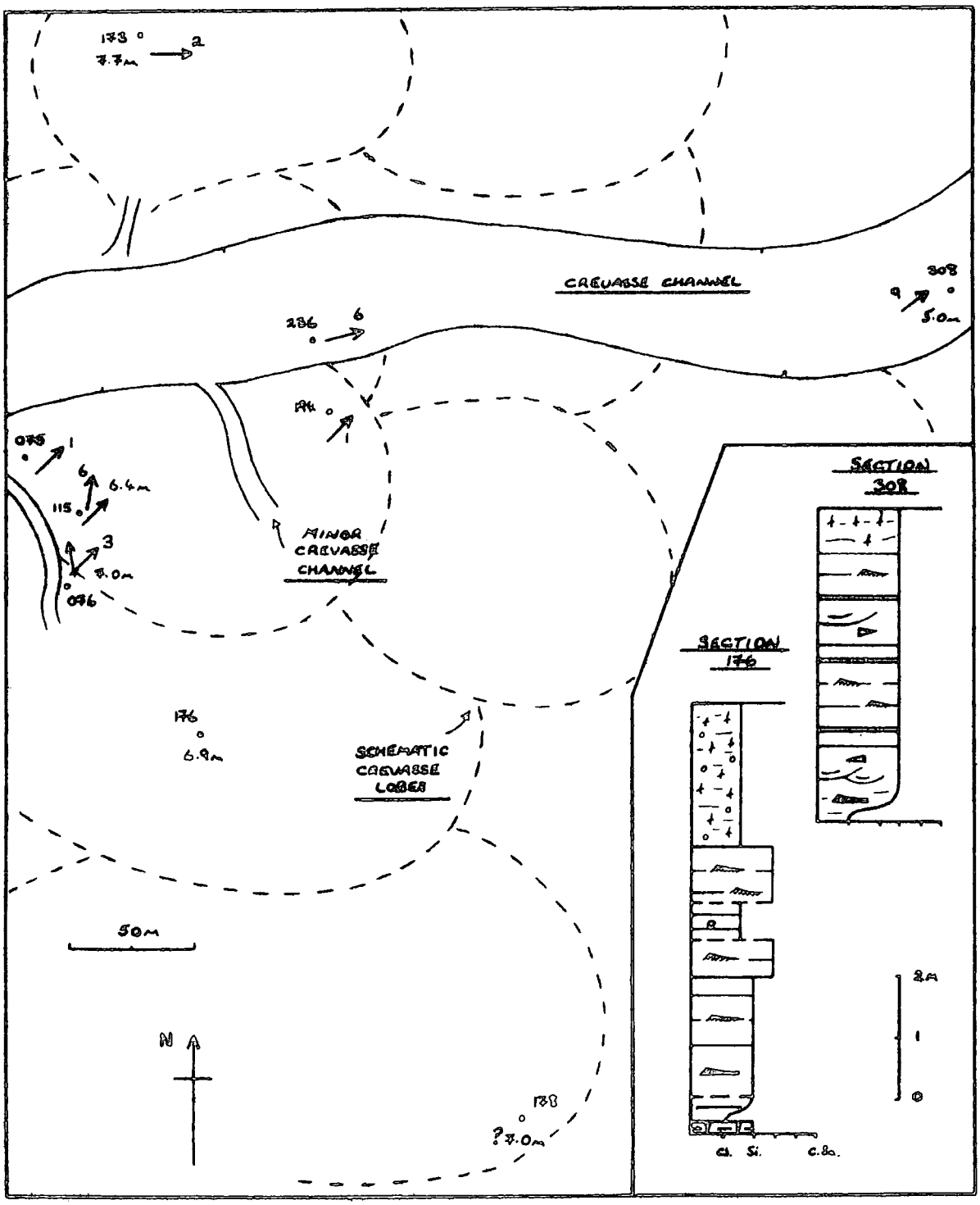
Fine-grained sediments, predominantly siltstones with "sandy streak", also contain abundant ripple form sets and cross-lamination, and common backflow ripples. Siderite nodules are sometimes present, and one horizon is occasionally characterized by abundant nodules up to 0.45 m in diameter (for example, see Section 076; Appendix 1).

In the north-central part of the site, virtually the entire interval is composed of fine-grained sandstone containing abundant small-scale (0.1 m) trough cross-bedding, ripple cross-lamination, uneven lamination and thin (up to 0.05 m) claystone partings (Fig. 6.30).

Abundant rootlets and stigmarian roots penetrate the uppermost 2 m of all sequences, forming the Bottom Tilly seatearth.

Fig.6.30

CREVASSE SPLAY AND CREVASSE CHANNEL SEDIMENTATION
AT CABIN HOUSE/MOWN MEADOWS O.C.C.S.
(TOP BUSTY - BOTTOM TILLEY INTERVAL)



→ PALAEOCURRENT VECTOR MEAN

176 ○ LOGGED SECTION - WITH
7.6m THICKNESS OF TOP BUSTY - BOTTOM TILLEY PARTING

Sedimentary units are traceable laterally for up to 200 m along individual faces, but diffiuclt to correlate between separate faces. While exposure of sequences was commonly incomplete, there does seem to be a general trend towards increasing interval thickness and decreasing sandstone content away from the north-central area described above (Fig. 6.30). Sandstone units do not appear to thicken or thin significantly in any direction, however.

Palaeocurrent measurements from trough cross-bedding and ripple cross-lamination indicate palaeoflow towards the north-east (Fig. 6.30).

Interpretation

The Top Busty-Bottom Tilley succession at Cabin House/Mown Meadows was deposited largely by tractional currents, in discrete "packages" representing single or multiple depositional events. Sedimentation via these episodic currents was interspersed with "quiet" periods when only "background" fine sediment settled from suspension. In the north-central area, tractional current activity seems to have been more continuous, or more frequent, resulting in the sandstone-dominated sequence.

The Top Busty-Bottom Tilley interval is interpreted as the sediments of a shallow, lacustrine basin which was filled by crevasse splay sedimentation, as was the underlying interval at this locality. The interbedded sediments exposed over much of the site are interpreted as the product of repeated crevasse splay deposition, and the continuous sandstone sequence in the north-centre as the active fill of a crevasse channel, which eroded through previously-deposited crevasse splay sediments (Fig. 6.30). The channel was probably of the order of 50 m wide, though no channel margins were exposed. The uniformly east-north-east-directed palaeocurrents suggest a common source for both crevasse splay and crevasse channel

sediments, situated to the west-south-west (compare with Ch. 6.6.4.3; Deborah O.C.C.S.). Minor deviations in the palaeocurrent pattern, and the irregular pattern of variation in sandstone bed thickness, suggest local palaeoflow divergence, but this variation is not as pronounced as might be expected, from the published descriptions of modern crevasse sedimentation (e.g., Arndorfer, 1973).

The sandstone content of the vertical sequences suggests that the crevasse channel probably originated as an early axis of sedimentation, and carried sediments across the prograding "crevasse lobe" to a minor delta front some distance to the east-north-east (*cf.* Elliott, 1974).

The lens-shaped sandstones (Plate 6.10) may represent minor crevasse "offshoots" from the channel (Fig. 6.30).

The basin was a maximum of about 7 m deep, though probably somewhat less than this, accounting for synsedimentary subsidence. In contrast to the underlying interval at this locality, no rootlets were present within the sequence except in the Bottom Tilley seatearth, possibly indicating a slightly greater depth of water in the post-Top Busty basin.

From a comparison of the post-Bottom Busty and post-Top Busty sequences at Cabin House/Mown Meadows, the latter example is thought to represent a more distal location with respect to the source of crevasse sediment. This is evident from the lack of high-energy sedimentary structures and rootlets, and abundance of gradationally-based sandstones in the Top Busty-Bottom Tilley interval (Figs. 6.25, 6.30, Appendix 1).

6.7.2.4 Cobey Carr Quarry

Description

At Cobey Carr Quarry (G.R. NZ 209340), (Fig. 6.2), the Top Busty-Bottom Tilley interval comprises a 6.0 m coarsening upward sequence (Fig. 6.31). A basal rhythmically-laminated claystone/silty claystone (Unit 2; Fig. 6.31), (Plate 6.11), overlain by sharply-based silty claystone with sandy streak, ripple form sets and occasional vertical burrows, coarsens over a vertical distance of 2.5 m into fine-grained sandstone with carbonaceous laminae (Unit 3). This sandstone contains abundant ripple cross-lamination the sets of which show wave influence, synsedimentary deformation, *Planolites* and other burrows. Small (up to 5 cms in diameter) siderite nodules are present throughout the sequence, except in the uppermost 0.6 m or so of heavily rootleted Bottom Tilley seatearth.

The sediments show little variation along the 100 m quarry face, and sandstone layers as thin as 5 mm can be traced laterally for at least several tens of metres. Current ripple cross-lamination indicates sediment transport towards both the north-east and south-south-west, with a minor contribution towards the north (Fig. 6.31).

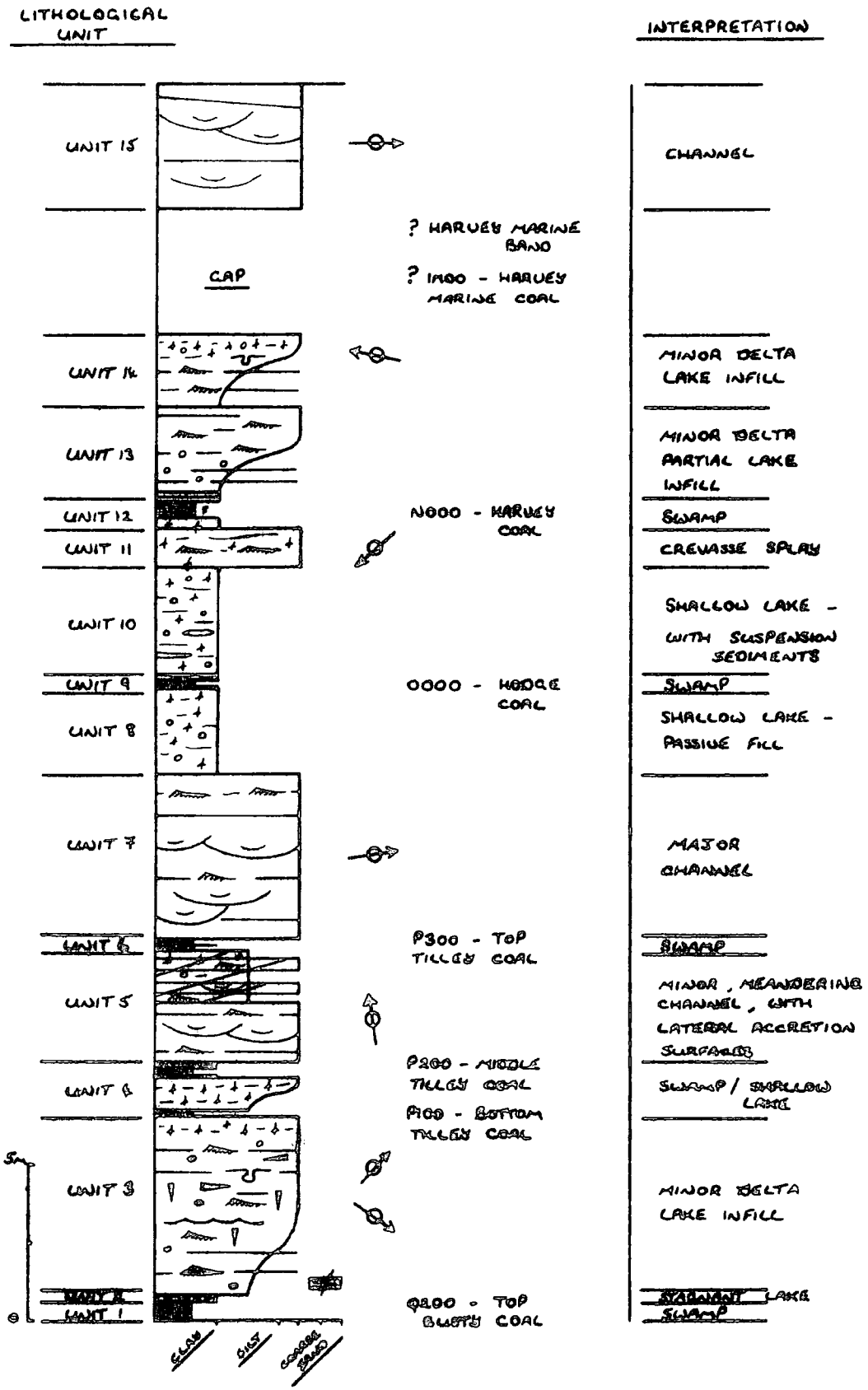
Interpretation

The fine-grained, rhythmically-laminated sediments exposed at the base of the Cobey Carr section (Unit 2) were probably deposited by a ? seasonal alternation of rapid fallout from suspension or low-energy tractional currents and slow fallout of clay grade sediment from suspension, in a standing body of water, (see also Chs. 6.5.2.2 and 7.9.2.4; Woodland O.C.C.S. and Edmondsley O.C.C.S., respectively). Tractional currents then began to deposit coarser material, and while evidently intermittent, from the interlaminated nature of Unit 3, became increasingly powerful and frequent. Waves probably redistributed some sediment in between current events, as shown by the

Fig.6.3I

COMPOSITE VERTICAL SECTION - COREY CARR QUARRY

(G.R.NZ209340) (BASED ON SECTION 241 :- APPENDIX I)



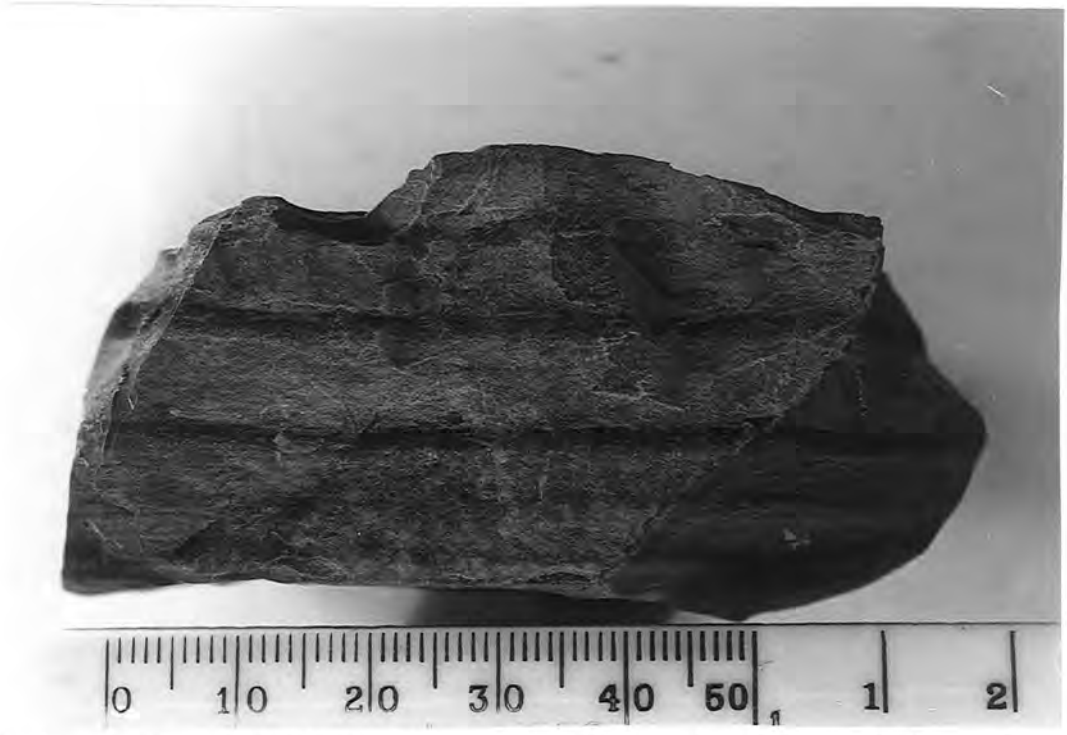


Plate 6.II - Rhythmically interlaminated claystone and silty claystone from immediately above the Top Busty coal, Cobey Carr Quarry. Scale divisions in mm.



Plate 6.I2 - Load-casted sandstone from the Top Busty - Bottom Tilley interval, Binchester Crags.
Scale divisions in mm.

wave-influenced cross-lamination and the bidirectional nature of palaeocurrents.

The exposed sequence is interpreted as the deposits of overbank floods and minor, crevasse-initiated deltas which prograded north-east and south-west-westward across a shallow, lacustrine basin. This is evident from the coarsening-upward nature of the sequence, the preserved sedimentary structures, the palaeocurrent distribution and comparison with vertical sequences of deltaic environments (Elliott, 1974; Heward, 1976), (Fig. 3.2). Water depth in the lake was no more than 6 m, before infilling commenced.

The position of the Cobey Carr exposure on the minor delta(s) with respect to the initial source of sediment, is considered to be distal, from the gradual coarsening-upward nature of the sequence, the comparative abundance of wave-infuenced ripples and burrows, and the lack of erosive contacts and high-energy sedimentary structures (compare Fig. 6.31 with Figs. 6.25, 6.27, 6.30).

The sequence probably accumulated beyond the influence of early crevasse pulses, and coarsened upward as a result of sedimentation on a minor mouth bar(s), perhaps fed by crevasse channels, as minor delta "lobes" advanced forward. The minor, northward-directed palaeocurrent component is interpreted as the result of wave action during lapses in current activity, produced by onshore (northward)-directed winds.

Loading affects the sandstone-dominated part of Unit 3, and is interpreted as the result of dewatering caused by rapid deposition of sand over water-saturated sediments.

6.7.2.5 Binchester Crags

Description

Binchester Crags (G.R. NZ 209331-209324), (Fig. 6.2) are a series of natural exposures on the banks of the River Wear. There, a 7 m sequence of sediments above the Top Busty coal is exposed. The outcrop on the east bank does not include the Top Busty coal itself, but does expose the overlying Tilley seams (Fig. 6.32).

The outcrop consists of interlaminated and interbedded siltstones and very fine-grained sandstones. Many individual beds are traceable laterally over as much as 100 m. The siltsones contain a sandy "streak", and the sandstones abundant ripple cross-lamination and ripple form sets (Unit 1:- Fig. 6.32). Some 5-10 cm thick sandstones display prominently loaded bases and convolute internal lamination (Plate 6.12).

Oblong to lens-shaped bodies of very fine-grained, well-indurated sandstone occur at the same horizon at five localities, over a lateral distance of about 100 m (Plate 6.13). These sandstone lenses (up to 3.2 m wide and 1.3 m thick) are mostly composite, and contain abundant ripple and climbing ripple cross-lamination, synsedimentary micro-faulting, occasional small (0.1 m) trough cross-sets and deformed bedding. They are often erosively-based, as are the bases of individual units within them. Some of these units extend beyond the margin of the sandstone body, where they taper somewhat, and may be traced laterally for up to 100 m in the interlaminated/interbedded sediments. Other units, however, are truncated abruptly at the edge of the sandstone body.

Rootlets are occasionally present in the interbedded sediments, particularly adjacent to the margins of the sandstone lenses. The uppermost 1.0 m or so of the sequence is mottled and heavily pene-

Fig.6.32

COMPOSITE VERTICAL SECTION - BINCHESTER CRAGS

(G.R.NZ209324 - 20933I) (BASED ON SECTIONS 191, 192, 193 :- APPENDIX I)

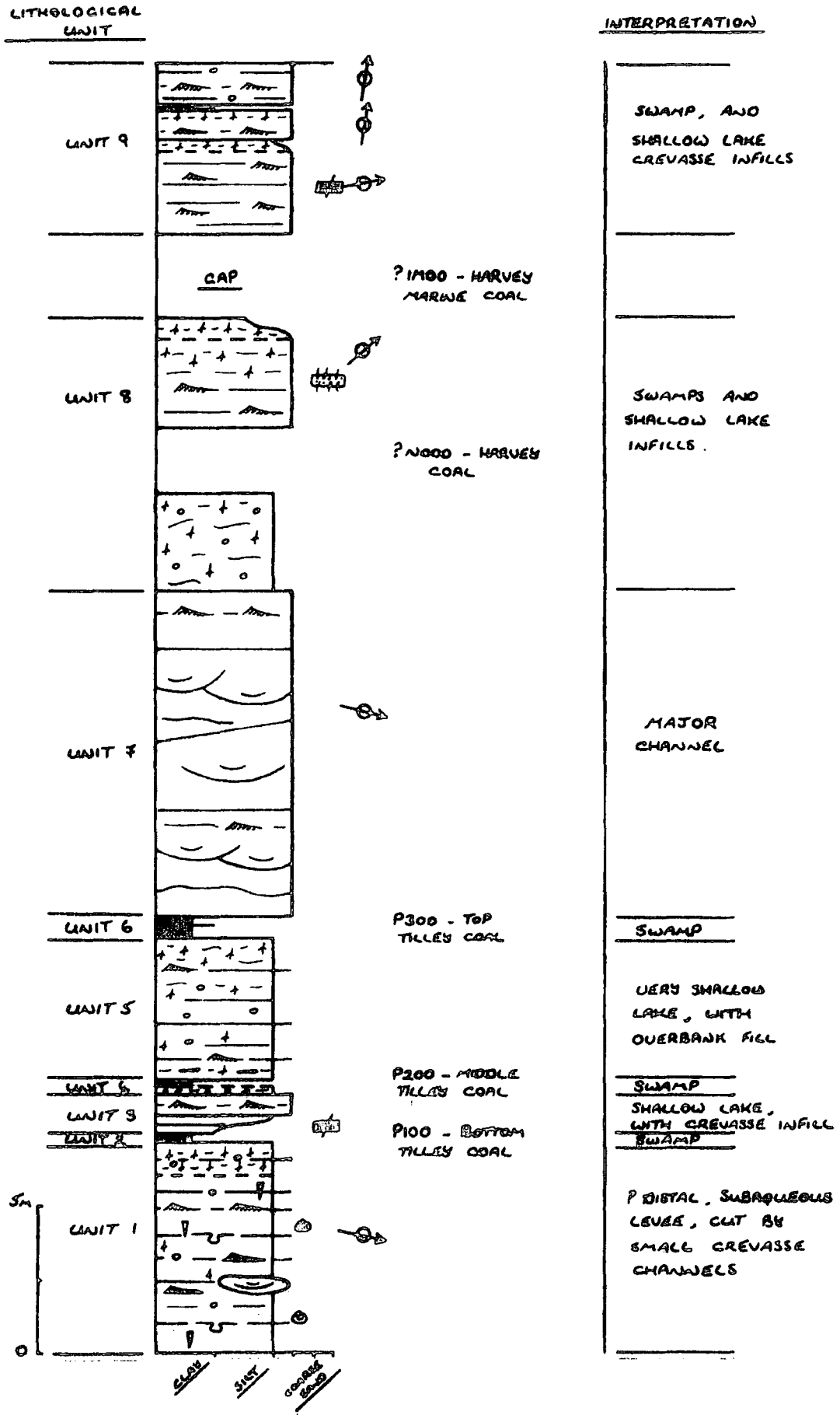




Plate 6.I3 - Two-storey, lens-shaped sandstone set in thinly interbedded sediments, Top Busty - Bottom Tilley interval, Binchester Crags. Hammer is 30cms long.



Plate 6.I4a - View of the Middle Tilley coal at Rowley O.C.C.S. Two intra-seam "bands" of kaolinitic claystone stand out as thin, rusty-weathering units. Rucksack is 35cms high. (See also Plate 6.I4b & c).

trated by rootlets, representing the Bottom Tilley seatearth.

Ripple cross-lamination indicates that palaeoflow was predominantly towards the east-south-east, both within and outside the sandstone lenses. A minor component was also directed towards the north-east.

Petrographically, the sandstones have been extensively cemented by siderite, which has all but destroyed the original fabric (Appendix 2).

Interpretation

The Binchester Crags sequence was deposited by an alternation of gentle tractional currents, which deposited silt-grade material and stronger currents, which deposited thin sand laminae and discrete sand units up to 0.15 m thick. The sandstone lenses were deposited by localized, erosive currents.

The interbedded/interlaminated succession is interpreted as the result of overbank sedimentation in a very shallow lacustrine setting. The repeated alternation of lithologies throughout the sequence supports an overbank, rather than a distal, minor delta, interpre-
-tation. The occurrence of rootlets indicates the very shallow nature of this basin, and non-marine bivalve remains and burrows imply a relatively well-oxygenated lake bottom. Load casting in some sandstone layers is interpreted as the result of dewatering of fine-grained sediment after rapid deposition of fine sand units above. No preferred orientation of load cast axes was observed, perhaps implying a lack of significant palaeoslope (Anketell, Cegla and Dzulynski, 1970).

The sandstone lenses are interpreted as varyingly orientated sections through small crevasse channels, some of which were probably cut and filled by a single event, whilst others were subsequently

reoccupied, forming single-storey and multi-storey bodies respectively. The low width:depth ratio of these channels (8:1-3:1) is interpreted as a result of rapid incision through relatively cohesive sediments which inhibited the lateral migration of channels. Climbing ripple cross-lamination, loading, micro-faulting and convolute lamination suggest rapid deposition in these channels, and some flows evidently extended beyond the channels to deposit thin layers of sand over the surrounding area. The occurrence of all five lenses at the same horizon implies that they formed at approximately the same time.

The consistent east-south-east-directed palaeoflow implies a common source for the interlaminated sediments and the sandstone lenses. It is suggested that a channel perhaps a km to the west debouched sediment eastward by overbank flooding, and occasionally (possibly only once) burst its banks, leading to the formation of a series of small crevasse channels.

Eventually the channel system was abandoned, and in the absence of sediment supply to the area, peat swamp conditions were established, leading to the accumulation of the Bottom Tilley peat. The extensive occurrence of siderite cement in the Binchester sediments may be due to their originally high organic matter content (including rootlets), and it is possible that peat swamp conditions were only prevented from being established earlier by the periodic supply of sediment from the west.

6.7.2.6 Deborah O.C.C.S.

Description

At Deborah O.C.C.S., the interval between the Top Busty (or its' presumed horizon; see Ch. 6.6.4.3) and Bottom Tilley coals comprises

around 10 m of poorly-laminated claystones, containing lenses and nodules of sideritic ironstone (Unit 3; Fig. 6.27). In some parts, a thin, unnamed coal (up to 0.10 m thick), designated 1POO by the N.C.B., occurs 1-2 m from the top of the sequence (Unit 4), underlain by a seatearth. The sediment between the 1POO and Bottom Tilley coals, or the top 1-2 m of the claystone sequence, is also heavily penetrated by rootlets, marking the Bottom Tilley seatearth (Unit 5).

Borehole records indicate that towards the western edge of the site (Area A; Enclosure 4), the parting increases to as much as 18 m, compensating for a thinning of the underlying interval (see Ch. 6.6.4.3, Enclosure 5). In this region, the section is also said to contain units of sandstone.

Interpretation

The described sequence was deposited largely from suspension, and is interpreted as having been laid down in a shallow, slowly, subsiding, lacustrine basin, probably over a long period of time. Evidently this basin was too distant from contemporary channels and minor deltas to have been affected by them, and was starved of sediment coarser than clay grade.

The thickening of the sequence in Area A is interpreted as the result of accelerated subsidence of the thickened and amalgamated Busty peat seam(s) in that area (Ch. 6.6.4.3) and thus represents a further example of the "see-saw" effect first documented in Ch. 6.5.4 (Fig. 6.23, Enclosure 5). The occurrence of the thin 1POO coal in the west of the site, was also seemingly related to this pattern of differential subsidence (Enclosure 5).

6.7.3 The Tilley coals

The Tilley coals (POOO: see Fig. 6.1) probably represent the most complicated group of seams in the Durham coalfield.

I.G.S. geologists divide the Tilley group into Bottom and Top Tilley coals, each of which is said to split into component leaves in many areas. In practice, the distinction between a Bottom and Top Tilley is commonly impossible to make. Rather, a sequence of up to eight coal seams occurs, separated by up to 15 m of clastic sediments.

The various coals split and rejoin over very short distances, and there seem to be few regional trends in the pattern of seam splits. The Tilleys do, however, deteriorate in thickness and quality towards the offshore extension of the Durham coalfield.

Individual "leaves" reach a maximum of 1.5 m, but most are thinner. The Tilleys are commonly composite, banded seams, containing partings of various lithologies, notably of kaolinitic, "flinty" claystone.

Sulphur values in the Tilley coals are highly variable, but commonly quite high, particularly in the south. Values encountered ranged from 0.69-3.37%.

Eight localities exposing the Tilley coals and the sediments between them were visited; Rowley O.C.C.S., Deborah O.C.C.S., Cabin House O.C.C.S., Mown Meadows O.C.C.S., Cobey Carr quarry, Binchester Crags, Esh Winning O.C.C.S. (G.R. NZ 199428) and Buckhead O.C.C.S. (G.R. NZ 133243),(Fig. 6.2, Appendix 1).

6.7.4 Sediments between the Tilley coals

6.7.4.1 Rowley O.C.C.S.

Description

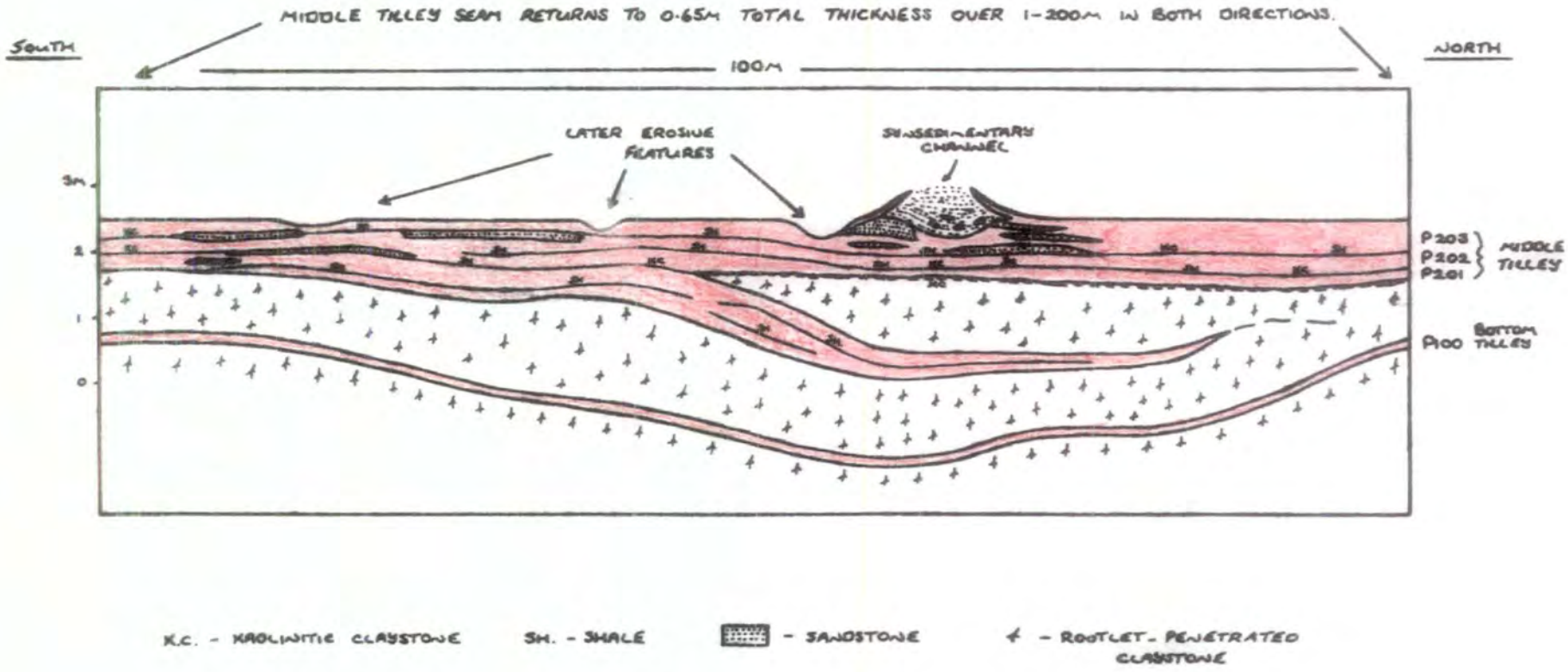
At Rowley O.C.C.S., three Tilley seams occur, and are separated by between 4.5 m and 7 m of clastic sediments in total (Fig. 6.26). These coals, and their enclosing strata, are characterized by frequent, rapid lateral changes in character, and with this in mind, Rowley site was chosen for particularly detailed study. The Tilley seams were extracted at Rowley by a series of long, north-south-trending "cuts", which were visited by the author at intervals between October 1979 and May 1981. Data from measured vertical sections and field notes is presented as a series of longitudinal sections (Enclosure 6) representing an intensely-studied area 750 m north-south by up to 200 m east-west (see also Appendix 1 and Enclosure 3).

The Bottom Tilley coal (P100) is an unbanded seam of 0.10-0.20 m, separated from the Middle Tilley seam by about 1.0 m of heavily rootleted claystones and silty claystones (Unit 5; Fig. 6.26). Abundant siderite nodules are present, some of which are elongated vertically. In one elongate area in the southern part of the site, this parting is increased to as much as 2.0 m, and contains an extra coal seam which thickens progressively and unites with the Middle Tilley to the south (see for example, Cut A8 South in Enclosure 6), (Fig. 6.33). In the same area, the overlying Middle Tilley coal is almost doubled in thickness.

The Middle Tilley coal (P200), (Unit 5) over much of Rowley O.C.C.S. comprises three "leaves" totalling about 0.65 m, separated by thin (up to 0.05 m thick) "bands" composed usually of kaolinitic

Fig.6.33

DETAILED LONGITUDINAL PROFILE OF THE MIDDLE TILLEY COAL AT ROWLEY O.C.C.S. (Cut A6S - See Enclosure 6)



claystone, although "normal" clastic lithologies also occur (Plate 6.14).

In hand specimen, the kaolinitic claystones usually comprise irregular to ovoid-shaped, light brown-coloured masses of clay grade material up to 2 cms in length, set in a "matrix" of dark grey, carbonaceous claystone. This commonly gives the lithology a conglomeratic appearance (Plate 6.14), and, indeed, has led to the coining of the term "fragmental clayrock" used to described these kaolinitic claystones (Richardson and Francis, 1971). On bedding plane surfaces, the impressions of rootlets are common, as are rootlet "hairs" on vertical surfaces. The kaolinitic claystones are usually well-indurated, and stand out in outcrop as sharply-bounded, brown-coloured bands in the Middle Tilley seam (Plate 6.14).

In thin section, the kaolinitic claystones are composed of varying proportions of cryptocrystalline to coarsely crystalline kaolinite, quartz and heavy mineral grains, and organic material (Appendix 2).

Kaolinite occurs in three forms; crystals, granules ("graupen") and groundmass. Discrete kaolinite crystals, some of which are vermicular in form (Plate 6.15), are generally up to 1.0 mm in diameter. Granules or "graupen", composed of aggregates of cryptocrystalline or microcrystalline material in optical continuity, range up to 2.0 cms in diameter and are usually lensoid or elongate-ovoid in cross-section (Plate 6.16). Groundmass iscomposed of finally crystalline or cryptocrystalline kaolinite admixed with organic matter, occasionally orientated prarallel to the unit contacts (Plate 6.17).

X-Ray Diffraction analysis indicates that kaolinite may occur in several structural forms, from disordered to highly ordered (Appendix 2).



Plate 6.I4b - Close-up of a kaolinitic claystone "band" from the Middle Tilley coal, Rowley O.C.C.S. Scale divisions in mm.

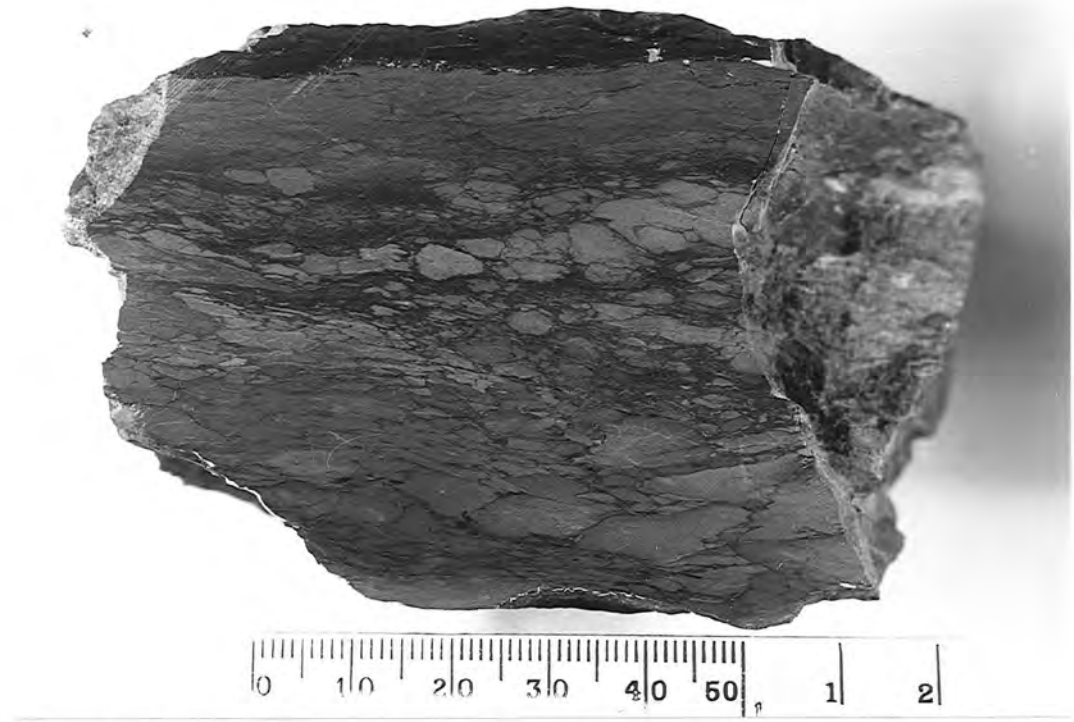


Plate 6.I4c - Close-up of a kaolinitic claystone "band" from the Middle Tilley coal, Mown Meadows O.C.C.S. Scale divisions in mm.



Plate 6.I5 - Vermicular kaolinite crystals in kaolinitic claystone, Middle Tilley coal, Rowley O.C.C.S. Length of photomicrograph I.2mm. (Plane polarized light).

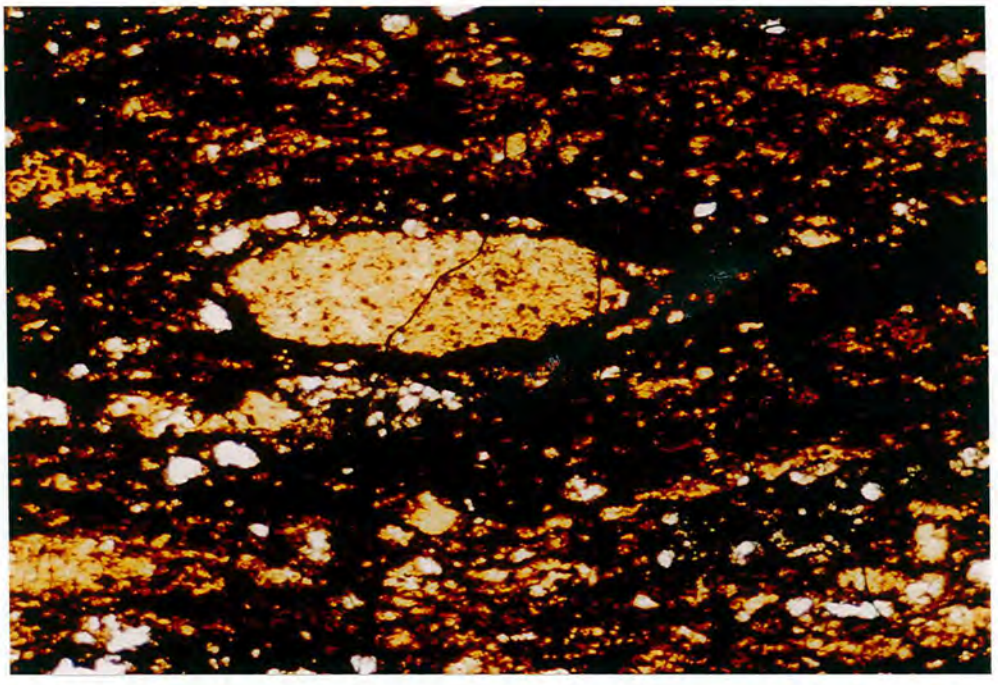


Plate 6.I6 - "Graupen" (granules) of microcrystalline kaolinite in kaolinitic claystone, Middle Tilley coal, Rowley O.C.C.S. Length of photomicrograph I.2mm. (Plane polarized light).

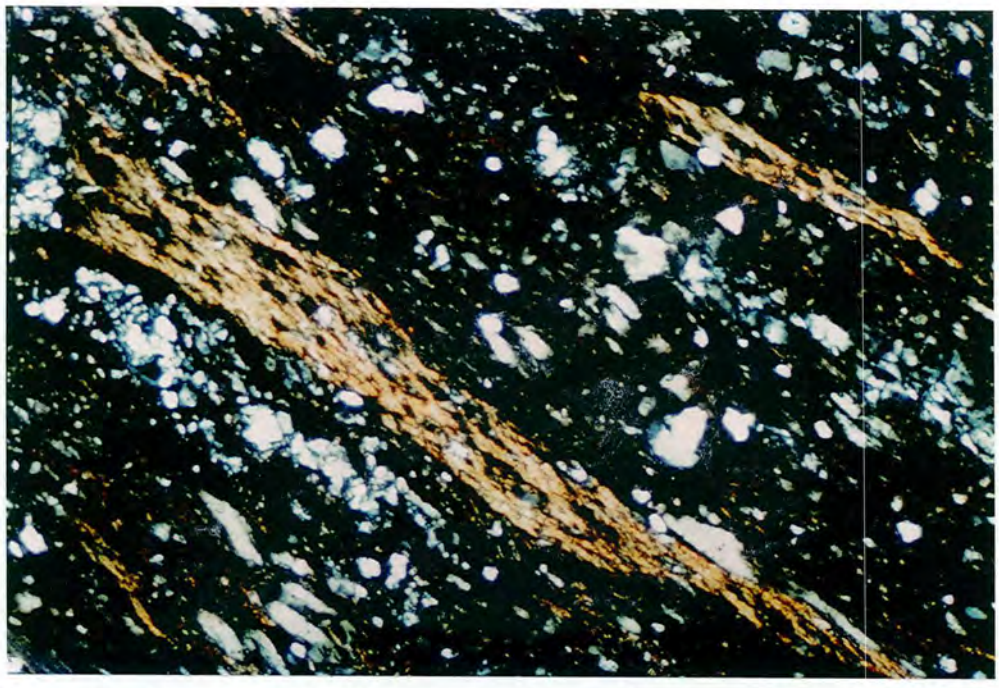


Plate 6.I7 - Kaolinite groundmass in kaolinitic claystone, showing preferred orientation (lamination), Middle Tilley coal, Rowley O.C.C.S. Length of photomicrograph I.2mm. (Plane polarized light).

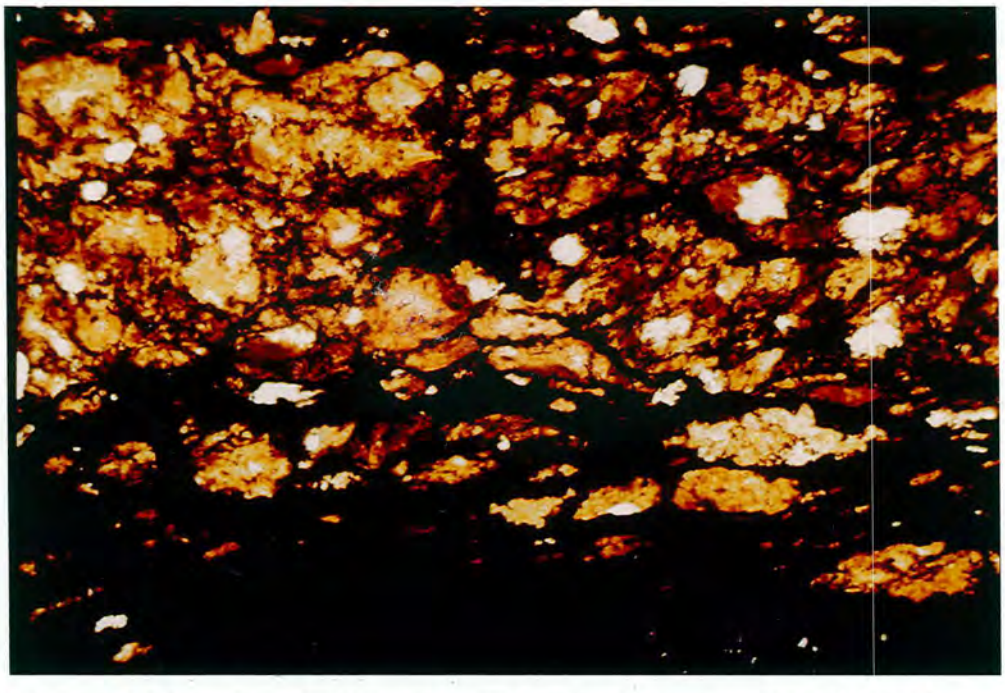


Plate 6.I8 - Gradational contact between kaolinitic claystone and coal, Middle Tilley, Rowley O.C.C.S. Length of photomicrograph I.2mm. (Plane polarized light).

Organic material may occur as discrete areas or laminae, as scattered particles in kaolinite graupen and groundmass, or as a brown staining of humic matter on kaolinite masses. Rootlet casts can occasionally be seen penetrating the sediment.

The proportion of organic matter and kaolinitic groundmass in a given claystone band commonly decreases upward through the unit and is compensated for by an upward increase in the graupen/crystal content of the rock.

"Accessory" phases include scattered quartz grains up to 0.12 mm in diamater, which vary from well-rounded to splinter-like in shape and are often contained within graupen (Plate 6.16), and rare, usually well-rounded, heavy mineral grains, including zircon, tourmaline and opaques. Inclusions of opaque minerals and apatite are commonly found contained within graupen or individual crystals of kaolinite.

Unit contacts, which appear to be sharp in hand specimen, can often be seen in thin section to be sharply gradational or transitional (Plate 6.18).

The distribution of kaolinitic claystone "bands" within the Middle Tilley coal varies considerably when traced laterally. While over much of the site, the seam is directly underlain by one band and contains two more (Plate 6.14), in one area the number of partings increases to as many as seven, concomitant with a 120% increase in the thickness of the coal (Enclosure 6, Fig. 6.33).

The sharply-defined "bands" of kaolinitic claystone may grade laterally into units of fine-grained sandstone (Plate 6.19) or into more diffuse partings of claystone/siltstone, particularly in areas later occupied by small channels. The sandstones are typically



Plate 6.I9 - View of the Middle Tilley coal at Rowley O.C.C.S., showing localized, sandstone intra-seam "bands". Hammer is 30cms long.



Plate 6.20 - Conglomerate and sandstone-filled minor channel, causing partial erosion of the Middle Tilley coal, Rowley O.C.C.S. (Section OIO). Hammer is 30cms long.

massive in hand specimen, and in thin section are characterized by an usually high proportion of cement (Appendix 2).

Apart from the thickening of the Middle Tilley coal mentioned above, this seam also displays several other notable lateral variations:

(1) at the north end of one cut (A6N; see Enclosure 6) a poorly-exposed split near the top of the seam was exposed, the upper "rider" being separated from the main seam by up to 2.1 m of fine-grained, trough cross-bedded and ripple cross-laminated sandstone,

(2) in the southern part of the site (Cut A8S; see Enclosure 6), the Middle Tilley seam is not present over an area some 90 m wide, in which the claystones of the underlying Bottom-Middle Tilley parting are not rootlet-penetrated, and towards which the individual leaves of the Middle Tilley Seam (separated by kaolinitic claystone "bands") gradually pinch out,

(3) further south still, the coal is partially "washed out" in a number of zones up to 25 m wide, the remaining part of the seam being erosively overlain by crudely stratified fine-to-coarse-grained sandstone and pebble conglomerate (Plate 6.20, Enclosure 6; see for example, Cut A5S),

(4) at certain localities, small, normal fualts with displacements of up to 0.15 m occur in the upper part of the seam, always where the coal is directly overlain by sandstone. These faults cause slight variations in seam thickness (Enclosure 6; see for example, Cut A7S).

Overlying the Middle Tilley coal across much of Rowley O.C.C.S. is an abruptly- or erosively-based fine-grained sandstone (Fig. 6.26; Unit 6), which varies considerably in thickness, and dies out laterally in places. Towards the south end of the site, the sandstone thickens from 0.5 m to 3.0 m over a lateral distance of 20-40 m, thins to about 1.0 m over a similar distance and then climbs up the succession to rest directly beneath the Top Tilley coal, some 5.0 m above (Plate 6.21, Enclosure 6; see, for example,Cut A8S). Abundant shale clasts up to 0.05 m in diameter are contained within this sandstone.

Above the sandstone, or above the Middle Tilley coal where the sandstone does not occur, the succession up to the Top Tilley coal comprises 2-5 m of poorly-laminated siltstones, interbedded with occasional, up to 0.20 m thick, units of fine-grained sandstone (Fig. 6.26; Unit 7). Some of these sandstone beds have erosive lower contacts, and cut through earlier-deposited sediments. The reader is referred to Enclosure 6 for precise geometrical and other details of sedimentary units.

The interbedded siltstones and sandstones contain ripple cross-lamination, occasional small-scale trough cross-bedding and symmetrical, sharp-topped ripples. Well-preserved plant remains, including complete pteridosperm fronds, are common, and small siderite nodules are locally abundant.

At several localities, upright or inclined *in situ* plant casts are preserved, dominantly of small (up to 0.4 m high) *Calamites*, attached to their root systems (Plate 6.22, Enclosure 6; see, for example, Cut A8S). At certain localities (for example, Section 167 on Cut A9N; see Enclosure 6), inclined casts of trees were preserved *in situ*. The uppermost 1.0 m or so of Unit 7 is heavily rootlet-



Plate 6.2I - View of southern margin of minor distributary channel above the Middle Tilley coal at Rowley O.C.C.S. (Cut A8S, facing north-west). The channel is defined by a depression of the overlying Top Tilley coal (T). Inclined beds in the left half of the photo (I) are overbank and crevasse splay deposits.



Plate 6.22 - Inclined, <u>in situ Calamites</u> embedded in overbank siltstones, Middle - Top Tilley interval, Rowley O.C.C.S. 30cms of tape exposed.

penetrated, and forms the seatearth to the Top Tilley coal. Towards the southern limit of the site, however, rootlets are preserved down to 2 m below the Top Tilley, and can be seen to have developed on a number of sediment surfaces.

In the northern part of the opencast, erosively-based channels cut through the Top Tilley coal and erode into the underlying siltstones (see, for example, Cut A6N; Enclosure 6). These represent post-Top Tilley sedimentation, and are considered later (Ch. 6.8.2).

Palaeocurrent measurements from a variety of current-formed sedimentary structures, inclined, *in situ* plant casts and drifted plant debris are plotted on Figs. 6.34 and 6.35, and show a variable direction of palaeoflow, from east- to southward-directed. The crests of wave-produced ripples strike in an east-west direction.

Interpretation

The Rowley sediments were laid down under a variety of conditions ranging from high-energy, confined and unconfined flows, leading to deposition of erosively-based, channelized and sheet sands respectively, to quiet-water situations in which peat was able to accumulate virtually uninterrupted.

The exposed sequence is interpreted as having been deposited in shallow lacustrine and swamp environments, which were crossed by minor distributary and crevasse channels. The channels filled adjacent shallow basins by means of overbank, ? levee, crevasse splay and minor delta activity, formaing a platform for peat development.

Following fairly even accumulation of Bottom Tilley peat across the area of the site, a period of quiet-water deposition of clays and silty clays ensued. Colonization by plants recurred, and the Middle Tilley peat began to accumulate.

Fig.6.34

SEDIMENTATION ABOVE THE MIDDLE TILLEY COAL

- ROWLEY O.C.C.S. a) Early stage.

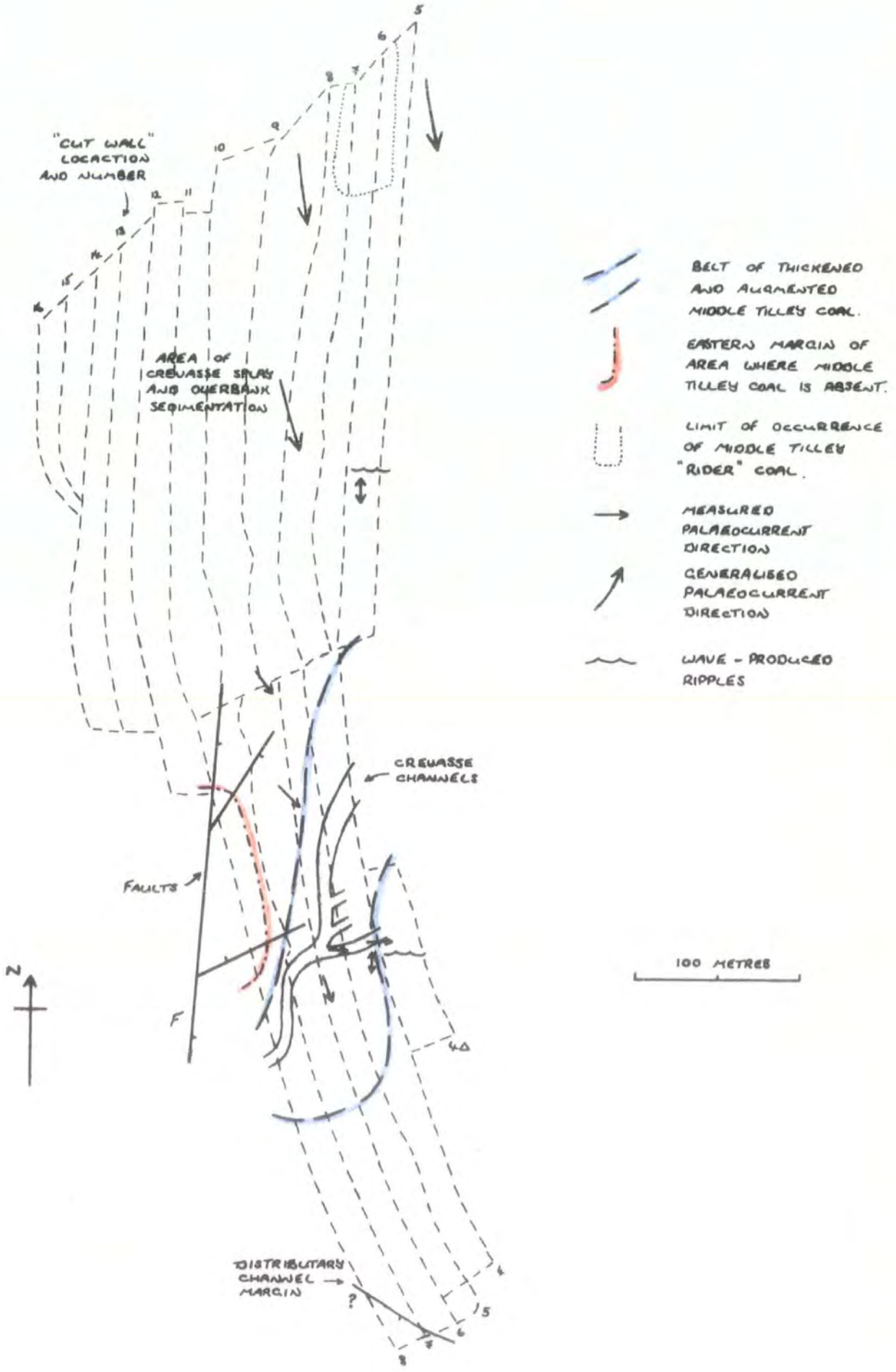
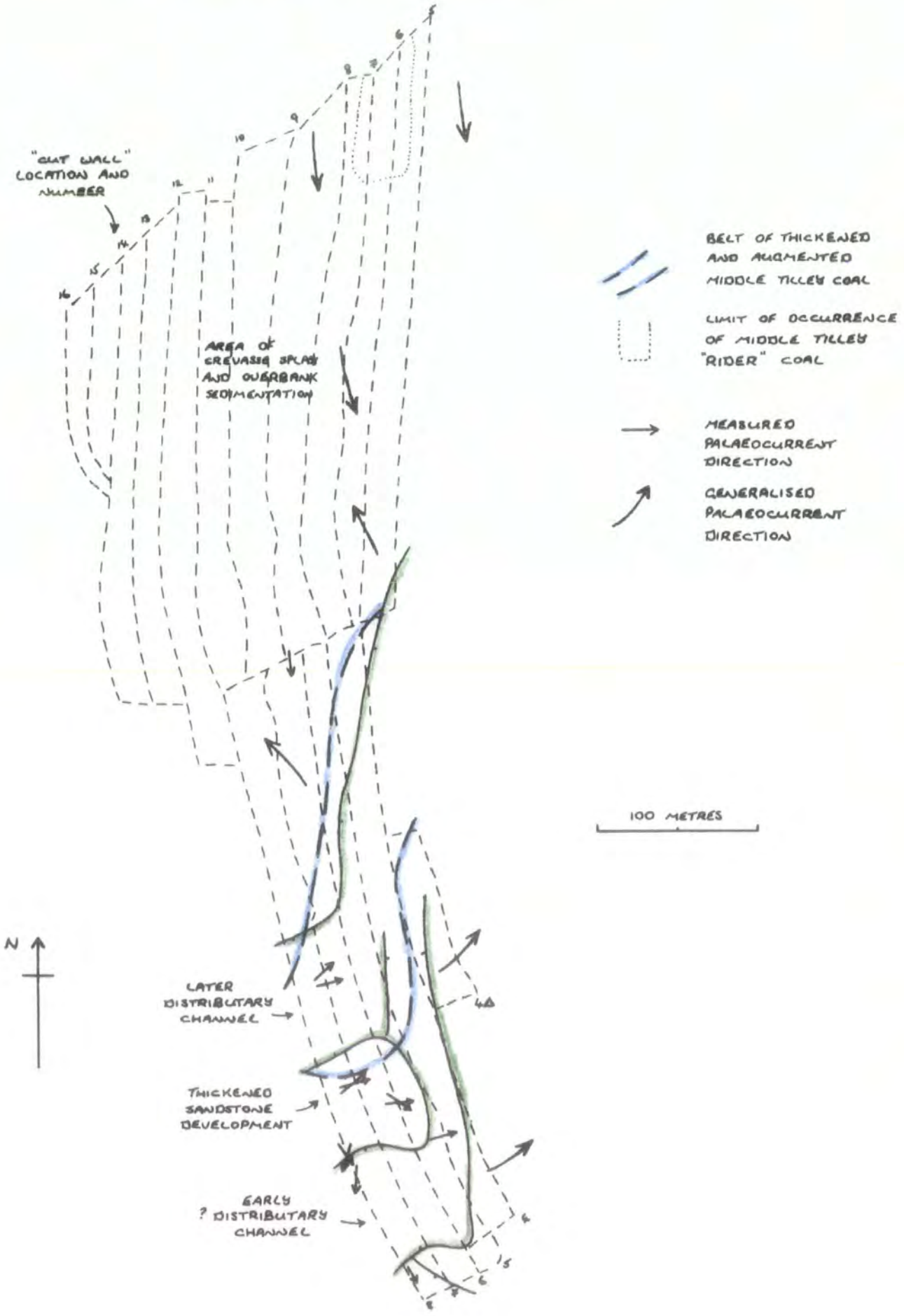


Fig.6.35

SEDIMENTATION ABOVE THE MIDDLE TILLEY COAL

- ROWLEY O.C.C.S. b) Later stage.



The diachroneity of the Middle Tilley is illustrated by the "extra seam" in the south of the site, and the arrangement of coal "leaves" and intervening "bands" illustrates that peat accumulated in the south while clastic material was still being deposited further north (Fig. 6.33). Eventually, after more clastic deposition, peat swamp conditions became established across virtually the entire area.

However, towards the centre-west of the opencast, no Middle Tilley coal is preserved (Enclosure 6; Cut A8S) and the thinning of the coal leaves, as defined by the kaolinitic claystone bands, possibly implies that the peat never accumulated, due to a subsidence rate which exceeded the rate at which peat could accumulate. Immediately south of the area of thinning and no coal, the Middle Tilley is thickened by as much as 120%, in an elongate belt trending approximately north-south (Fig. 6.34), and the thickness of the Bottom-Middle Tilley claystone parting decreases northward with that of the Middle Tilley coal towards the area of no coal. This implies that the area where the Middle Tilley is absent was one of comparatively slow, rather than rapid, subsidence.

An alternative and more likely explanation for the absence of the Middle Tilley seam in Cut A8S lies in a complex of minor faults in this area (Fig. 6.34), which may have displaced and disturbed the coal.

The thickened Middle Tilley in the south-centre of the site (Fig. 6.34) is probably a result of slightly enhanced subsidence in the peat swamp, stimulated by the compaction of the underlying "extra seam".

The poorly-exposed "roof split" in the Middle Tilley at the northern limit of the site (Enclosure 6: Cut A6N) is tentatively interpreted as a result of channel or crevasse splay sand deposition, followed by abandonment and plant colonization (Fig. 6.34).

The small, sandstone and conglomerate filled "partial washouts" in the roof of the Middle Tilley are interpreted as the deposits of minor crevasse channels (up to 25m wide) of moderate sinuosity which flowed eastward and northward across the still-existent Middle Tilley peat swamp (Fig. 6.34). The channels are narrow and deep (width: depth ratios vary between 7.1:1 and 12.5:1), possibly due to their being incised into leathery, partly-compacted peat deposits. The channels lie within the zone of inferred accelerated subsidence mentioned above, and it seems likely that their positions were controlled by this subsidence, enhanced by the autocompaction of the thickened peat (Fig. 6.34).

The kaolinitic claystones forming the prominent intra-seam "bands" in the Middle Tilley coal are interpreted as the result of precipitation of kaolinite, possibly from a colloidal gel, beneath and within the peat deposits of the Middle Tilley peat swamp, during or shortly after formation of the peat itself. This conclusion will be discussed at greater length at the end of the present passage.

"Bands" of sandstone and finer-grained clastic lithologies may be explained in any of three ways:

(1) as clastic accumulations within the hydromorphic soil profiles of the peat swamp,

(2) as original detrital material washed into the peat swamp, or

(3) as injected material, squeezed into the peat of the Middle Tilley seam by compactional pressure.

The sandstones are considered unlikely to represent original clastic material, since it is difficult to envisage a non-erosive, yet widespread, accumulation of sand forming in an environment which must have acted as a very efficient sediment filter. Similarly, the sandstones are difficult to imagine as pedogenic features, and are thus interpreted as the result of soft-sediment injection. This interpretation is supported by the almost ubiquitous association of sandstone bands with overlying channel sandstones, and by the structureless, almost clay-supported nature of the sandstone bands.

Claystone and siltstone bands seem unlikely to have been formed by injection, and are thus considered to be either pedogenic or detrital in origin. The former interpretation is perhaps favoured by the very regular spacing of the bands in the Middle Tilley coal, and the lateral passage into kaolinitic clays containing very little quartz.

Peat accumulation eventually ended in the Middle Tilley swamp, and subsidence led to the formation of a shallow lake. Plant-rich, silt-grade sediment then began to accumulate in the southern part of the study area, interpreted as overbank material from nearby channels. It is possible that the southward-inclined sequence of interbedded fine-grained sandstones and siltstones at the extreme southern end of Cut A8S (Enclosure 6) represents part of the fill of the channel from which early overbank sediments, and the small crevasse channels mentioned previously, were derived (Fig. 6.34).

At the same time, crevasse splay sands cut through previously-accumulated peats and sands, and accumulated in the northern part of the site as sharply-based units (Fig. 6.34, Enclosure 6; see, for example, Cut A6N). The source of these latter crevasse splays, lying to the north, is not exposed, but the elongate, narrow form

of individual lobes, inferred from comparison of adjacent exposed "cut walls" (see, for example, Cuts A8N, A6N and A5N on Enclosure 6), implies that the source was quite close, perhaps less than 100 m away.

The next important stage in the development of the Rowley sequence was the switching of a minor distributary channel to a course which crossed the southern part of the site (Fig. 6.35). This channel flowed towards the north and displays some evidence of lateral accretion on the northwestern bank (Enclosure 6; see for example, Cut A8S). Observations on laterally accreted sandstone units give an instantaneous depth for the channel of 1.5-2.0 m, a probable width of 100 m and a width/depth ratio of 50-67/1.

While the north-western bank of the channel was dominantly accretionary, the south-eastern bank was erosive. At the upstream limit of exposure, the composite channel deposit is approximately 220 m wide, but is though to represent an early channel (the southern-most 75 m or so; see Fig. 6.35), which was abandoned by chute cut-off (Allen, 1965b), and a later, slightly straighter channel.

Pioneer communities of *Calamites* began to grow on the floor and banks of the abandoned early channel. Influxes of sediment from the later channel intermittently inundated the plants and filled the abandoned channel course. The 3 m thick sand body between the two channel courses was probably a deposit of the early channel, which subsequently formed the erosive bank of the later channel. The location of the later channel seems to have been controlled partly by the existence of this sand body, and partly by rapid subsidence in the area of thickened peat, mentioned previously (Figs. 6.34, 6.35).

The fill of the later channel, like that of the earlier one seems to be largely an abandonment fill of claystones and silty claystones. Occasional fine sandstones may indicate an "incomplete" abandonment of the channel (Meckel, 1972).

The exposed channels show great similarity in form and sedimentary sequences to the modern "muddy, fine-grained", meandering streams described by Jackson (1981), and ancient analogues described by Guion (1978) and Stewart (1981a, b). Accretionary and erosive channel margins, chute cut-off and incomplete channel abandonment are all features associated with sinuous or meandering channels (Allen, 1956b; Collinson, 1978).

The channels distributed sediment northwestward and probably also southeastward across the surrounding floodbasin in the form of overbank, crevasse splay and crevasse-initiated minor delta deposits, forming the plant-rich silts, sharply-based sandstones and small-scale coarsening-upward sequences, which occur across much of the site (Enclosure 6). Limited wave reworking took place during quiet periods, as a result of ? northward-directed winds. Wave ripples indicate water depths of 2-3 m and wave fetch of 2-10 kms (using the methods of J. Allen, 1979b; P. Allen, 1981). A minimal water depth is also implied by the abundance of rootlets in various parts of the sequence (Enclosure 6). Similar sediments accumulated in the north of the site which, from the geometry of sandstone beds and the orientation of *in situ*, inclined plants, were derived from the northern source mentioned earlier (Fig. 6.35).

Eventually the channel systems were abandoned, the entire area subsided and the resulting shallow basin was filled with silts and muds which settled out of suspension, and formed a platform for the accumulation of the Top Tilley peat (Enclosure 6).

The Middle-Top Tilley sequence at Rowley O.C.C.S. thus records the operation and abandonment of sinuous, minor distributary channels which flowed across a subsiding floodbasin environment.

The kaolinitic claystones which form intra-seam "bands" in the Middle Tilley coal are interpreted as the result of subsurface, pedogenic or very early diagenetic precipitation of kaolinite within swamp peat deposits, as was briefly mentioned above.

The kaolinite claystone lithology bears considerable resemblance to the "tonsteins" or "kaolin-coal tonsteins" of the East Midlands and of other European coalfiels (Kimpe, 1966; Spears, 1970; Burger, 1980; see also Ch. 4.4). In the tonstein classification of Schuller (1951), the Rowley kaolinitic claystones would be named "graupen tonsteins" or "dichte tonsteins", and would fall into the "Typengruppen" 1 and 2 of Burger (1980),(Fig. 4.3).

The origin of kaolinitic claystones and tonsteins in the British Coal Measures has been variously interpreted as volcanic (Spears, 1970), pedogenic (Moore, 1968b) and the result of early diagenetic modification of swamp and shallow lake clay deposits (Richardson and Francis, 1971). From a list of world-wide occurrences of kaolinitic claystones (Keller, 1981), the outstanding common factor is an association with terrestrial or marginal-marine swamp and marsh environments.

The Rowley kaolinitic claystones are considered unlikely to be volcanically derived, since they are not laterally traceable over distances of greater than about 5 kms, and since they do not display features diagnostic of a volcanic derivation (euhedral feldspar and

quartz grains, restricted heavy mineral assemblages, shard-like quartz fragments, pseudomorphs of kaolinite after biotite and hornblende). The ubiquitous association between a kaolinitic claystone unit and an *overlying* coal at Rowley suggests that the kaolinitic claystones did not form on an unburied sediment surface, but beneath already-formed peat deposits. This is supported by the regular spacing of the bands between coal leaves in the Middle Tilley seam, and by the observation that where a coal seam dies out (e.g., the "extra seam" of the area of P200 thickening), intra-seam bands likewise thin and disappear (Fig. 6.33).

In thin section, the kaolinitic claystones often pass gradationally into coal (Plate 6.18), and the coal of the Middle Tilley seam contains common inclusions and veins of kaolinitic material. These features possibly suggest that peat and kaolinitic material formed simultaneously, or nearly so.

From the above considerations, the Rowley kaolinitic claystones are thus interpreted as having formed within peat deposits either during the active life of the swamp or during early diagenesis. Three observations strengthen this interpretation, and point towards a pedogenic, i.e., syndepositional, rather than diagenetic origin:

(1) The regular spacing of the bands is difficult to imagine as a diagenetic feature,

(2) The displacement of kaolinitic claystone bands by small faults induced by early compaction of the Middle Tilley peat implies that formation of the bands predated the faults, and

(3) The massive, "clay-supported" nature of the local sandstone "bands" is perhaps a result of injection into soft, ? gel-like kaolinite after establishment of crevasse channels in the still-accumulating Middle

Tilley peat.

The source material may have accumulated, perhaps as a colloidal gel, on the (subaqueous) swamp surface, subsequently redistributed and precipitated in the subsurface. Such organic "oozes" are common in modern day swamp, lacustrine and even fluvial settings (Staub and Cohen, 1979; Hyne, Cooper and Dickey, 1979; Jackson, 1981), and kaolinite has been recently discovered in high concentrations beneath freshwater, minor deltaic sedimentary sequences (Hyne, Laidig and Cooper, 1979).

Many authors believe that subaerial, or at least partly-exposed conditions are necessary to form kaolinite in soil profiles, through vertical leaching processes (e.g., Richardson and Francis, 1971). However the subaqueous formation of kaolinite has been advocated by Moore (1968b), among others, and there are no indications of subaerial exposure at Rowley during the time of accumulation of the Middle Tilley coal, although it is possibly that earlier-formed kaolinite could have been introduced into the peat swamp. From the ubiquitous association of kaolinitic claystones with paludal sedimentary environments, it seems that the geochemical conditions necessary for the precipitation of kaolinite (high Si and Al activities, low pH and ? moderate Eh) were commonly fulfilled within hydromorphic swamp peat deposits. Fluctuating groundwater levels in the peat swamps, perhaps controlled by short-term changes in weather or by longer-term climatic changes, may have played a significant part in concentrating the kaolinitic material (Moore, 1968b), and thin layers of detrital material within the swamp peat may have acted as "nuclei" of precipitation.

While the Rowley examples may thus be accepted as sub-peat swamp developments, many other occurrences of kaolinite claystones in the Westphalian A of the Durham coalfield, such as the "laminated" lithology overlying the Bottom Busty coal at Deborah O.C.C.S. (Ch. 6.6.4.3), obviously cannot. In these cases, a stagnant, acidic shallow lacustrine setting is inferred, whereby colloidal gels accumulated with organic matter and fine-grained detrital material, perhaps on the lake bottom, and were subsequently concentrated and transformed to kaolinite in the subsurface (Keller, 1968; Tankard and Horne, 1979).

The subject of kaolinitic claystone origin will be returned to in Ch. 10.

6.7.4.2 Deborah O.C.C.S.

Description

At Deborah O.C.C.S., as at Rowley, three Tilley coals are present, enclosing between 4 and 10 m of clastic sediments. No direct correlation between the Tilley seams at individual localities has been attempted, since the extreme lateral variability of these coals would render such a correlation suspect.

The Bottom Tilley seam (P100) is about 0.10 m thick over much of the site, but increases to at least 0.30 m in the north-west. Seam isopachs trend east-north-east- to - west-south-west, and are similar both in orientation and location to those of the underlying interval (Enclosure 7). Occasional areas of thin coal occur across the site (less than 0.10 m).

The parting between the Bottom and Middle Tilley coals comprises 1-3 m of claystones, siltstones and fine sandstones, most of which is penetrated by abundant rootlets. Ripple cross-lamination

is common in the sandstones, while finer-grained sediments are characterized by abundant siderite nodules (Appendix 1:- Sections, 107, 138). From outcrop and borehole data, isopachs for the interval were constructed, and describe a sinuous, lobate pattern (Enclosure 7).

The Middle Tilley (P200) comprises around 0.20 m of bright coal across much of the Deborah site, but as with the underlying seam, thickens towards the north-west to at least 0.30 m. Isopachs for the seam show an east-west orientation, and have a similar disposition to those for the underlying partings and coal (Enclosure 7). As before, scattered areas of thinned coal occur across the site.

The Middle-Top Tilley interval comprises between 3 and 8 m of clastic deposits, which vary somewhat, laterally (Plate 6.23). Above the Middle Tilley coal, poorly-laminated claystones (which occasionally make up the entire interval; see Section 081 in Appendix 1) are succeeded by up to two coarsening-upward cycles, which are each typically 2-3 m thick (Plate 6.23),(Enclosures 4 and 8).

The coarsening-upward cycles can occasionally be seen to thin and die out laterally along a single face (Plate 6.23), but few regular trends in thickness variation are discernible for individual coarsening-upward cycles or for the entire interval. Approximate limits of the coarsening-upward sequences are shown on Enclosure 8, which also indicates three areas with above-average sequence thickness:

(1) in the extreme north-west,

(2) in the centre of Area D, and

(3) in the extreme south-east.

Limited palaeocurrent measurements from ripple cross-lamination in the lowermost cycle indicate a general southerly direction of



Plate 6.23 - View of the Middle - Top Tilley interval at Deborah O.C.C.S. (Cut D_4 44), facing north, showing two coarsening-upward sequences (CI&C2). The lower sequence (2.2m thick) can be seen to pinch out north-westward.

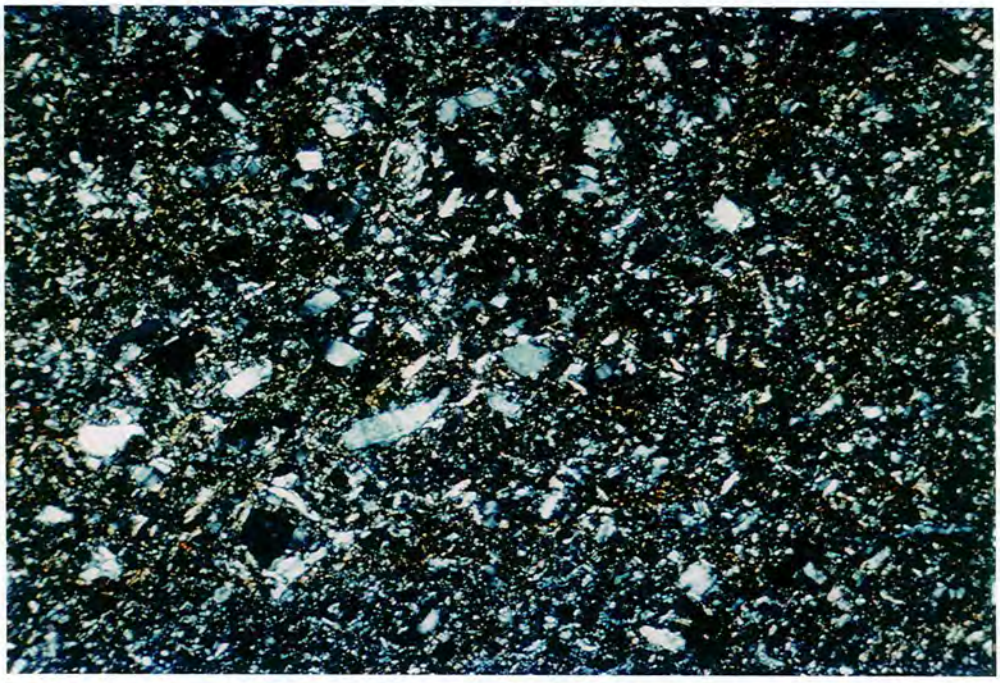


Plate 6.24 - Photomicrograph of Middle Tilley kaolinitic claystone from Mown Meadows O.C.C.S., showing common flecks of white mica. Length of photomicrograph I.2mm. (Crossed polars)

sediment transport.

Where either coarsening-upward unit is absent, its' place is taken in the succession by unlaminated-to-laminated claystones with nodules, and where both are present, the two sequences are separated by a similar lithology.

The uppermost parts of both sequences (where present) display evidence of rootlet penetration and bioturbation. Indeed, where two cycles do occur, the upper one is often completely penetrated by rootlets and Stigmarian roots, which obliterate any primary sedimentary structures (Enclosure 8). The uppermost 0.3 m or so of the interval, representing the upper part of the Top Tilley seatearth, is commonly mottled brown and yellow, particularly in the northern half of the site.

The Top Tilley coal (P300) comprises two leaves separated by a parting of rootlet-penetrated siltstones and claystones 0.20-1.00 m thick (Plate 6.23). A band of light grey, plastic, illitic clay is present near the base of the parting across much of the site (Appendix 2). Occasionally a partly-indurated kaolinitic claystone is also present.

The bottom coal leaf (P301) is about 0.40 m in thickness, and shows no consistent pattern of vaiation (Enclosure 8). The top leaf of the seam (P302) is typically about 0.20 m thick, but is erosionally truncated by an overlying major sandstone.

Interpretation

The Bottom Tilley is interpreted as having formed in an area characterized by differential subsidence. The thickening of the seam and the underlying interval towards the north-west indicates that the accelerated subsidence inferred for the Top Busty-Bottom Tilley interval in this area continued (see Ch. 6.7.2.6). Areas

of thinned Battom Tilley coal might be interpreted as local areas of reduced subsidence in the peat swamp (Enclosure 7).

The P100-P200 parting, being composed largely of claystones and siltstones, was probably laid down by gentle tractional currents and suspension fallout. Occasional, fine-grained sandstone units were deposited by short-lived, and apparently, unconfined currents.

Isopachs for the P100-P200 interval bear little relationship to previously-deposited units, and the sinuous, lobate pattern is interpreted as the result of south-eastward progradation of a crevasse splay lobe across a shallow, subsiding basin (no more than 2.5 m deep; Enclosure 7). This lobe was possibly 750 m wide and at least 1.5 kms long, and its' interbedded deposits suggest it may have been active intermittently over some time. As might be expected, the crevasse lobe appears to originate from the area of accelerated subsidence in the north-west, where a contemporaneous channel may have been located.

The Middle Tilley coal shows a similar thickness variation to that of the Bottom Tilley, indicating that enhanced subsidence continued in the north-west (Enclosure 7). Once again, areas of thinned coal are tentatively interpreted as areas of reduced subsidence.

The P200-P300 parting shows evidence of having been deposited under alternating quiet-water conditions, leading to deposition of poorly-laminated claystones, and relatively higher energy events in which unconfined currents became progressively more powerful, culminating in the deposition of the coarsening-upward sequences described above.

The interval is interpreted as the deposits of a shallow, subsiding, freshwater basin, which filled periodically by minor delta

lobe progradation from the north and north-east. The limits of coarsening-upward sequences, shown on Enclosure 8, define several such lobes, and the vertical stacking pattern of sequences delimits "early" and "later" phases of deposition, although these may not be entirely separated in time.

The largest "early" minor delta lobe, which was of the order of 600 m wide and covered much of Area D, appears to have had a complex sedimentation history, judging by the lateral variability in sequence thickness and complexity of deposit within the lobe (Enclosure 8). In contrast, the south-easterly lobe, which was probably about 150 m wide, displays a more regular pattern, and may represent a single progradational event. The westernmost lobe is possibly the most complex, though data control here is somewhat scattered.

The "early" minor delta sequences generally vary up to 3.2 m in thickness and commonly show signs of rootlet penetration in more proximal areas, indicating that the basin was no more than 4 m in depth. The same is true of the "later" delta lobes, implying that following abandonment of the "early" lobes the surface subsided for a considerable time with little or no sedimentation.

"Later" delta lobes are concentrated in the south-eastern part of the site, and are of the order of 150-400 m wide. Their character suggest again that the possibly represent single depositional episodes. All these minor delta lobes probably represent deposition at the distal end of a well-established, crevasse-initiated, lake infill (Elliott, 1974), and were probably fed by crevasse channels similar to those exposed, for example, above the Busty seams at Cabin House O.C.C.S. (Chs. 6.6.4.1 and 6.7.2.3).

As a result of the "later" phase of minor delta progradation, the shallow basin was completely infilled, allowing plant colonization

over the entire area. The mottled and oxidized upper part of the Top Tilley seatearth in the northern half of the site possibly represents a partly subaerial soil profile, developed on the completely infilled ? landward parts of the basin.

The lack of significant variation in thickness of the Top Tilley coal implies, by this time, more or less uniform subsidence over the area of the Deborah site. The clastic parting in the Top Tilley coal is interpreted as a low-energy clastic influx into an area of subaqueous peat swamp.

The Tilley seams and their enclosing sediments at Deborah O.C.C.S. thus represent the final parts of a saga of differential subsidence and shallow basin formation over this region, initiated by channel sand deposition above the Bottom Busty peat (described in Ch. 6.6.4.3), and concluded with the accumulation of the Top Tilley peat.

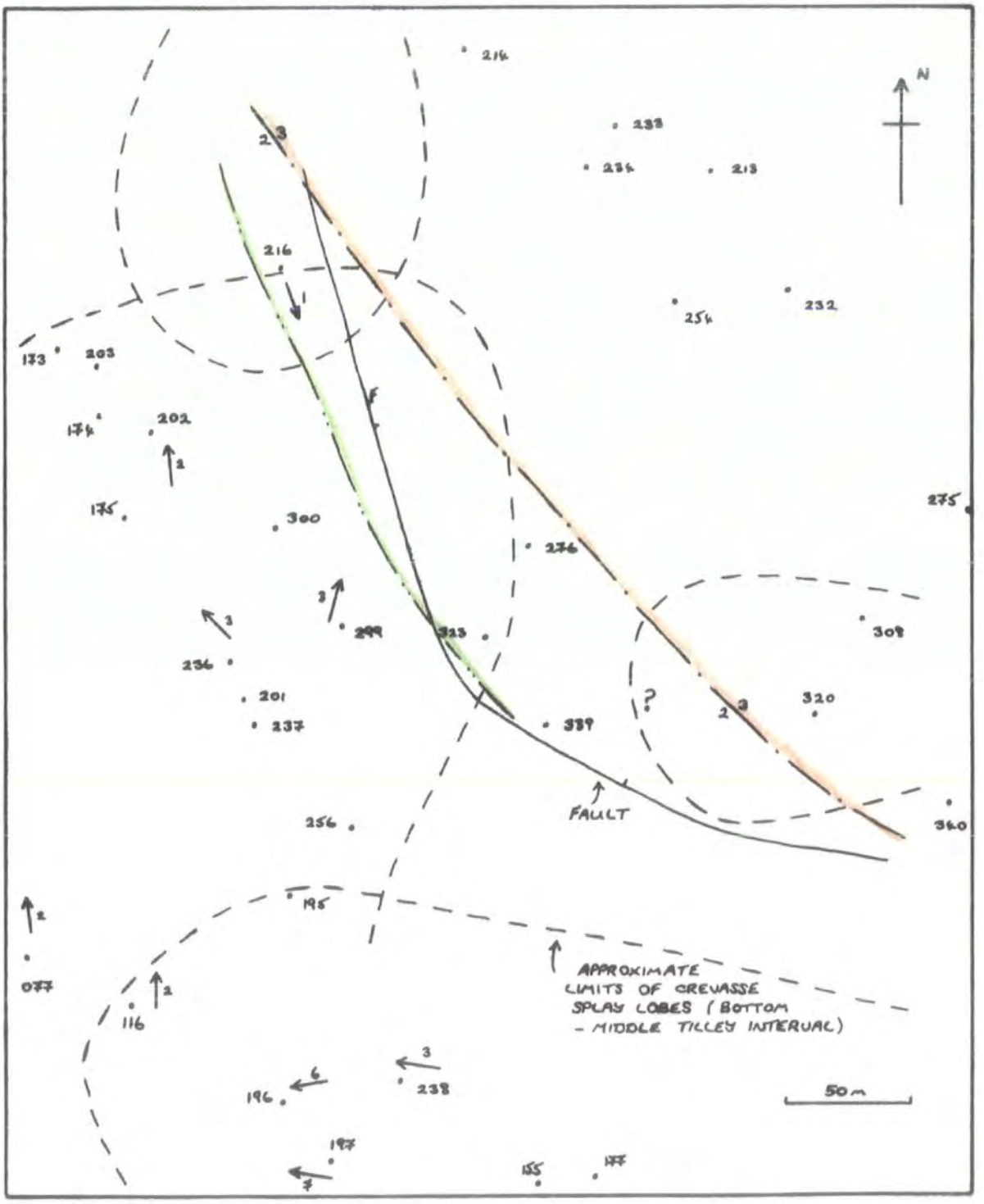
6.7.4.3 Cabin House/Mown Meadows O.C.C.S.

At the Cabin House and Mown Meadows sites, up to five Tilley seams are present, individually as much as 0.70 m thick, and contained within a 4-5 m sequence (Fig. 6.36). The coals are divisible into simple Bottom and Top Tilley seams, and a composite Middle Tilley consisting of several closely-spaced leaves. The north-eastern part of the area is characterized by a three-leaved Middle Tilley, whilst two leaves occur elsewhere (Fig. 6.36).

The sediments between the Tilley seams are largely claystones, most of which are highly sulphurous and thoroughly penetrated by rootlets. They include soft plastic clays, crumbly to laminated varieties and hard, kaolinitic claystones.

Fig.6.36

THE TILLEY COALS AND INTER-TILLEY SEDIMENTATION AT CABIN HOUSE/MOWN MEADOWS O.C.C.S.



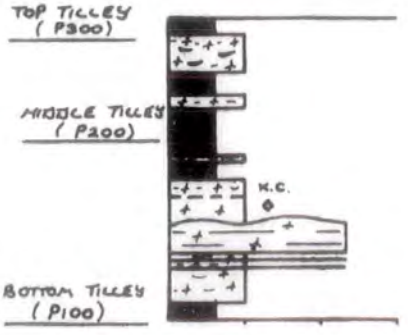
3/2 BOUNDARY BETWEEN THE OCCURRENCE OF 2 AND 3 "LEAVES" IN THE P200 SEAM.

SOUTHWESTERN LIMIT OF ROOTLETS THROUGHOUT THE P100 - P200 INTERVAL.

3 PALAEOCURRENT VECTOR MEAN (P100 - P200 INTERVAL)

077 LOGGED SECTION.

SECTION 320



The latter are restricted to the north-east of the site, bounded by a north-west-south-east-trending line similar to that marking the "split" in the Middle Tilley coal.

The kaolinitic claystones are similar in composition to those at the same horizon at Rowley O.C.C.S., but differ in occasionally containing significant amounts of crystalline, possibly authigenic, white mica (Plate 6.24, Appendix 2). Some samples were seen to contain virtually no quartz. These lithologies occur as discrete units, up to 0.20 m thick, often with transitional contacts, within the composite Middle Tilley seam, and are usualy to be found directly beneath a coal. In hand specimen, "fragmental" textures are common, similar to the Rowley examples, (Plate 6.14), though in some cases the entire rock appears to be composed of the buff-coloured kaolinitic clay. In the latter case, thin sections show the individual lens-to-elongate shaped "graupen" to be fused together, forming large masses of continuous kaolinite, separated by thin carbonaceous partings. Occasionally, the kaolinitic claystones take on a more laminated texture and contain more quartz grains, and fewer, smaller "graupen" reminiscent of the lithology described from above the Bottom Busty coal at Deborah O.C.C.S. (Ch. 6.6.4.3).

The less well-indurated claystones present between the Tilley seams often contain siderite nodules, and may be partly oxidized and mottled. North-east of the approximate limit of the kaolinitic claystones, the entire inter-Tilley sequence is rootlet-penetrated (Fig. 6.36). To the south-west, the Bottom-Middle Tilley parting commonly contains a significant proportion of sandstone, is characterized by animal burrows and by incomplete rootlet penetration, and a dark-coloured carbonaceous claystone containing coaly traces represents the lowermost leaf of the Middle Tilley coal, absent in this area (Enclosure 2, Appendix 1:- see, for example,

Sections 203, 299). Usually a single, sharply-bounded sandstone, up to 2.10 m thick, occurs between the Bottom and Middle Tilley seams. The sandstone is typically fine-grained and contains abundant trough cross-bedding (0.3 m thick ets), and ripple cross-lamination.

Palaeoflow is variable, though predominantly towards the north and west (Fig. 6.36).

In the south-east part of the site, the Middle-Top Tilley parting increases from less than 1 m to as much as 8.5 m, composed largely of laminated, plant fragment-rich claystones and siltstones with occasional thin, fine-grained sandstone beds (Appendix 1:-Section 177). Only the uppermost 0.50 m or so is rootlet-penetrated.

Interpretation

The Tilley peats evidently accumulated under conditions of negligible sedimentation, and the majority of the sediments separating the coals, being of clay and silt grade, were probably deposited either from suspension or by very gentle tractional currents. Only the sharply-based sandstones in the south-west show evidence of having been laid down by stronger currents, which from the absence of channel margins were probably unconfined.

The Tilley sequence is interpreted as having accumulated in a backswamp environment, which occasionally subsided sufficiently to allow clastic sedimentation.

Following accumulation of the Bottom Tilley peat, a number of crevasse splays prograded across the subsiding swamp, probably from several sources. Limits of individual splay lobes have been tentatively ascertained from palaeocurrent patterns and thickness variations in the sandstones (Fig. 6.36).

The thickness of the crevasse splay sandstones, and the presence of rootlets in their upper parts, suggests that over the western half of the site, the subsiding "floodbasin" was of the order of 2 m deep at the time of crevasse splay progradation.

Having effectively filled the shallow, subsiding basin, the crevasse sediments served as a platform for plant development once again, and the peats of the Middle Tilley began to accumulate. However, three lines of evidence suggest that the water depth in the swamp was somewhat greater in the south-west of the site than in the north-east:

(1) the incomplete penetration of the Bottom-Middle Tilley parting by rootlets in the south-west,

(2) in the same area, the presence of a coaly shale in place of the Middle Tilley bottom leaf, and

(3) occurrence of kaolinitic claystones beneath the Middle Tilley, interpreted as the result of ? pedogenic processes, almost exclusively in the north-west (Fig. 6.36).

This may have been due to slightly enhanced subsidence, caused by rapid compaction of Bottom Tilley peat beneath crevasse splay sands in the south-west (Fig. 6.36).

The substitution of coaly shale for bright coal in the Middle Tilley bottom leaf is seen largely as a result of dilution by clastic detritus; although the basin was slightly deeper to the south-west, allowing the movement of clastic sediment, it could not have been substantially so, since there are abundant rootlets in the upper half of the underlying interval.

The kaolinitic claystones are similar in most respects to those described from Rowley O.C.C.S., and are again considered as the product of subsurface, ? pedogenic precipitation of kaolinite beneath the accumulating Middle Tilley peat. However, the occurrence of a "laminated" lithology more reminiscent of that described from above the Bottom Busty at Deborah O.C.C.S. might imply a more subaqueous environment of formation (see Ch. 6.6.4.3). The Mown Meadows kaolinitic claystone bands are 3-4 times thicker than their counterparts at Rowley, and may thus record the maintenance of kaolinite-forming conditions over a longer period. The uppermost parts of seatearth profiles in the same area are commonly oxidized rather more than might be expected to result from recent weathering.

The increase in thickness of the Middle-Top Tilley parting in the south-east is interpreted as the result of accelerated subsidence, though data coverage in this area is poor.

6.7.4.4 Buckhead O.C.C.S.

Description

During operations in the Laundry Extension of Buckhead O.C.C.S. (G.R. NZ 133243), (Enclosure 9), a small excavation north of the major Wigglesworth Fault exposed sediments within the Tilley group of coals. The Bottom Tilley coal, comprising two leaves, was uncovered along with an 8.5 m sequence overlying the seam. The Top Tilley is thought to occur a short distance above.

The sequence, exposed in two adjoining faces, is composed largely of interbedded fine sandstone-go-granulestones and silty claystones (Enclosure 10, Plate 6.25).

Between the two thin leaves of the Bottom Tilley seam, (P101, P102), is a 2.6 m thick sequence comprising two coarsening-upward



Plate 6.25 - The Bottom Tilley coal and overlying sediments at Buckhead O.C.C.S., showing rapid lateral changes in sandstone bed thickness, and large-scale loading (L). The exposed face is about 11 m high.

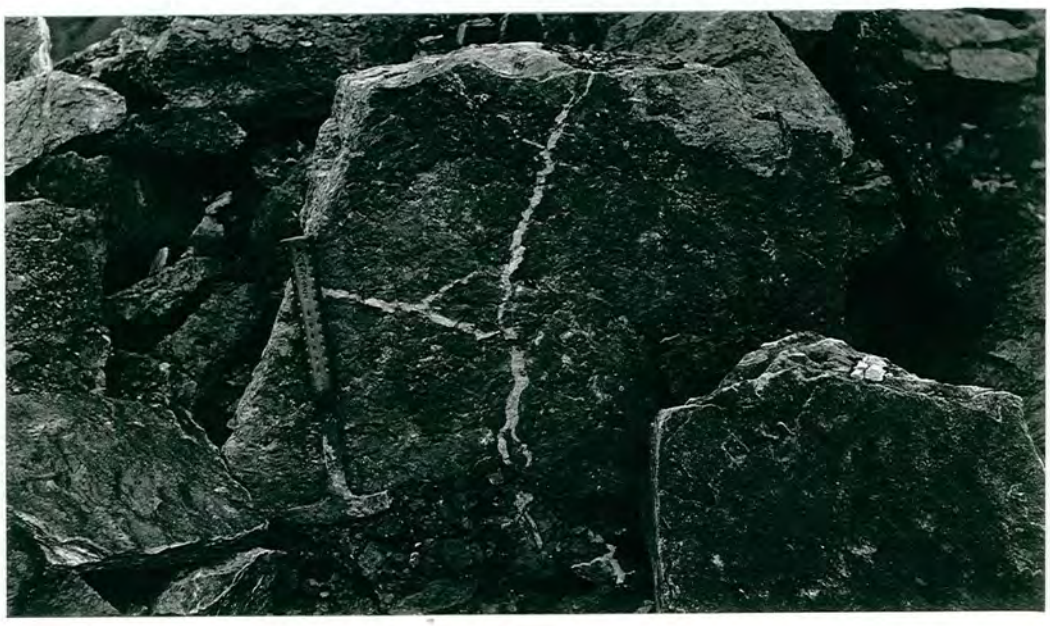


Plate 6.26 - Sandstone-filled ?desiccation cracks in root-penetrated sediment beneath the Bottom Tilley (PIO2) coal, Buckhead O.C.C.S. Hammer is 30cms long.

cycles of subequal thickness (Enclosure 10), (Appendix 1; Section 425). The lower of these ranges up to fine-grained sandstone, whereas the higher cycle passes only up to siltstone with sandy streak. Stigmarian rootlets penetrate almost the entire sequence, and many may be traced from the lower sequence into the upper one.

The higher coarsening-upward sequence is notable in containing an assemblage of sandstone-filled cracks, vertical dewatering pipes, and siderite nodules with vertically oriented long axes, immediately below the P102 coal. The fine-grained sandstone-filled cracks are of the order of 5-20 mm wide, are slightly folded and may be up to 0.3 m long in vertical section, and are polygonal in plan view (Plate 6.26).

Immediately above the P102 seam is a series of medium-grained sandstone-to-granulestones interbedded with laminated claystones (Enclosure 10). The sandstones contain abundant "coaly scares", have loaded bases and occasionally show convolute lamination and even complete internal disorganization. Claystone dykes up to 0.15 m in width pass through the sandstone into the underlying coal (Plate 6.27). Interbedded claystones occasionally show a sandy streak and contain abundant siderite nodules and lenses.

Further up the sequence, sandstones are finer-grained, and interbedded sediments are mainly silty claystones. Burrows, referable to *Pelecypodichnus*, *Arenicolites* and *Monocraterion*, are common in the sandstones, particularly where thin intercalations of silty claystone are present.

Towards the top of the exposed section, an erosively-based sequence of interbedded fine-grained sandstones and claystones



Plate 6.27 - Close-up of Bottom Tilley (PIO2) coal and overlying sediments at Buckhead O.C.C.S., showing a claystone dyke (D) which penetrates a sandstone bed and the underlying coal. Hammer is 30cms long.



Plate 6.28 - Panorama of the exposed Tilley sequence at Buckhead, showing a ?laterally-accreted, minor channel in the uppermost part of the face.

occurs, displaying prominent low-angle accretion surfaces (Plate 6.28, Enclosure 10).

Throughout the sequence are indications of synsedimentary instability including large-scale loading (Plate 6.25), dewatering structures, abrupt changes in sandstone thickness and listric synsedimentary faults, in addition to previously-mentioned dewatering pipes, disrupted bedding and claystone dykes (Enclosure 10).

The exposed section is characterized by abundant lateral variation, principally in the thickness and abundance of sandstone beds (Enclosure 10). Although three small faults disrupt the sequence, these are not thought to significantly affect facies distribution. Many sandstone beds pinch out abruptly, and sudden changes in thickness or character are equally common.

Palaeocurrent measurements from trough cross-bedding and ripple cross-lamination indicate palaeoflow towards the south and south-south-east. Low-angle accretion surfaces, exposed in two areas, dip towards the south-south-east and north-west (Enclosure 10).

Many of the sandstones, particularly the coarser types, contain an association of euhedral dolomite and pyrite/marcasite cements, which postdate the ubiquitous quartz and kaolinite/illite phases (Plate 6.29),(Appendix 2). Indeed, many of the sandstones contain veins of pyrite, marcasite, sphalerite, galena, fluorite and gangue phases, a mineral suite reminiscent of the North Pennine orefield.

Interpretation

The alternation of sharply-based sandstones and fine-grained claystones implies fluctuating conditions of deposition, varying probably from quiet-water to high-energy tractional currents. The

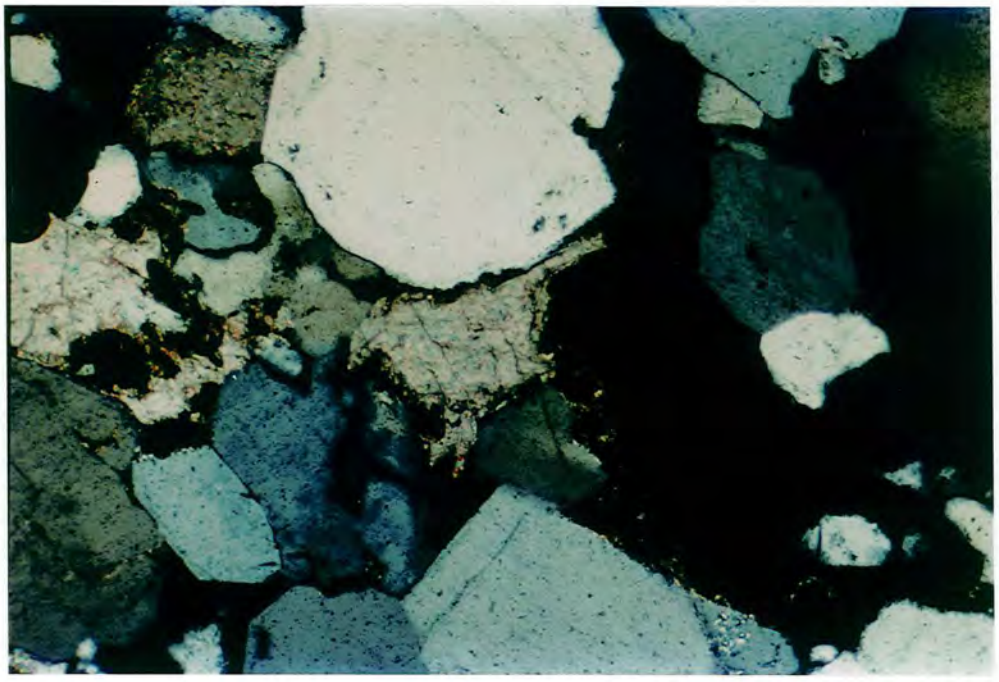


Plate 6.29 - Dolomite and pyrite/marcasite cements in sandstone from above the Bottom Tilley (PI02) coal at Buckhead O.C.C.S. Length of photomicrograph I.2mm. (Crossed polars).



Plate 6.30 - Laterally-accreted, minor channel deposit between the Middle and Top Tilley coals at Cobey Carr Quarry, and overlying major channel sandstone of the "Top Tilley Post" (6m thick).

apparent sheet geometry and flat-lying aspect of most of the sandstones implies deposition by unconfined flows. However, the two areas with low-angle accretionary dips probably represent channels.

The exposed sequence is interpreted as the deposits of a shallow, subsiding, lacustrine basin fed by overbank and crevasse-derived sediment from a northerly source (Enclosure 10b). Water depth in the lower part of the sequence (between the P101 and P102 seams) was about 2.0 m, and in the upper part is uncertain, though from the lack of rootlet penetration and a comparison with similar sequences exposed elsewhere is likely to have been 3-5 m.

The two areas displaying low-angle accretion surfaces and channel morphology are interpreted as the remnants of laterally-accreted, minor distributary channels which, from their geometry, flowed across the shallow basin towards the north-east, though not simultaneously. Geometrical relationships indicate that the channels were about 10 m wide and 2 m deep, giving width/depth ratios of 5:1 (Enclosure 10b).

The polygonal, sandstone-filled cracks are tentatively interpreted as desiccation cracks, and are thus further possible indications of fluctuating water tables in the Upper Westphalian A Coal Measures. These cracks are considered unlikely to have been produced by synaeresis, from the large-scale polygonal plan outline, depth of penetration and a lack of ptygmatic folding which might be expected from the compaction of water-rich sediment. Admittedly, synaeresis cracks might well be expected to form in a waterlogged environment characterized by occasional, rapid influxes of sediment (Plummer and Gostin, 1981).

The abundance of features indicative of sediment instability reflected the water-saturated nature of the sediment column, and rapid deposition by crevasse splays. Reversed density gradients occurred frequently, inducing thixotropic behaviour of sediment. The identification of synsedimentary listric faults is one of few reported from the Coal Measures (Elliott and Ladipo, 1981; and Kirk, in press, a, being the others), although this is possibly due to lack of large outcrops, and difficulty of recognition.

The variety and abundance of sedimentary instability features in the Buckhead exposure might be a consequence of proximity to the possibly active Butterknowle fault system, a Lower Carboniferous "hinge line" which is thought to have had a complex history of movement (see Ch. 2.2).

The exotic cements contained with many sandstones are considered to have been derived from the nearby Butterknowle/Wigglesworth fault system, along which mineralizing fluids travelled either during the "Hercynian" or "Alpine" phases of earth movement.

6.7.4.5 Cobey Carr Quarry/Binchester Crags

Description

At Cobey Carr Quarry and Binchester Crags, both mentioned previously, closely comparable sections through the Tilley coals are exposed.

Thin Bottom and Middle Tilley seams (P100 and P200, respectively) are separated by 1-2 m of interbedded fine-grained sandstones, siltstones and claystones (Figs. 6.31; Unit 4 6.32;Units 2-4). At Binchester Crags, the Middle Tilley coal deteriorates in quality towards the south (compare Sections 191 and 192:- Appendix 1). At

both localities the Top Tilley (P300) is a banded seam of variable thickness.

At Cobey Carr, the Middle-Top Tilley parting, 2.5-4.5 m in thickness, comprises a trough cross-bedded/ripple cross-laminated, fine-grained, silty sandstone. Towards the south end of the quarry, this is overlain by interbedded sediments of similar grain size, which display low-angle accretionary foresets (Plates 6.30, 6.31; Fig. 6.31; Unit 5). Grain-size variations are difficult to discern due to the weathered nature of the section, but individual foreset units could occasionally be seen to fine both vertically upwards and up foreset bedding planes.

Overlying the low-angle cross-bedded unit, or laterally equivalent sandstone, is a variable thickness of rootlet-penetrated silty claystone. At one locality in the northern quarry wall, this claystone increases in thickness to occupy the entire Middle-Top Tilley interval.

Apart from the variations described above, considerable lateral change in character of the sandstone occurs, although this is difficult to quantify. The thickness of the parting as a whole decreases from about 4.5 m in the centre of the main north-south quarry face to about 2.5 m near the north and south ends, fairly abruptly in the latter case (Plate 6.31). A small (1 m high, 10 m wide) channel form is visible in the continuous sandstone sequence towards the north end of the quarry.

Palaeocurrent measurements from cross-bedding and ripple cross-lamination indicate considerable variance in palaeoflow direction (Fig. 6.37). The directions of dip of the low-angle accretion surfaces at the south end of the quarry are 75-90 degrees different from those of trough cross-sets in the same area (Fig. 6.37).



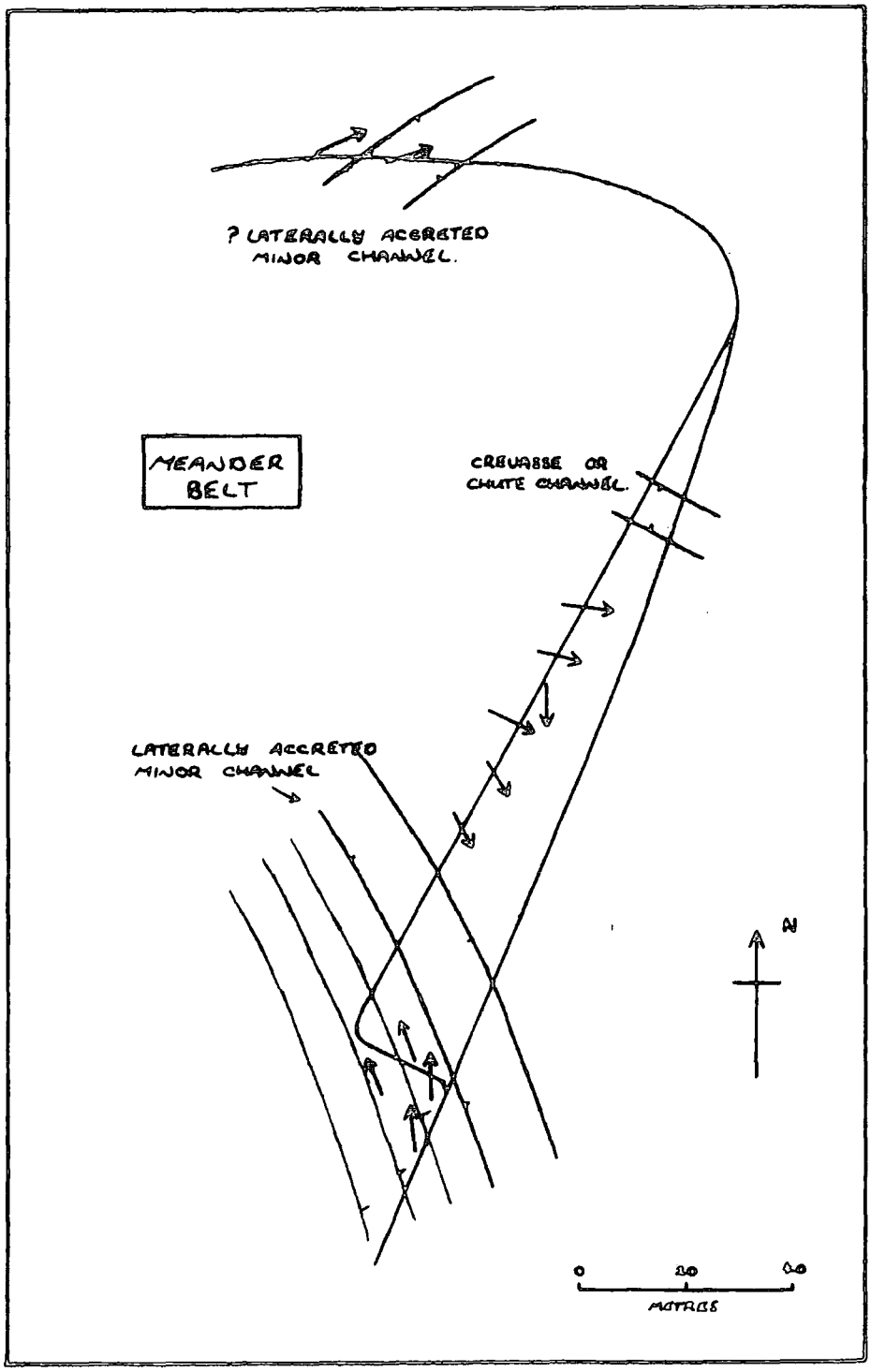
Plate 6.3I - Panorama of Cobey Carr Quarry, showing the entire exposed sequence. The bench in the left half of the photo is at the level of the Bottom Tilley coal. A minor channel (c) above the Harvey coal is exposed in the upper part of the face.



Plate 6.32 - Plant debris preserved as flattened, carbonaceous casts in the Top Tilley Post sandstone at Deborah O.C.C.S. (Hammer is 30cms long).

Fig.6.37

INTERPRETATION OF SEDIMENTS BETWEEN THE MIDDLE AND TOP TILLEY COALS AT COBEY CARR QUARRY



Palaeocurrent measurement

Channel margins

Lateral accretion surfaces

At Binchester Crags, the P200-P300 parting comprises a 4.75 m sequence of siltstones with occasional siderite nodules and thin beds of fine-grained sandstone, much of which is penetrated by rootlets (Fig. 6.32: Unit 5).

Interpretation

The interbedded sediments of the P100-P200 parting are again interpreted as overbank or crevasse-derived deposits of a shallow floodbasin environment. The thin, banded and impure nature of the coals implies clastic detrital influx during the accumulation of the Tilley peats themselves.

The P200-P300 parting at Cobey Carr is interpreted as the meander belt of one or more high sinuosity channels. The sequence at the south end of the quarry is interpreted as the remnants of a meandering channel which accreted laterally towards the north-east, whilst flowing towards the north-north-west (Fig. 6.37). Evidently this channel was filled while partially abandoned, from the interbedded nature of the final fill (exposed where the sequence is at minimum thickness).

The siltstone sequence at the north end of the quarry is interpreted as the abandoned fill ("clay plug") of the same or another channel, which flowed towards the east-north-east.

From the distribution of facies and angles of lithological contacts, these channels are estimated to have been about 15 m wide and 1.5-2.0 m deep at any one time, giving width depth ratios of 10-7.5/1. These channels seem to have carried a significant proportion of fine-grained material ("muddy, fine-grained streams" in the terms of Jackson, 1978), and bear considerable similarity to the classic "fining-upward cycles" of Allen (1965b).

The small, sandstone plugged channel near the north end of the quarry is interpreted as a minor crevasse or chute channel which originated from one of the larger adjacent channels.

The sandstones exposed along much of the quarry face are interpreted as undifferentiated earlier channel and channel-derived floodbasin sediments (Fig. 6.37). The thickness of the sequence, the presence of large-scale trough cross-bedding and the overlying rootleted siltstone all favour the former alternative, although it is likely that both cases are represented, and these are impossible to separate in the absence of three-dimensional data.

The siltstones overlying the channel deposits are interpreted as channel abandonment deposits, which served as a base for plant colonization and peat development.

Whether the channels represent minor distributaries or true fluvial channels is also difficult to ascertain, although the inferred presence of a "meander belt" might argue for the latter.

The fine-grained equivalent sequence exposed at Binchester Crags is interpreted as the deposits of a shallow floodbasin 1.5 kms distant from the meander belt exposed at Cobey Carr. The distribution of rootlets in these shallow lake deposits indicate that the water depth only occasionally exceeded that at which plants could colonize the sediment surface.

6.7.4.6 Esh Winning O.C.C.S.

Three Tilley seams, and the sediments between them were examined at Esh Winning O.C.C.S. (G.R. NZ199428). The coals, and to some extent the clastic sediments also, are similar in character to those from the nearby Rowley site. It is not intended

to consider this exposure in detail, but representative vertical sections are contained within Appendix 1 (see, for example, Section 038), (Enclosure 11), and a generalized log given in Fig. 6.38.

6.7.5 Discussion

Patterns of detrital sedimentation and peat accumulation in the Busty to Top Tilley interval show similar characteristics and controls to those of underlying intervals.

Channels and channel belts for the Busty-Tilley parting have been identified from outcrop and subsurface data (Fig. 6.39). The major channel belts were of low-to-moderate sinuosity, of the order of 2-5 kms wide, and deposited thick major sandstone bodies. One such sandstone is exposed at Cockfield Reeves (Ch. 6.7.2.1, Plate 6.9). Within these, individual channels may have been more sinuous and up to 3 kms wide.

By comparing Figs. 6.22, 6.24, and 6.39, it can be seen that major channel courses avoided areas previously occupied by channels, and preferentially developed above areas where the Busty is a thickened single seam. Certain channel belts, particularly in the north, however, are aligned parallel to the major structural grain of the area, and may therefore be, at least in part, structurally controlled.

"Washouts" in the Busty or Top Busty coal, also plotted on Fig. 6.39, for the most part probably represent erosion of peat and deposition of sands in minor distributary channels or channel belts of low-to-high sinuosity, although some washouts undoubtedly were caused by major channels.

The washout at NZ 160490, which cuts through both Top and

Fig.6.38

COMPOSITE VERTICAL SECTION - ESH WINNING O.C.C.S.
(G.R. 199428), (BASED ON SECTIONS 021, 022, 023 :- APPENDIX 1)

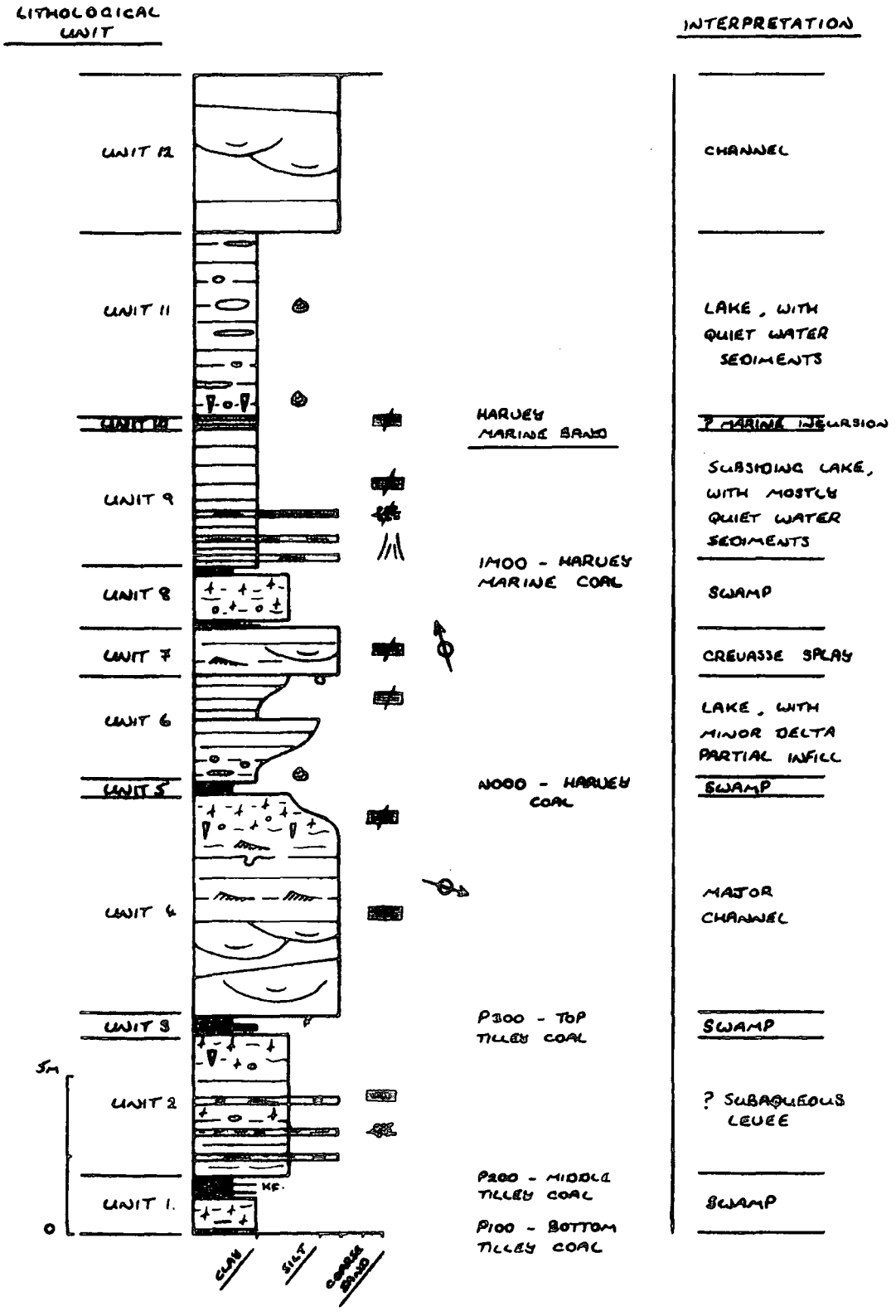
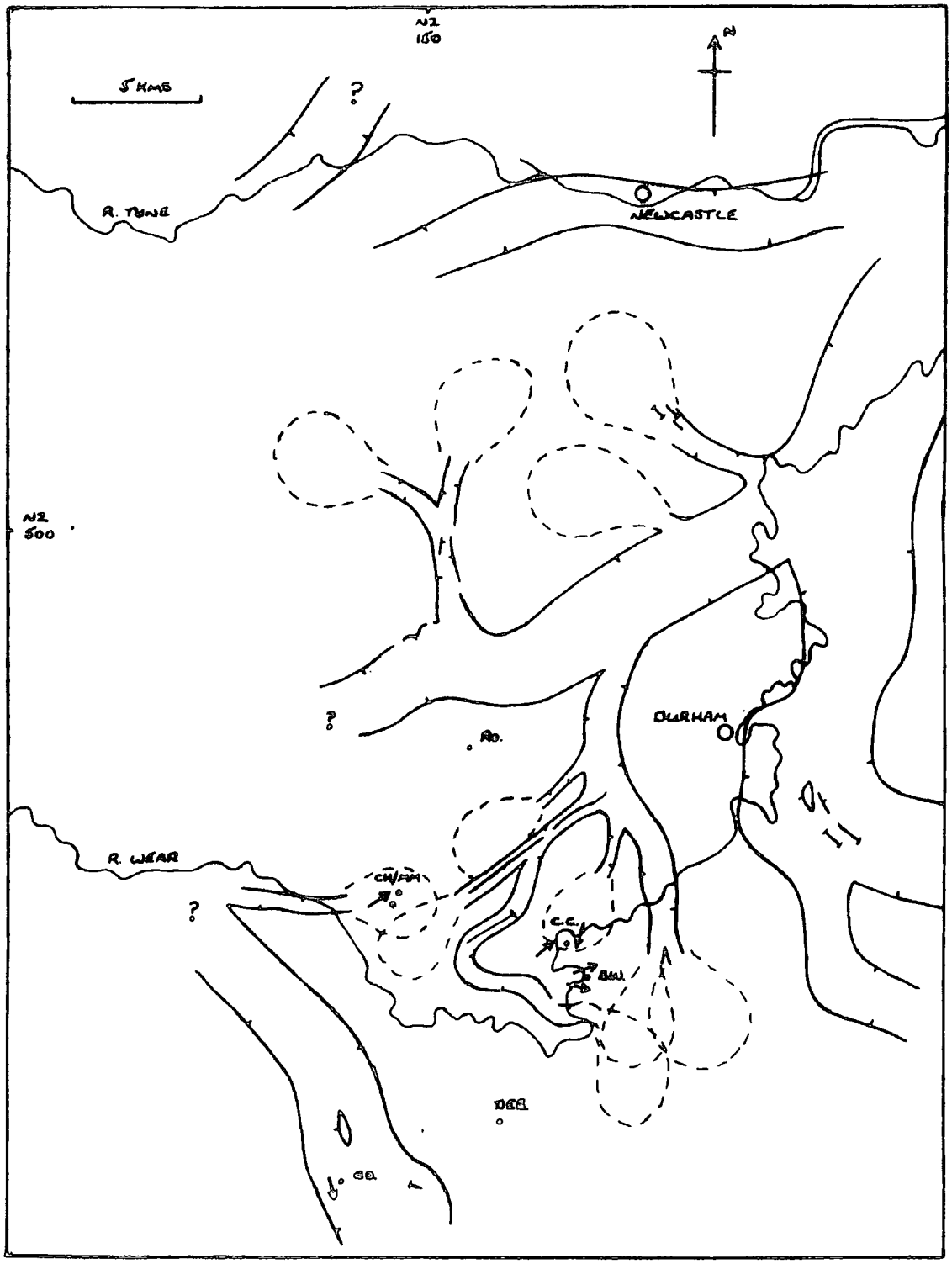


Fig.6.39

POST-TOP BUSTY PALAEOCURRENTS, AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS



CHANNEL MARGINS

WASHOUTS IN TOP BUSTY COAL.

MINOR DELTA LOBE (SCHEMATIC)

PALAEOCURRENT VECTOR MEAN.

RO - ROWLEY O.C.C.S.

CH/MM - CABIN HOUSE / MOWN MEADOWS O.C.C.S. (∧ = 28)

CC. - COSEY CARR QUARRY (∧ = 13)

DEB. - DEBORAH O.C.C.S.

CO. - COCKFIELD REEVES (∧ = 10)

BIN. - BINCHESTER CRAGS (∧ = 27)

Bottom Busty coals, is interpreted as the result of post-Top Busty channel switching and erosion (Fig. 6.39).

Fig. 6.39 places the examined sedimentary sequences in their regional perspective. Post-Top Busty sequences at Rowley, Mown Meadows, Cabin House, Cobey Carr, Binchester Crags and Deborah were deposited in shallow floodbasins fed by major and minor channels.

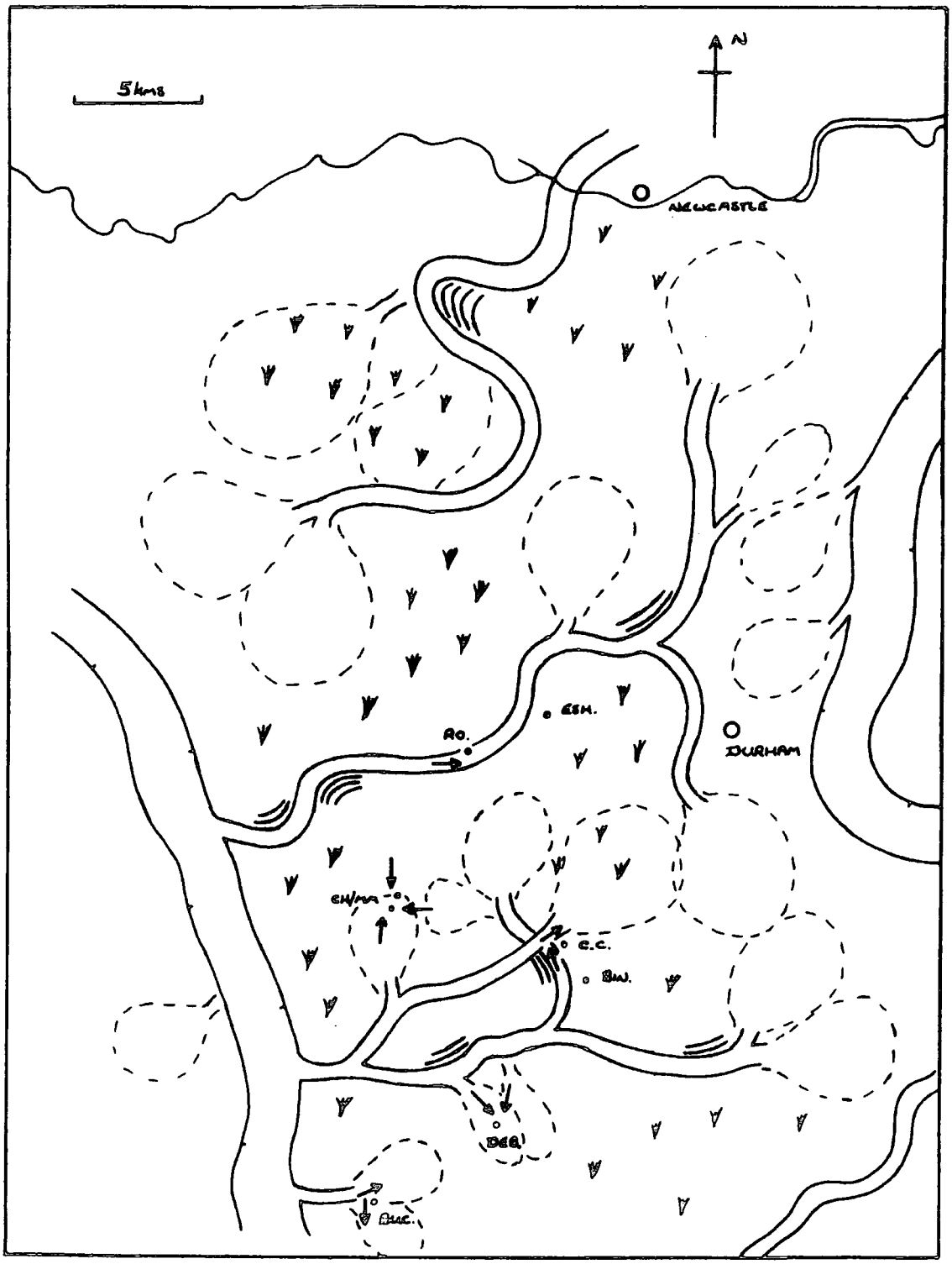
The examined intra-Tilley sequences were deposited in similar settings, and in the case of the Buckhead exposure, in a shallow, subsiding lake developed over an abandoned major channel deposit (Figs. 6.39, 6.40).

The Tilley coals, characterized by extreme lateral variability, are thought to have accumulated under conditions of sediment supply intermediate between those of the underlying clastic interval and the quiescent setting necessary for widespread, thick peat accumulation. It seems that much of the coalfield was supplied intermittently with sediment throughout this period, leading to the deposition of thin, laterally discontinuous peat seams over abandoned minor channels and floodbasins, and consequent regional complexity of the Tilleys. Accelerated subsidence may have led to locally thickened peat accumulations, but regional subsidence patterns are not considered to have been significant.

The north-south-trending major channel system near the eastern margin of Fig. 6.39 shows considerable evidence of having been active during the time of accumulation of the Tilley peats. In many records from this area, Tilley seams are missing and are inferred never to have been deposited, and in several others a "Top Tilley" coal overlies thick (up to 25 m) channel sandstones occupying the entire Busty-Tilley interval (Smith and Francis, 1967, Plate 3).

Fig.6.40

INTER-TILLEY PALAEOCURRENTS, AND SCHEMATIC INTERPRETATION OF SEDIMENTARY ENVIRONMENTS



MAJOR CHANNELS

MINOR CHANNELS, WITH LATERAL ACCRETION SURFACES

MINOR DELTA LOBE

- ALL SCHEMATIC

PALAEOCURRENT VECTOR MEAN

PEAT SWAMP

RO. - ROWLEY O.C.C.S. ($\bar{\wedge}$ = 37)

CH/MM - CABIN HOUSE/MOWN MEADOWS O.C.C.S. ($\bar{\wedge}$ = 29)

C.C. - COBEY CARR QUARRY ($\bar{\wedge}$ = 19)

DEB. - DEBORAH O.C.C.S. ($\bar{\wedge}$ = 6)

BUC. - BUCKHEAD O.C.C.S. ($\bar{\wedge}$ = 22)

ESH. - ESH WINNING O.C.C.S.

BIN. - BINCHESTER CRAGS.

This channel system, and probably another in the western part of the coalfield, supplied the minor channels which crossed the Tilley floodbasins and peat swamps in broadly easterly and westerly directions, and led to the development of complex minor channel sequences between the laterally impersistent Tilley peats (Fig. 6.40). The total width of the central Durham "Tilley basin" was of the order of 20 kms, a figure in accord with calculations from wave ripple parameters.

6.8 TOP TILLEY TO HARVEY COALS

6.8.1 Introduction

The interval between the Top Tilley and Harvey coal seams varies between 3 m and 30 m, thicker values being associated with major sandstone deposits. Thick sandstones, known collectively as the "Top Tilley Post", occur commonly in exposures at this level, and will be considered separately in the following passage.

Where major sandstones are absent, the interval consists of the characteristic Coal Measure assemblage of interbedded claystones, siltstones and thin, fine-grained sandstones, along with up to three thin coal seams. One of these seams, known as the Hodge (0000) lies a short distance below the Harvey coal, and occasionally reaches exploitable thickness in the north-west part of the coalfield (Fig. 6.1).

Eight localities exposing the Top Tilley-Harvey parting were visited, four of which also exposed the Harvey coal itself.

6.8.2 Sediments between the Top Tilley and Harvey coals

6.8.2.1 The "Top Tilley Post"

Description

"Top Tilley Post" is a polite local miners' term for the sandstone overlying the Top Tilley coal over parts of the Durham coalfield.

Generally, the sandstone is 5 - 15 m thick, but may be as much as 27 m.

Where examined, the sandstone was generally fine-grained, though commonly the basal 1 m or so was medium-grained, coarse or even granular, and contained clasts of shale and ironstone. At Deborah O.C.C.S., granules of garnet and blue quartz were found in this basal deposit. Coalified plant casts up to at least 1 m in length (Plate 6.32) and coalified peat clasts are common at many localities.

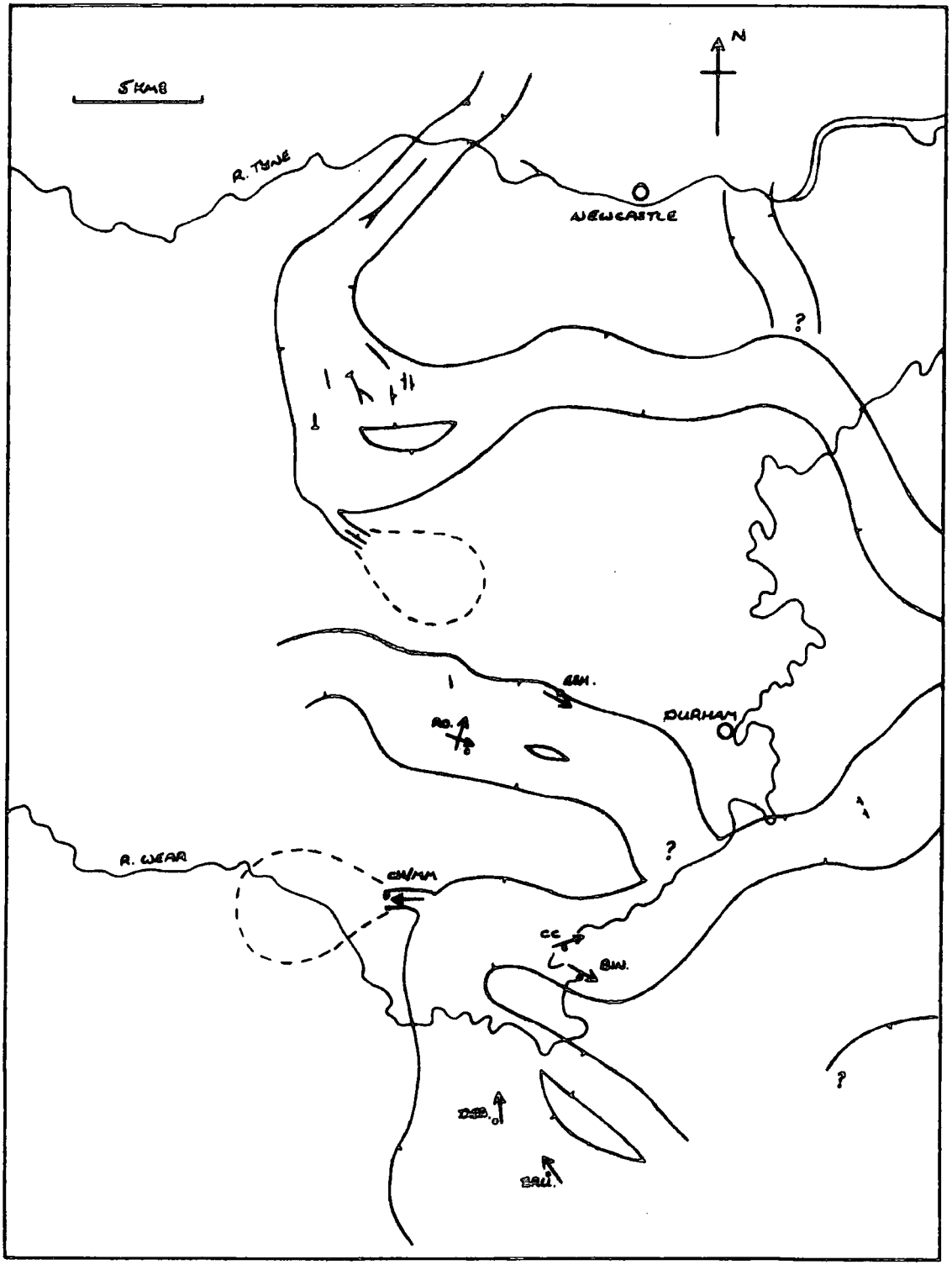
The "Top Tilley Post" is similar to other major sandstones of the Durham Coal Measures in containing abundant trough cross-bedding (in sets up to 2.0 m thick) and ripple cross-lamination, and occasional major, erosive, bounding surfaces. On Deborah O.C.C.S., ? dessication cracks were seen on a bedding plane at one locality (see Section 329; Appendix 1).

The sandstone generally has an erosive base, often directly overlying the Top Tilley coal. The upper contact varies from gradational (i.e., fining-upward), as at Esh Winning O.C.C.S., to more abrupt, as at Deborah O.C.C.S. (Appendix 1; see Sections 021 and 024 respectively, Fig. 6.38; Unit 4).

Palaeocurrent measurements from trough cross-bedding and ripple cross-lamination indicate (regionally) a palaeoflow in more or less all directions possible (Fig. 6.41).

Fig.6.4I

POST-TOP TILLEY PALAEOCURRENTS AND SPECULATIVE CHANNEL BELT TRENDS



CHANNEL AND CHANNEL BELT MARGINS ("TOP TILLEY REF" SANDSTONE)

WASHOUTS IN TOP TILLEY COAL

MINOR DELTA LOBE (SCHEMATIC)

PALAEOCURRENT VECTOR MEAN

ESH. - ESH WINNING O.C.C.S. (n = 9)

RO. - ROWLEY O.C.C.S. (n = 5)

CH/MM - CABIN HOUSE / MOWN MEADOWS O.C.S. (n = 31)

CC. - COBEY CARR QUARRY (n = 18)

BIN. - BINCHESTER CRAGS (n = 92)

DEB. - DEBORAH O.C.C.S. (n = 57)

BRU. - BRUSSELTON WOOD QUARRY (n = 2)

At Rowley O.C.C.S., the "Top Tilley Post" was seen to possess a complex internal structure (Enclosure 6). A number of channel forms could be identified in various positions on several "cuts" Plates 6.33, 6.34), filled either by silty claystones, interbedded fine-grained sandstone and siltstone, or more rarely, entirely by sandstone. Most of these channel forms occur in the lower part of the "Top Tilley Post" sandstone, and locally cut through the Top Tilley coal.

Channels are 30-60 m wide, and their geometry and contained structures indicate a palaeoflow towards the east-south-east (Fig. 6.42). Low-angle accretion surfaces are common at certain channel margins, and within the sandstone-dominated sequences between these channel-associated sediments (Enclosure 6, Plates 6.33, 6.34).

The "Top Tilley Post" was examined at:

(1) Cobey Carr Quarry (Fig. 6.31; Unit 7)

(2) Binchester Crags (Fig. 6.32; Unit 7)

(3) Brusselton Wood Quarry (G.R. NZ 202251),

in addition to the localities mentioned.

Interpretation

The sandstones of the Top Tilley post were deposited by high-energy tractional currents. From the preserved height of some cross-sets (up to 2 m), these bedforms probably formed under water several metres deep. Primary current lineation at certain localities implies that flow strength was commonly within the Upper Flow Regime. High energy conditions must have been sustained over a considerable period to deposit the thick sandstone sequence preserved. However, the presence of carbonaceous siltstone partings, indicating low energy deposition, points to a periodic pattern of high stage flows.



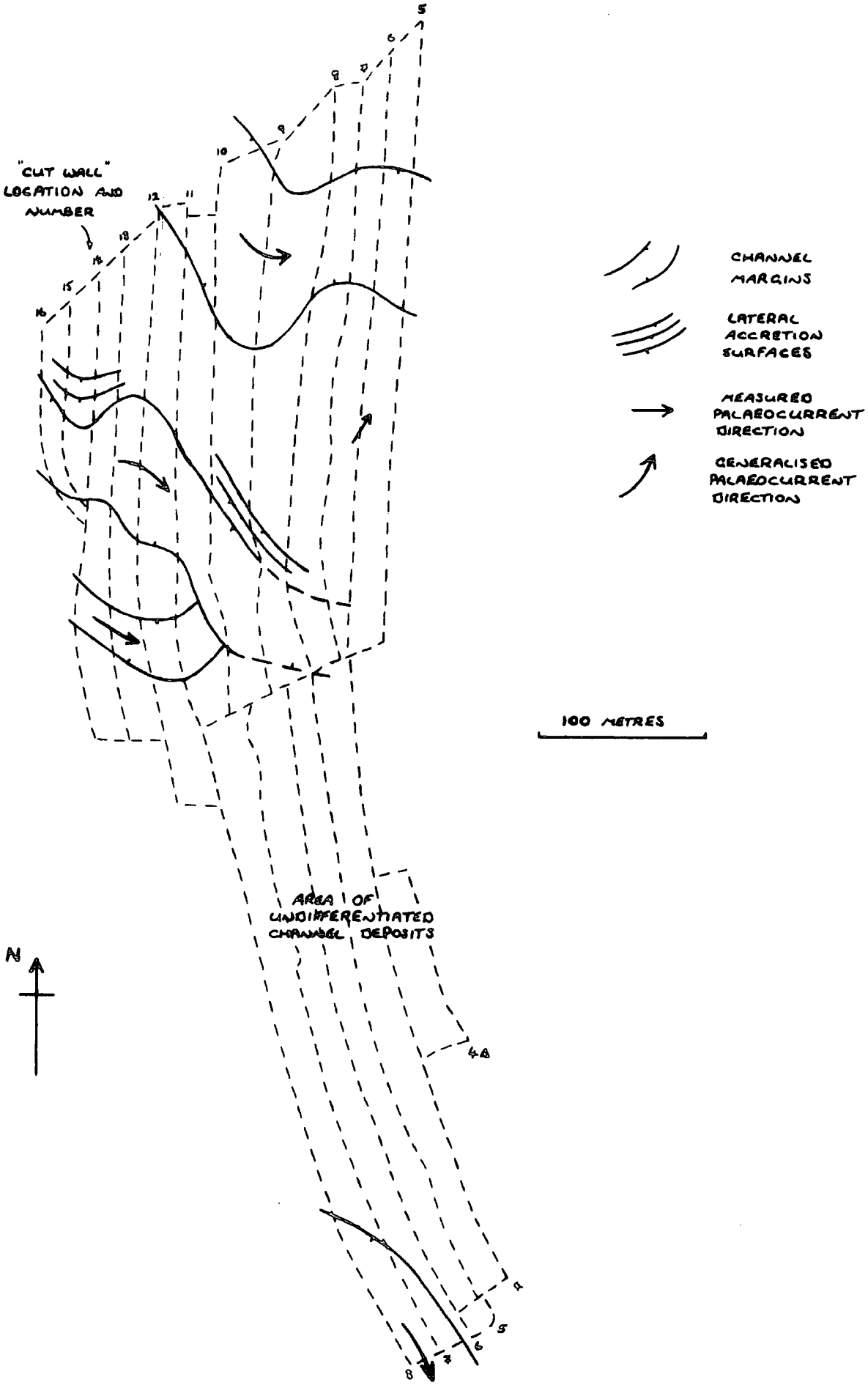
Plate 6.33 - Close-up view of a laterally-accreted minor channel margin in the "Top Tilley Post", Rowley O.C.C.S. (Cut AI3N). Exposed face is about 7m high.



Plate 6.34 - View of a laterally-accreted, claystone-filled minor channel (C) exposed in the "Top Tilley Post", at Rowley O.C.C.S. (Cut AI4N). Exposed face is about IOm high.

Fig.6.42

MINOR CHANNELS IN THE "TOP TILLEY POST" SANDSTONE AT ROWLEY O.C.C.S.



The thick, laterally extensive sandstones of the Top Tilley post are interpreted as the deposits of major and minor channels. No major channel margins were observed and channel morphologies remain uncertain. However, the extreme spread in palaeocurrent directions between localities and the probably lateral accretion surfaces at Rowley (see below) may be indicative of a sinuous channel style (Fig. 6.41).

From the abundance of low-angle cross-bedding, interpreted as lateral accretion surfaces, the channels exposed at Rowley are interpreted as east-south-east flowing, meandering minor channels (Plates 6.33, 6.34). This interpretation is supported by the documented courses of channels across the site (Fig. 6.42). The channels have width:depth ratios of 13-20:1, lower values being associated with channels cutting through the cohesive Top Tilley Coal, as might be expected. The predominantly fine-grained sediment within channels is interpreted as abandoned or partly abandoned channel fill. The sandstone-dominated sequences between these minor channel sediments are also interpreted as the deposits of sinuous channels which, from the lack of recognizable channel margins, were probably deposited in larger channels than those fully exposed (Enclosure 6).

From the complex cross-cutting relationships of channels and low-angle accretion surfaces (Enclosure 6), the "Top Tilley Post' at Rowley is thought to have built up by development of a meander belt, formed by the operation of a number of sinuous channels over a considerable period of time. The development of such a sandstone-dominated channel belt sequence over a long period would probably require low aggradation rates.

Abandonment of the "Top Tilley Post" channels seems to have varied from quite rapid, as at Deborah O.C.C.S., to more gradual fining-upward/waning flow at Esh Winning O.C.C.S.

6.8.2.2 Cabin House/Mown Meadows O.C.C.S.

Description

At Cabin House and Mown Meadows sites the sequence overlying the Top Tilley coal differs from that described above, and so merits separate consideration.

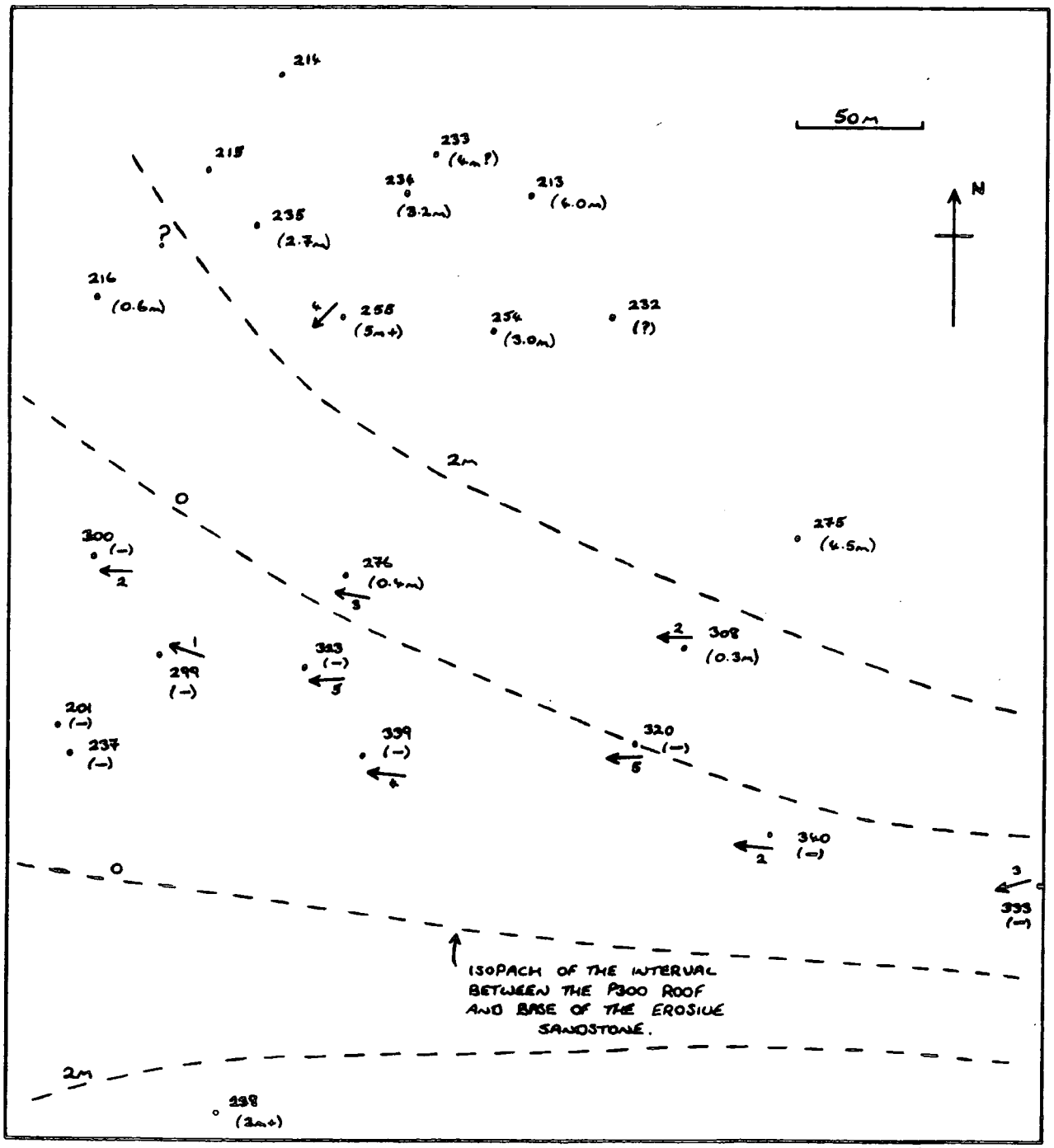
Across the northern half of the area, and in the extreme south, the Top Tilley coal is overlain by "blocky" to laminated, medium grey claystones, with sandy streak, siderite nodules, plant debris and impressions of non-marine bivalves (Fig. 6.43, Appendix 1). Occasional thin, fine-grained sandstones occur (up to 0.3 m). These are laterally persistent over 50-100 m, have transitional bases and are ripple cross-laminated. At one locality, cross-lamination indicated a palaeoflow towards the south-west (Section 255; Appendix 1, Fig. 6.43).

Above the claystone, which may be at least 5 m thick, lies a gradationally- to erosively-based sandstone containing small-scale trough cross-bedding and ripple cross-lamination. The upper part of this sandstone is generally truncated by superficial deposits.

In an east-west-oriented belt across the site, the sandstone cuts down to lie directly on the Top Tilley coal. It is coarse-grained or even conglomeratic near its' base, with ironstone, shale and coalified peat clasts, and contains ripple cross-lamination and truncation cross-bedding which indicate palaeoflow towards the west (Fig. 6.43). The basal surface commonly loads into the underlying Top Tilley coal, and an elongate rill mark was observed in the base

Fig.6.43

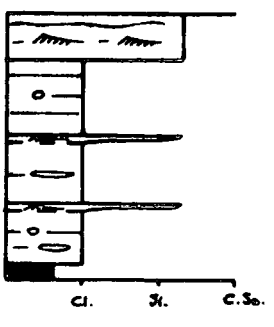
POST-TOP TILLEY SEDIMENTATION AT CABIN HOUSE/ /MOWN MEADOWS O.C.C.S.



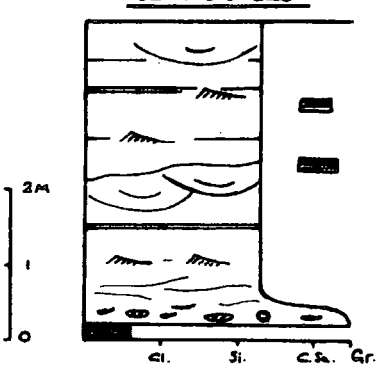
THE SEQUENCE IS INTERPRETED AS THE DEPOSIT OF A "PROXIMAL", CHANNELISED, MAJOR CREVASSE SPLAY WHICH EMANATED FROM A CHANNEL SITUATED A SHORT DISTANCE TO THE EAST, AND ERODED PREVIOUSLY - DEPOSITED LAKE SEDIMENTS.

339 - NO. OF LOGGED SECTION, + DISTANCE FROM P300 ROOF TO BASE OF EROSIVE SST,
• (3.0m) PALAEOCURRENT VECTOR MEAN, WITH NO. OF READINGS.
3

SECTION 235



SECTION 320



of the sandstone, at one locality. The upper part of the sandstone, which is 2.5-5 m in total thickness, contains frequent carbonaceous claystone partings, and may be overlain by up to 2 m of laminated siltstone (see, for example, Section 340; Appendix 1).

The depositional dip of the sandstone was traced along several west-north-west-trending "cuts" (slightly oblique to palaeoflow:- Enclosure 2, Fig. 6.43), and showed that the sandstone directly overlies the coal along the central belt, and gradually ascends the sequence to the north and south.

At the same time, the sandstones north of the central belt cut down and drape over previously-deposited sediments in a down current situation, i.e., westward.

Interpretation

The fine-grained sediments over the Top Tilley seam were laid down largely from suspension, but with occasional traction flows supplying fine sand layers and laminae. The erosively-based sandstone was deposited by a high-energy, ? semi-confined traction flow or series of flows, which swept across and eroded previously-deposited sediments. Following this period of high-energy activity, tractional currents waned somewhat, and deposited silt grade sediment above the high-stage sand deposits.

The claystones with bivalve impressions are interpreted as the deposits of a shallow lacustrine basin, developed as a result of subsidence of the Top Tilley peat swamp. Occasional influxes of coarser sediment may have been overbank-derived or from a distant crevasse splay.

The erosive-based, downcutting sandstone is interpreted as the channelized deposit of a westward-prograding, major crevasse splay, the axis of which lay in an east-west belt across the centre of the site (Fig. 6.43). This crevasse splay is considered to be exposed not far from its' channel source, from:

(1) the evidence for erosion of at least 5 m of fine-grained sediments,

(2) the ? channelized nature of the splay deposit, inferred from "sandstone base" contours (Fig. 6.43),

(3) the presence of "intraformational" pebble-sized clasts and the internally disorganized nature of the lower part of the splay deposit,

(4) the abundance of coaly detritus throughout the sandstone perhaps indicating proximity to an eroded peat seam, and

(5) the presence of numerous, well-preserved casts of *Calamites* within the sandstone, indicating proximity to their point of entrainment.

Crevasse splays in modern delta plain environments are commonly channelized near their channel source, becoming less confined downcurrent (Coleman, Gagliano and Webb, 1964; Arndorfer, 1973), and are characterized by periodic, high energy discharges into standing water. Initial channel bank breaching causes erosion and entrainment of channel bank material which is subsequently re-deposited further downcurrent (Elliott, 1978).

Thus, the sequence deposited at Cabin House/Mown Meadows may be assigned to a proximal, axial setting in the crevasse splay/minor delta depositional sub-system and distinguished from others, examples of some of which have been described already.

From the multi-storey nature of the sandstone body, deposition on the crevasse splay lobe is inferred to have taken place in several, possibly discrete, events (The loaded base of the crevasse sandstone implies that crevasse sedimentation took place while the underlying peat was still soft). Following abandonment of the crevasse lobe, which in this case apparently took place without any major diversion of the source channel, silts were laid down perhaps by overbank and other comparatively low-energy processes.

The ripple cross-lamination in thin sandstone beds contained within the claystone sequence in the north suggest that these beds may not represent preliminary pulses of sedimentation from the major crevasse, but may have come from a separate source to the north-east (Fig. 6.43).

6.8.2.3 Sediments above the "Top Tilley Post"

Description

The sediments between the top of the "Top Tilley Post" sandstone and the Harvey coal were examined at five localities; Rowley, Esh Winning, Deborah, Binchester Crags and Cobey Carr.

At these localities, vertical sequences of between 2 and 8 m of mainly fine-grained, rootlet-penetrated sediments were exposed, and in certain cases included a thin coal or coaly shale referable to the Hodge (0000), (see, for example, Section 024:- Appendix 1).

At Rowley, a sequence of laminated claystones with sandy streak contains northward-directed ripple cross-lamination and ripple form sets (Unit 10; Fig. 6.26). A similar sequence at Cobey Carr is overlain by a 1.33 m thick, sharply-bounded sandstone containing ripple cross-lamination directed towards the south-west (Fig. 6.31; Units 8-11). Small siderite lenses and nodules are abundant in almost all

the observed sequences.

Interpretation

The sediments described above were largely deposited from suspension, with minor contributions from relatively low-energy tractional flows. The sharply-bounded sandstone at Cobey Carr was deposited by a comparatively powerful, probably unconfined, traction current.

The exposed sequences are interpreted as the products of shallow floodbasins and swamps, which developed as the deposits of the abandoned "Top Tilley Post" channel systems slowly subsided. The completely rootlet-penetrated nature of the sequences suggest that water depths were rarely greater than the threshold for plant colonization; 3-4 m sequences of sediment are unlikely to have been penetrated by a single generation of plant and root development, and rootlets can be seen to terminate at all levels within sequences, implying repeated colonization of sediment surfaces.

The sharply-based sandstone exposed at Cobey Carr is interpreted as the deposit of a minor crevasse splay which flowed towards the south-west, and probably infilled the shallow basin (1.5 m deep) in which it accumulated.

6.8.3 The Harvey Coal

The Harvey coal (NOOO in the N.C.B. nomenclature; see Fig. 6.1) has been extensively worked across the Durham coalfield, being of great lateral persistence and good quality. The seam generally ranges up to 2,0 m in thickness, but in one narrow belt in the south reaches the exceptional thickness of 2.29 m (Fig. 9 of Smith and Francis, 1967).

Where of workable thickness, the Harvey is often banded, but may equally be composed of continuous coal.

Towards the south of the coalfield, and along the coast, the Harvey coal splits into Bottom and Top Harvey seams (N100 and N200 respectively), which are rather more unpredictable in thickness and quality, and of which only the Bottom Harvey has generally been worked (Fig. 6.44).

Sulphur values in the Harvey coal are characteristically variable, values encountered being between 1.1 and 3.05%.

Six exposures of the Harvey horizon were examined, those mentioned in the previous passage, and Buckhead O.C.C.S. (G.R. NZ 138243), (Section 208:- Appendix 1).

6.8.4 Discussion

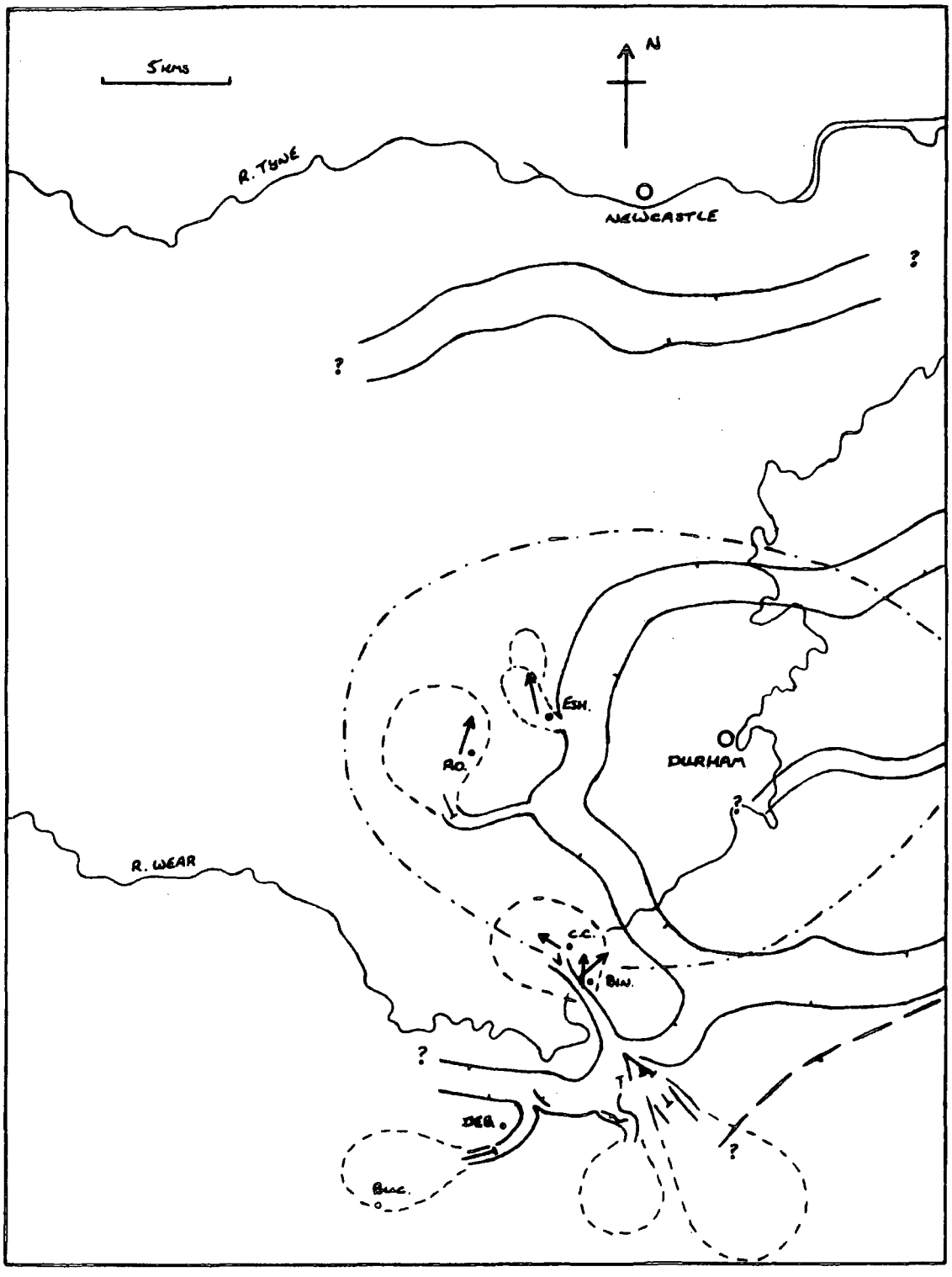
From first impressions, the Top Tilley-Harvey interval would seem to be characterized by numerous channel sandstones; of five man-made exposures visited, four exposed the "Top Tilley Post".

Tentative channel and channel belt patterns for the interval are presented in Fig. 6.41, and show that areal channel density was no greater than for underlying sequences. This implies that recurrent encounters with channel sandstones are probably a sampling bias.

Fig. 6.41 shows that the "Top Tilley Post" channels were contained in belts of moderate sinuosity up to 10 kms wide. The identification of uneroded "islands" of sediment within channel belts suggests that individual major channels may have been of the order of 1-2 kms wide, and the orientations of palaeocurrent vectors and seam washouts within the channel belts suggest that individual channels were sinuous in form (Fig. 6.41). Migration of these channels within "meander belts" produced the complex internal structure of the "Top Tilley

Fig.6.44

THE HARVEY COAL, POST-HARVEY PALAEOCURRENTS AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS



CHANNEL AND CHANNEL BELT MARGINS

WASHOUTS IN HARVEY COAL

MINOR DELTA LOBE (SCHEMATIC)

AREA OF IMPOVERISHED HARVEY COAL.

LINE OF SPLIT IN HARVEY COAL (SEAM SPLIT ON ORNAMENTED SIDE)

ESH. - ESH WINNING O.C.C.S. ($\wedge = 6$)

RO. - ROWLEY O.C.C.S. ($\wedge = 2$)

C.C. - COBEY CARR QUARRY ($\wedge = 8$)

BW. - BWCHESTER CRAGS ($\wedge = 15$)

DEB. - DEBORAH O.C.C.S.

BUC. - BUCKHEAD O.C.C.S.

PALAEOCURRENT VECTOR MEAN.

Post" sandstones shown, for example, by the Rowley exposures (Enclosure 6).

The general setting for the Top Tilley-Harvey interval is not thought to differ greatly from that of lower stratigraphical levels; inspection of channel belt maps discussed previously reveals many of the features better-displayed on Fig. 6.41 (largely a function of the availability of data).

Thus it is suggested that major channels crossing the Upper Westphalian A plain were of sinuous or meandering form, and given adequate time, developed the tendency to migrate within quite narrow belts. From the presence of minor channel deposits superimposed upon those of larger channels at Rowley (Enclosure 6, Fig. 6.42), the discharge pattern at any one locality within the channel belts was variable in the long term, as well as on the shorter timescale already demonstrated. The variety in the style of abandonment shown by the deposits of these channels is to be expected, given this pattern of controlled migration (Ch. 6.8.2.1).

One feature of the upper Westphalian A sediments (Busty to Harvey) worthy of note is the increasingly terrestrial aspect of the sequence, manifested in the abundance of features suggestive of base level fluctuations (kaolinitic claystones, desiccation cracks, vertically oriented nodules in palaeosol profiles), of rootlet penetration and coals in sequences, of very shallow lacustrine basins. and of the development of channel meander belts.

The increase in "continentality" may in turn reflect a transition to fluvial plain conditions; this topic will be returned to in Ch. 10, 3.

The controls on peat accumulation for the Hodge and Harvey seams are considered to be similar to those of lower seams. The

areas of impoverished Harvey can be related, to some extent, to the inferred distribution of underlying channel sands (Figs. 6.41, 6.44). As before, channels show evidence of avoiding pathways taken by former channels (Figs. 6.39, 6.40, 6.41).

The proximal crevasse lobe sequence exposed at Cabin House/ Mown Meadows is shown in its' regional context on Fig. 6.41. The available evidence suggests that this exposure was situated approximately 1 km from the channel from which its' sediment was derived.

6.9 HARVEY COAL TO HARVEY MARINE BAND

6.9.1 Introduction

The uppermost part of the Westphalian A (or Lower Coal Measures) sequence in Co. Durham, between the Harvey coal and the Harvey (=*VANDERBECKEI)* Marine Band, generally comprises 6-20 m of strata. Thin, impersistent coals are present at several horizons (e.g., the 2MOO and 1MOO seams, sometimes named Penny Hill and Harvey Marine, respectively; Fig. 6.1), and thick, laterally extensive sandstones are relatively rare.

Over a large part of the coalfield, the Harvey coal is overlain by a prominent non-marine faunal horizon, the "Hopkins Shell Bed" (Armstrong and Price, 1954). This bed is characterized by abundant non-marine bivalves, annelids and ostracods (Smith and Francis, 1967). Also in the roof measures of the Harvey coal, certain workers have noted the presence of "fragmental clayrocks" (Richardson and Francis, 1971; Smith and Francis, 1967, p. 57).

In addition to the presence of laterally impersistent seatearths and coals throughout the interval, the horizon immediately under-

lying the Harvey Marine Band often comprises a seatearth, occasionally accompanied by a thin coal.

The base of the Harvey Marine Band marks the base of the Middle Coal Measures or Westphalian B sequence in the Durham coalfield, and this horizon will be considered in Ch. 7.2.2.

Sediments representing the interval between the Harvey Coal and Harvey Marine Band were examined at six localities; Rowley O.C.C.S., Esh Winning O.C.C.S., Cobey Carr Quarry, Binchester Crags, Buckhead O.C.C.S., and Deborah O.C.C.S.

6.9.2 Sediments between the Harvey coal and Harvey Marine Band

6.9.2.1 Rowley O.C.C.S.

Description

At Rowley O.C.C.S., a 9 m thick sequence was exposed in two sets of workings (Enclosure 3, Fig. 6.26).

A rootlet-penetrated siltstone or fine-grained sandstone overlies the Harvey coal across much of the area exposed (see, for example, Sections 110, 111, 289:-Appendix 1), (Unit 10; Fig 6.26). In some sections, the upper part of this unit contains small, angular, buff-coloured aggregates of kaolinite (up to 1 cm in diameter) and at the same horizon exhibits alternating laminae of ankeritic clay and comminuted organic debris (Section 289, for example).

Above this bed, or its' fine-grained lateral equivalent, lies a thin (0.10-0.20 m), well-indurated, very fine-grained sandstone containing abundant shell impressions of non-marine bivalves, occasionally underlain by a thin claystone band. This laterally persistent shelly sandstone served as a useful marker horizon across the site.

A 2.7 m sequence of mostly laminated claystones, the upper part of which is rootlet-penetrated and contains coaly traces, then underlies the 0.17 m thick "Harvey Marine" Coal (Units 12 and 13; Fig. 6.26).

Above this coal, up to 3.5 m of dark grey, thinly-laminated claystones (Unit 14) are overlain by Pleistocene drift deposits. These "shales" yield occasional fish scales.

Limited lateral variability was displayed by the exposed sediments, particularly in those between the Harvey coal and the shaly sandstone. However, data coverage is not sufficient to allow a meaningful three-dimensional analysis. Palaeocurrent measurements from ripple cross-lamination in the basal sandstone indicate palaeoflow towards the north, and this sandstone also appears to thin and fine in the same direction.

Interpretation

The exposed sediments were evidently deposited largely from suspension or by gentle tractional currents, with occasional influxes of coarser material transported by stronger currents. The Rowley sequences are interpreted as having been laid down largely in shallow, lacustrine environments. The basal sandstone/siltstone unit may be interpreted as a crevasse splay deposit, which prograded northward, filling the shallow basin and allowing plant colonization. The kaolinitic claystone lithology within this unit, and the interlamination of ankeritic clay and organic matter, are tentatively interpreted as the result of soil-forming processes in a shallow water submerged environment.

The mode of occurrence of kaolinite in these sediments is very similar to that in the Middle Tilley kaolinite claystones exposed at the same site (see Ch. 6.7.4.1), although the sediment itself in the former case is rather less well-indurated. This in turn could be a simple function of enclosing lithology and compaction. Ankerite is commonly associated with oxidation of coal and coal-bearing rocks, and this unusual mode of occurrence may be significant.

The tentative interpretation of this kaolinitic claystone as a soil phenomenon does not entirely accord with that of Richardson and Francis (1971), who ascribed the supra-Harvey and other "fragmental clayrocks" to kaolinite gel formation in a swamp environment, subsequent crystallization and compactional deformation. Derivation by subsurface pedogenic processes is considered here to be more important than swamp surface crystallization, as proposed by Richardson and Francis (1971), from the similarity between the supra-Harvey lithology and the Middle Tilley kaolinitic claystones at the same locality. Furthermore the wide range in shape of kaolinite "graupen" seems unlikely to have resulted from extensive compactional deformation, (Plates 6.14, 6.16), and implies that the "graupen" were formed before any substantial compaction took place (see also Ch. 6.7.4.1).

The shelly sandstone may be interpreted as the distal deposit of a crevasse splay, which overwhelmed and transported bottom-living bivalves.

Lacustrine environments seem to have been very shallow around the time of accumulation of the Harvey Marine coal, judging by the frequent presence of rootlets beneath the seam.

Following accumulation of the Harvey Marine coal, subsidence

led again to a lacustrine environment, but in this case with virtually no traction current-derived sediment input. The fine-grained well-laminated nature of the sediments and the fish remains may suggest that the lake was somewhat deeper than the 2-3 m characteristic of Westphalian A environments, but no direct evidence is available.

The sequence exposed above the Harvey coal thus records the transition from swamp conditions to a ? deep, lacustrine environment.

6.9.2.2 Esh Winning O.C.C.S.

Description

At Esh Winning O.C.C.S. the entire interval between the Harvey coal and Harvey Marine Band was exposed, and was broadly similar to that described from Rowley (Fig. 6.38), (Appendix 1, Enclosure 11).

A series of two coarsening-upward sequences 2.0 and 1.25 m thick (Unit 6; Fig. 6.38) overlie the Harvey seam. The basal claystones of the lowermost contain abundant flattened bivalve impressions (Hopkins Shell Bed), and at one locality, the whole of Unit 6 was represented by claystones (Section 040:- Appendix 1). The two coaraseing-upward sequences are erosively overlain by a 2m thick sandstone (Unit 7), in turn succeeded by 6.5 m of interbedded fine-grained sandstones, siltstones, claystones and thin coals (2MOO, 1MOO), leading up to the horizon of the Harvey Marine Band (Units 8-10), (Plate 6.35). The upright *in situ* cast of a tree trunk 0.3 m in diameter was found in the roof sediments of the uppermost coal (1MOO - Harvey Marine). Dark-coloured shales with abundant, flattened plant casts comprise the uppermost part of the sequence.



Plate 6.35 - Sediments overlying the Harvey Marine coal at Esh Winning O.C.C.S., including the horizon of the Harvey Marine Band (H). Exposed face is about I5m high.

Palaeocurrent measurements from ripple cross-lamination in Unit 7 indicate a palaeoflow towards the north-north-west.

Interpretation

The two coarsening-upward sequences are interpreted as partial infills of shallow lakes, since they contain no evidence of plant colonization or subaerial exposure. The sharply-based sandstone is interpreted as a north-north-west prograding,crevasse splay deposit, and the overlying coals as swamp peat accumulations. The upright tree may be interpreted as having been preserved due to rapid burial by coarse sediment as the "Harvey Marine" swamp subsided,and the uppermost part of the sequence as the deposits of a subsiding lake which received little or no coarse-grained clastic input. The horizon of the Harvey Marine Band lies in the middle of a 10.5 m sequence of dark-coloured shales.

Thus at Esh Winning, as at nearby Rowley, the sediments immediately underlying the Harvey Marine Band record a decline in sediment supply, accompanying the development of a subsiding, sediment-starved lake environment.

6.9.2.3 Cobey Carr/Binchester Crags

Description

Similar sequences representing the Harvey-Harvey Marine Band interval are exposed at the adjacent Cobey Carr and Binchester Crags exposures (Figs. 6.31, 6.32).

At Binchester Crags the sequence, with occasional gaps, comprises a total of 12.2 m of interbedded sharply bounded, fine-grained sandstones and thin coals which may include the horizon of the Harvey Marine Band (Units, 8, 9; Fig. 6.32). Ripple cross-lamination indicates palaeoflow towards the north-east, east-north-

east and north. The upper parts of most sandstones are penetrated by rootlets and *Stigmarian* roots.

At Cobey Carr Quarry, two stacked coarsening-upward sequences (Units 13 and 14 ; Fig. 6.31), in total 5-6 m thick, comprise the entire Harvey-Harvey Marine Band interval. Equivalent to the lower coarsening-upward sequence in the inaccessible south-east corner of the quarry is a 30 m wide and 1 m or so deep channel (Plate 6.31). The lowermost of these coarsening-upward sequences is 2.7 m thick and contains no evidence of rootleting, whilst the upper sequence, 2.3 m thick, contains rootlets in its' uppermost part. Ripple cross-lamination in the upper sequence indicates palaeoflow towards the west-north-west.

The uppermost part of the Westphalian A sequence at Cobey Carr is no longer exposed, but subsurface records and spoil heaps indicate that a thin coal is overlain by the shales which include the Harvey Marine Band.

Interpretation

The sequence exposed at Binchester Crags is interpreted as the result of repeated north to eastward-directed crevasse splay deposition in shallow lacustrine basins which, from the presence of rootlets in the upper parts of sandstones, were no more than 3 m deep and probably less than this. Occasionally, the basins were infilled sufficiently to allow peat accumulation, giving rise to the thin coals.

The lower and upper coarsening-upward sequences at Cobey Carr are interpreted, as a partial lacustrine delta infill, and as a complete infill respectively. The anomaly between sequence thickness and degree of lacustrine infill, as interpreted from the

presence or absence of rootlets, may be explained by the timing of the two events; the first phase of partial infill was followed by the second phase before the lake bottom had time to subside back to its' original level.

The sequences at the two localities, or at least the lower levels, may have been part of the same crevasse-initiated lacustrine infill complex, from the general similarity in interpreted setting and palaeocurrent directions. The channel exposed at the south-east end of the Cobey Carr quarry may then be interpreted as a minor distributary channel which crossed the abandoned part of the minor delta system to supply the actively prograding delta front. The crevasse splays at Binchester Crags may have been lateral offshoots from the delta, or may possibly have been in a similar setting to those exposed above the Bottom Busty coal at Deborah O.C.C.S. (Ch. 6.6.4.3).

6.9.2.4 Deborah O.C.C.S./Buckhead O.C.C.S.

Description

At the Deborah and Buckhead sites, sequences of dark grey, thinly laminated claystones containing flattened impressions of non-marine bivalves overlie the Harvey coal (Sections 140 and 208 respectively:- Appendix 1). In one part of Deborah O.C.C.S. a 2 m+ sharply-based sandstone containing trough cross-bedding, and primary current lineation was observed overlying approximately 2.8 m of shales.

Interpretation

The thinly laminated, bivalve-bearing claystones are interpreted as the deposits of sediment-starved lakes, and the sharply-based sandstone as a crevasse or series of crevasse splay deposits.

6.9.3 Discussion

The pattern of channel belts operative during the Harvey coal-Harvey Marine Band interval is shown on Fig. 6.44, and shows that channels or channel belts 1-2.5 kms wide avoided areas of former channel courses, and in some cases flowed across areas of thickened Harvey peat where autocompaction might have stimulated accelerated subsidence.

Comparison of Fig. 6.44 with channel belt maps for earlier intervals shows a marked decrease in channel density. This is not believed due to a shorter period of time being available for channel operation, since the Harvey-Harvey Marine Band interval is as thick as those lower in the sequence, and composed predominantly of slowly-deposited sediments. The low channel density and comparative narrowness of channel belts, and the abundance of thick claystone sequences at this level in the Durham coalfield, is considered most likely to reflect diminishing sediment supply to the area (increased subsidence is discounted as a possible cause, from the inferred shallowness of post-Harvey lacustrine basins, and abundance of coals and rootlet penetration of sequences).

The widespread development of the Hopkins Shell Bed in the roof of the Harvey coal is consistent with an overall decline in sediment supply.

The decrease in inferred sediment in uppermost Westphalian A times forms an interesting progression from the increased continentality deduced from the Busty to Harvey (and post-Harvey) intervals, and evidently led to gradual drowning of the sediment surface (on a regional scale), as indicated by the preservation of thick claystone sequences above the 2MOO/1MOO coals.

It is thus likely that the *VANDERBECKEI* marine incursion was encouraged, or possibly even caused, by failure in sediment supply in latest Westphalian A times. This failure seems likely to be the result of large scale deltaic processes, i.e., delta switching, following a build-up of the sediment surface to more-or-less entirely terrestrial, ? fluvial plain levels. This topic will be returned to during a discussion of the evolution of the Coal Measures environment in Ch. 10.3.

CHAPTER VII - THE WESTPHALIAN B OF THE DURHAM COALFIELD

7.1 INTRODUCTION

The Westphalian B succession of the Durham coalfield is approximately 300 m thick (Fig. 7.1). It lies between the Harvey (=*VANDERBECKEI*) and Ryhope (=*AEGIRANUM*) Marine Bands and contains at least thirteen workable coals, concentrated in the lower half of the interval. Many of these coals reach thicknesses of greater than 2.0 m, and are generally thicker than their Westphalian A counterparts.

The upper part of the Westphalian B interval is similar to the basal Westphalian A in containing a number of marine horizons, notably the High Main (=*MALTBY*), Kirkby's (=*HAUGHTON*) and Hylton (=*SUTTON*) Marine Bands (Fig. 7.1), (Ramsbottom *et al.*, 1978). In contrast to the latter, however, no quartz arenitic sandstones occur within the upper Westphalian B sequence.

The Westphalian B Coal Measures of north-east England have previously been described by Haszeldine (1981a), who provided detailed case studies on three intervals (Hutton to Brass Thill, Low Main to Maudlin and Maudlin to Main; see Fig. 7.1).

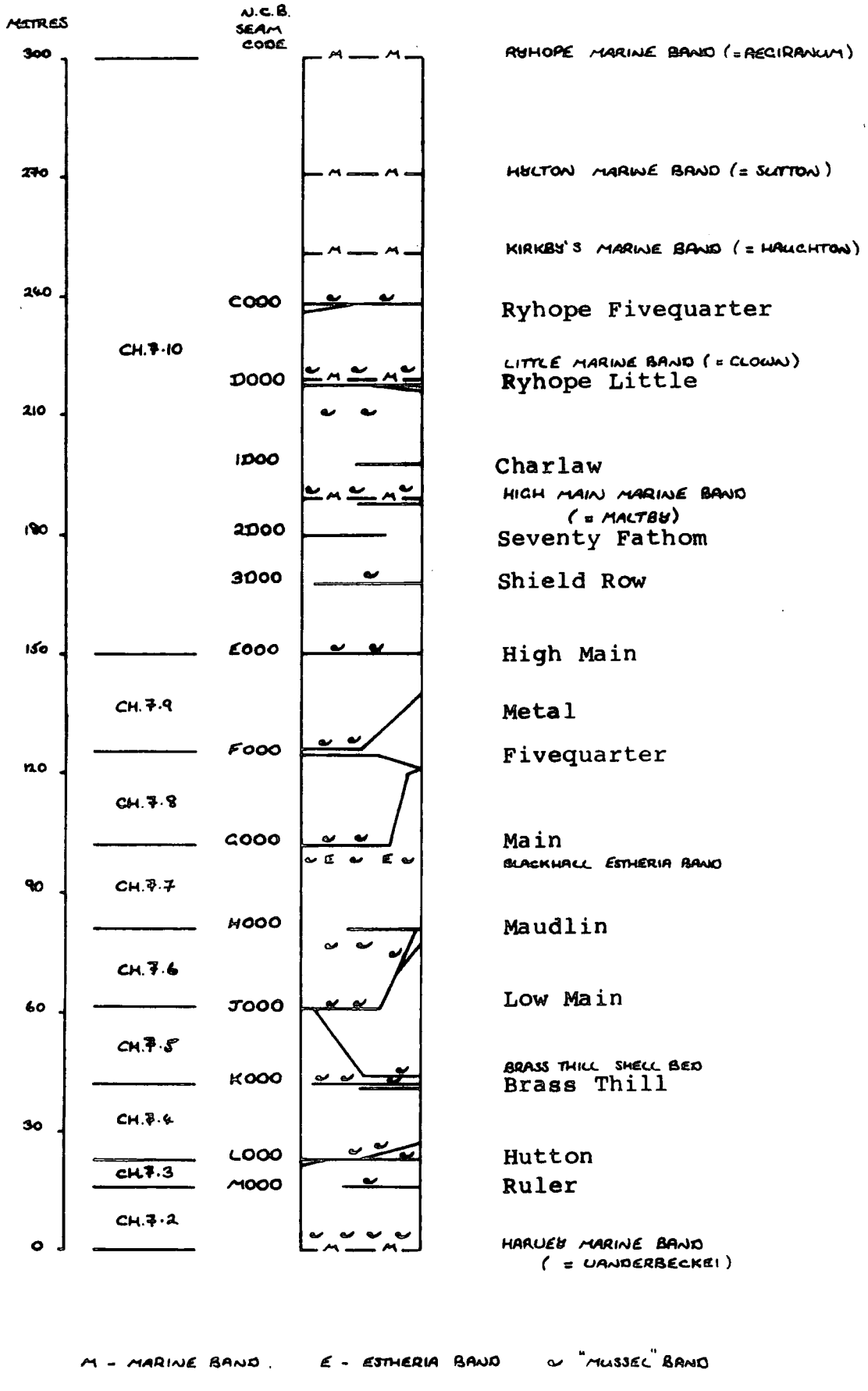
7.2 HARVEY MARINE BAND TO RULER COAL

7.2.1 Introduction

The interval between the Harvey Marine Band and Ruler coal comprises 15-30 m of strata, of variable character. Seatearths and thin coals are present in some areas, whereas in others thick sandstones occupy much of the interval.

Fig.7.I

WESTPHALIAN B STRATIGRAPHY OF THE DURHAM COALFIELD



Several non-marine "mussel bands" occur, one of which, lying directly above the Harvey Marine Band, is laterally persistent (Fig. 7.1).

In the Consett area, a claystone above the Harvey Marine Band is rich in siderite nodules and bands, and has been worked commercially in the past. It is known locally as the "Ten Bands Ironstone".

The Harvey Marine Band itself was not positively identified by the author, although its' horizon was probably exposed at four examined localities. Four exposures of overlying sediments were examined.

7.2.2 The Harvey Marine Band

The Harvey (=*VANDERBECKEI*) Marine Band, which marks the base of the Westphalian B or Middle Coal Measures, generally consists of a few cms of fissile, dark-coloured claystone, containing abundant remains of *Lingula mytilloides*. Other fossils occasionally found include *Orbiculoidea*, *? Holinella* and fragments of several species of fish (Smith and Francis, 1967; Mills and Hull, 1976). In the Durham coalfield, the *VANDERBECKEI* Marine Band is thus of "Lingula facies" (Calver, 1968a).

The band is commonly developed across the Durham coalfield, but is not ubiquitous. At Esh Winning O.C.C.S. (Fig. 6.38), dark "platy" shales marking the horizon of the Marine Band were seen, but no marine fossils were collected. Elsewhere, for instance at Rowley O.C.C.S. (Fig. 6.26) and Binchester Crags (Fig. 6.32), the level of the Harvey Marine Band is occupied by sharply-based, fine-grained sandstones.

7.2.3 Sediments between the Harvey Marine Band and Ruler Coal

Description

Sandstones representing the sequence above the Harvey Marine Band were examined at Esh Winning O.C.C.S. (Fig. 6.38, Plate 6.35), Cobey Carr Quarry (Fig. 6.31), Sheep Hill Quarry (G.R. NZ 174573) and Langley West Quarry (G.R. NZ 194462), (Fig. 7.2).

Exposures range up to 14 m in vertical thickness (at Sheep Hill), and borehole records indicate that sandstones in this stratigraphical interval are commonly greater than 20 m. The sandstones are similar in character to previously-described "major sandstones", being erosively-based and trough cross-bedded. Shale clasts are common, as are ferruginous concretions and fine-grained micaceous/carbonaceous partings.

Trough cross-sets are typically shallow and wide (for example, 0.3 m high and 3.0 m wide, at Sheep Hill).

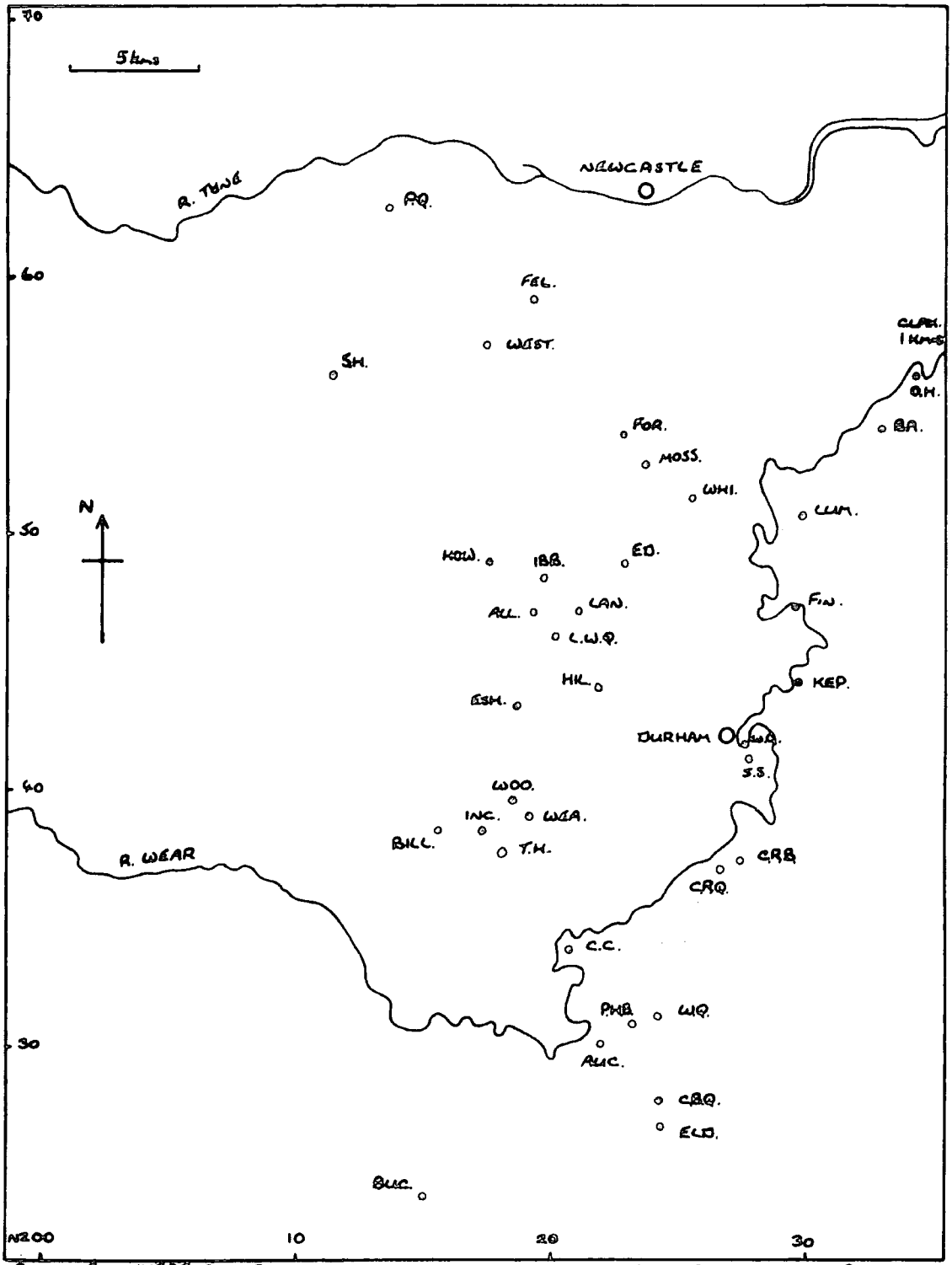
Palaeocurrent measurements from trough cross-sets indicate palaeoflow towards the east (Cobey Carr) and north (Sheep Hill and Langley West),(Fig. 7.3).

Interpretation

The exposed thick sandstones, and those detected from subsurface records, are interpreted as major channel deposits. No channel margins were deserved, and likewise no indication as to the structure of channel fill was seen, other than that channels were obviously filled whilst active (from the sediment grain size).

Fig.7.2

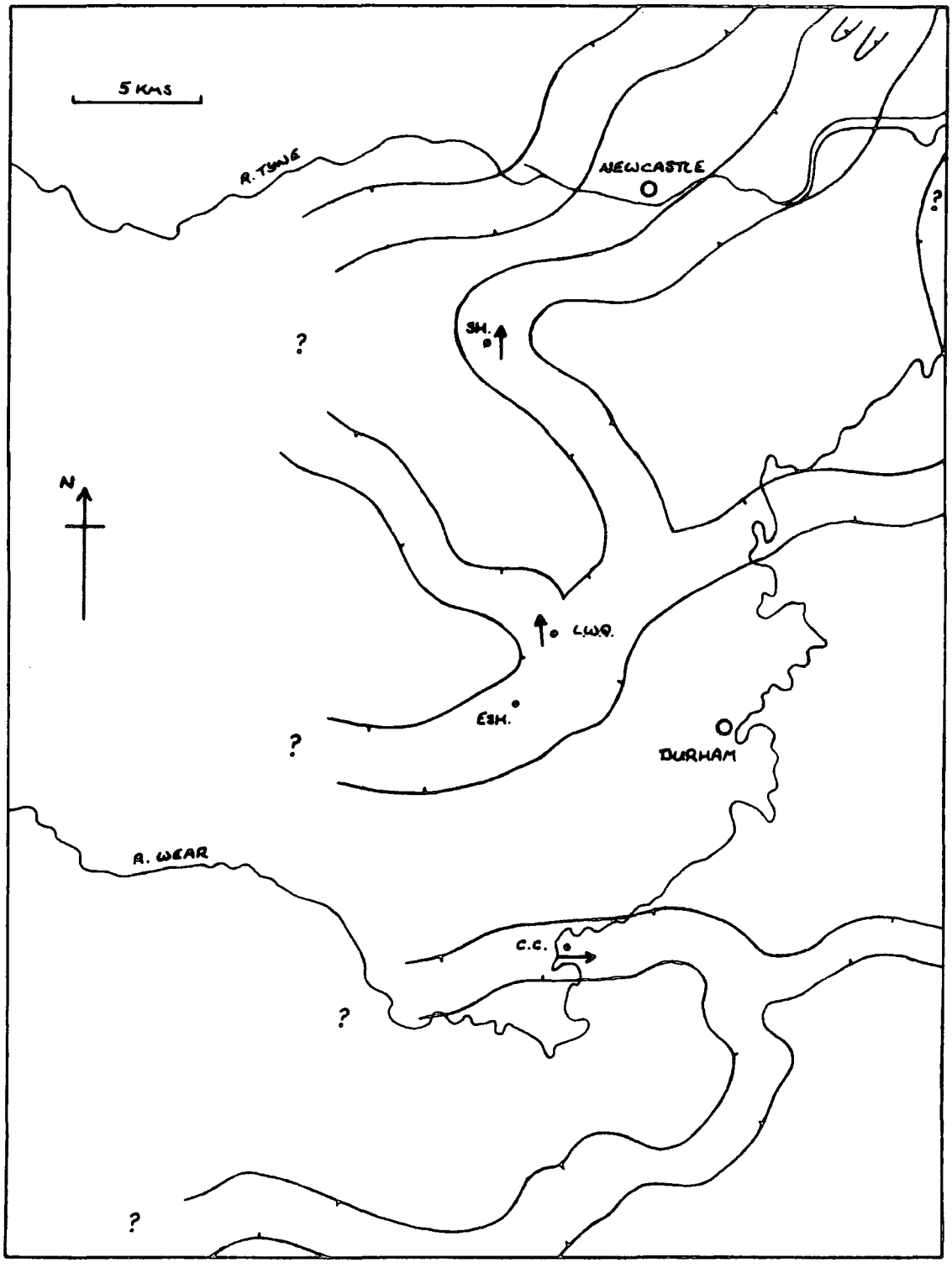
LOCATIONS OF EXAMINED EXPOSURES IN WESTPHALIAN B/C SEDIMENTS



BUC. - BUCKHEAD O.C.C.S.
BARN. - BARNWELL QUARRY
BILL. - BILLY HILL O.C.C.S.
CLAR. - CLAXHEUGH ROCK
C.C. - COREY CARR
CRB. - CROWDALE BECK
CRQ - CROWDALE QUARRY
CBQ - CROSSLEY BRICKS QU.
ESH. - ESH WINNING OFFS.
ELD. - ELDON HILL QUARRY
FIN. - FINCHALE GORGE.
FEL. - FELLSIDE QUARRY
FOR. - FORCEBANK PLANTATION
HIL. - HILLTOP QUARRY
HOW. - HOWDEN GILL
INC. - INCLINE O.C.C.S.
IBB. - IBBETSONS O.C.C.S.
KEP. - KEPIER QUARRIES
LWQ. - LANGLEY WEST QUARRY
LAN - LANGLEY O.C.C.S.
LUM. - LUMLEY PARK BURN
MOSS. - MOSS CLOSE O.C.C.S.
O.H. - OFFERTON HEUGH
P.Q. - PHOENIX QUARRY
P.H.B. - PARK HEAD BANK
S.S. - SCIENCE SITE B.H.
SH. - SHEEP HILL QUARRY
T.H. - TANNERS HALL O.C.C.S.
WEST. - WESTWOOD COLLIERY QU.
WOO. - WOOLEY O.C.C.S.
W.C. - WEAR GORGE, DURHAM.
WEA. - WEATHER HILL QUARRIES.
WHI. - WHITEHALL SHALE QUARRY.
WQ. - WESTERTON QUARRIES
ALL. - ALLOTMENT QUARRIES
ALC. - ALCKLAND PARK
ED. - EDMONDSLEY O.C.C.S.

Fig.7.3

POST-HARVEY MARINE BAND PALAEOCURRENTS, AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS



CHANNEL AND CHANNEL BELT MARGINS

WASHOUT IN HARVEY MARINE BAND

PALAEOCURRENT VECTOR MEAN

SH. - SHEEP HILL QUARRY (∧ = 9)

LWQ. - LANGLEY WEST QUARRY (∧ = 6)

ESH. - ESH WINNING O.C.C.S.

C.C. - COBEY CARR QUARRY (∧ = 6)

7.2.4 The Ruler Coal

The Ruler coal (M000 in the N.C.B. nomenclature; see Figs. 2.6, 7.1) is a relatively unimportant seam in mining terms, but marks the first return to coal-forming conditions after the *VANDERBECKEI* marine incursion (Fig. 7.1).

The seam is generally of the order of 0.15-0.20 m thick, but is laterally very persistent and used as a stratigraphical marker in the basal Westphalian B sequence. In the extreme south-west and north-west parts of the coalfield, the Ruler coal (known in these parts as the Jubilee and Plessey respectively) reaches workable thickness and may be up to 0.97 m thick (Mills and Hull, 1976),(Fig. 7.4). In these areas the seam is often "banded", or even split into two or more separate "leaves" (Bottom Ruler:- M100 and Top Ruler:- M200). Further north, the Plessey coal becomes one of the principal seams of the Northumberland coalfield (Land, 1974).

Sulphur levels in the Ruler coal are highly variable, values encountered ranging from 0.69 - 3.32%. The higher values of this range are associated with samples from the southern part of the coalfield.

No surface exposures of the Ruler seam were examined.

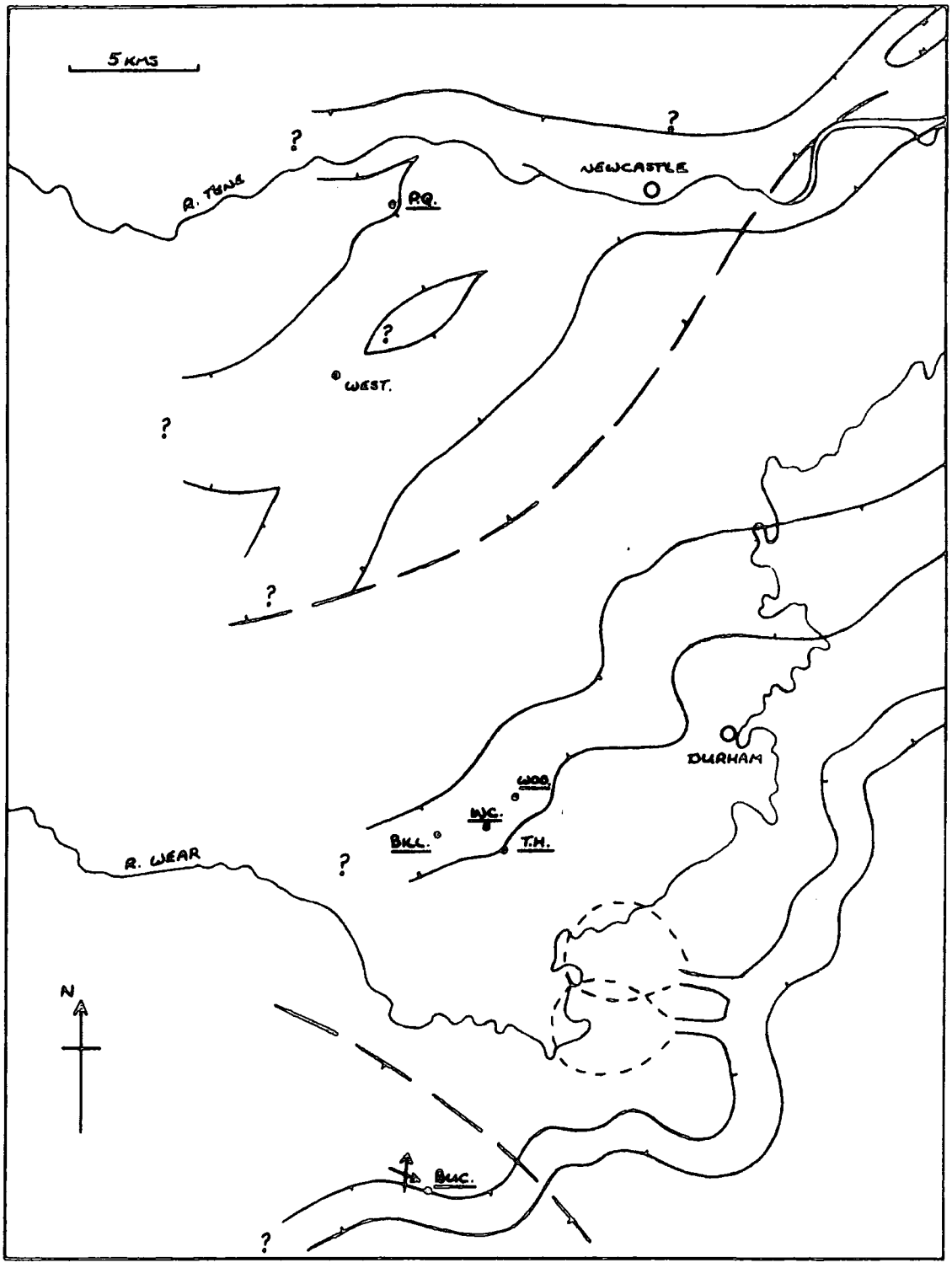
7.2.5 Discussion

The interval between the Harvey Marine Band and the Ruler coal may be regarded as the result of adjustment by the Coal Measure depositional system to the elevated base level conditions of the *VANDERBECKEI* marine incursion, and the gradual return to conditions established prior to this inundation.

The return of widespread coal-forming conditions was achieved

Fig.7.4

THE RULER COAL, AND SPECULATIVE POST-RULER CHANNEL/CHANNEL BELT TRENDS



CHANNEL AND CHANNEL BELT MARGINS (RULER - HUTTON/BOTTOM HUTTON)

WASHOUT IN RULER COAL

MINOR DELTA LOBE (SCHEMATIC)

RULER COAL OF WORKABLE THICKNESS (ON ORNAMENTED SIDE OF LINE).

WEST. - WESTWOOD COLLIERY QUARRY

P.Q. - PHOENIX QUARRY

WOO. - WOOLEY O.C.C.S.

INC. - INCLINE O.C.C.S.

T.H. - TANNERS HALL O.C.C.S.

BKL. - BILLY HILL O.C.C.S.

BUC. - BUCKHEAD O.C.C.S. (Λ = 11)

DAILY BOTTOM - TOP HUTTON EXPOSED

over a considerable period of time, judging by the common occurrence of thick (up to 30 m), unbroken claystone sequences, and from the complexity of inferred major channel patterns, shown on Fig. 7.3, (see Ch. 5.2.2 for an introduction to the channel belt maps used in this thesis, their construction and sources of data).

The channels themselves are closely similar in size and form to those identified in underlying levels, being of moderate to high sinuosity and up to 3.5 kms in width. Channel courses proved difficult to trace over distances of greater than about 15 kms, but from the absence of sediment "islands", and from a comparison with Upper Westphalian A channel belt patterns, the channel courses shown on Fig. 7.3 are mostly considered to represent single channels.

The presence of ? single channels and the evidence for a number of major crevasse events on Fig. 7.3 are interpreted as the result of adjustment to deeper water conditions brought about by the *VANDERBECKEI* marine incursion, whereby channels accreted dominantly in a vertical direction and then became unstable with time (see Ch. 6.2.4). The increased channel density shown on Fig. 7.3 in comparison to Fig. 6.44 confirms that although relative base level rise may have contributed to the low channel density of post-Harvey coal times, diminished sediment supply was probably the dominant control. As mentioned in Ch. 6.9.3, this reduction in sediment supply, perhaps coupled with a resurgence of local tectonic movements, could have caused the widespread development of the Harvey Marine Band in the Durham area. The depth of water in the "*VANDERBECKEI* sea" cannot have been more than 10-15 M, since sinuous distributary channels were still able to pass across the basin floor, directly

over marine sediments and since palaeontological evidence suggests that only marginal marine conditions were developed (Calver, 1968a). A lack of minor delta progradational deposits in the lower part of the Harvey Marine Band-Ruler interval may be explained by the vertical accretion of channels suggested above; coarse-grained sedimentation was probably restricted to the areas around channels until such time as the sediment surface had "recovered" to some extent.

No evidence of any substantial shoreline reworking has been recorded at the level of the Harvey Marine Band; this is interpreted as a result of the great distance between the Durham area and the fully marine Upper Carboniferous ocean, where the effects of waves and tides would be more pronounced, and the inability of storm waves in the shallow-water setting to create sufficient energy to redistribute sediment significantly. This situation may be contrasted with that surrounding the basal Westphalian A marine bands, where the lower delta plain environment of that time seems to have been more open to direct marine influence (Ch. 6.2). Significantly, no quartz arenite "ganisters" are known from the Westphalian B.

Despite the lack of true marine influence on the basal Westphalian B sediments, the *VANDERBECKEI* incursion had a profound "dampening" effect on sedimentation, and only by the time of accumulation of the Ruler peat had the depositional surface returned to its previous elevation.

Controls of the thickness of the Ruler seam are not immediately obvious, though by comparison with earlier coals may be associated with the presence or absence of underlying channel sand deposits (Figs. 7.3, 7.4).

7.3 RULER TO HUTTON COALS

7.3.1 Introduction

The interval between the Ruler and Hutton coal seams varies between about 5 and 30 m, thicker partings being associated with a greater content of sandstone.

A thin, unnamed coal (IL00) is sometimes present in the middle of the interval.

An abundant assemblage of non-marine bivalves, *Spirorbis* and fish scales is commonly found in the roof of the Ruler coal, or its' horizon where absent, and a similar association occurs in the Bottom Hutton roof shales.

One exposure of sediments representing the Ruler-Hutton interval was examined, and a further six of the Hutton seams and sediments between them.

7.3.2 Sediments between the Ruler and Hutton or Bottom Hutton coals

Only one poorly-exposed outcrop of sandstone was examined in this interval, that at Westwood Colliery Quarry (G.R. NZ 118559), (Fig. 7.2). No detailed description or interpretation has been attempted, due to the poor quality of the exposure.

7.3.3 The Hutton coal

The Hutton coal (L000:see Fig. 7.1), is the lowest worked seam in the Durham Westphalian B sequence, and ranges up to 2.36 m in thickness.

It is generally thickest in the northern half of the coalfield, where it occurs as a single, commonly banded, seam. However, it is known to split into Top Hutton (L200) and Bottom Hutton (L100) coals in three areas (Fig. 7.5), (N.C.B., 1961). These "seam splits" are of two types; "floor splits", where the separation occurs near the base of the seam, and "roof splits", where the coal divides towards the top. Separation between the split Hutton coals begins as a thin (as little as 0.01 m) band, and may develop to as much as 5 m in the case of "floor splits" and 20 m for "roof splits".

Immediately to the south of the east-west-trending "roof split" along latitude NZ40, both Bottom and Top Hutton seams are of workable thickness (usually 0.51-1.02 m), but further south only the Bottom Hutton (up to 1.30 m thick) is worked, the Top Hutton being thin and laterally impersistent (Fig. 7.5), (N.C.B., 1961).

Sulphur values for the Hutton coals vary greatly between 0.9% and 5%, the higher values being most commonly associated with the split Hutton seams in the southern part of the coalfield where the ash content of the seam is also increased.

Six localities exposing the separated Bottom and Top Hutton seams were examined; Pheonix Quarry (G.R. NZ 135628), (Fig. 7.6), Incline O.C.C.S. (G.R. NZ 173385),(Fig. 7.7), Billy Hill O.C.C.S. (G.R. NZ 156382),(Fig. 7.8), Tanners Hall O.C.C.S. (G.R. NZ 176375), (Fig. 7.9), Wooley O.C.C.S. (G.R. NZ 183396),(Fig. 7.10) and Buckhead O.C.C.S. Area B (G.R. NZ 145243),(Fig. 7.11),(Fig. 7.2).

Fig.7.5

THE HUTTON COAL, POST-HUTTON PALAEOCURRENTS AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS

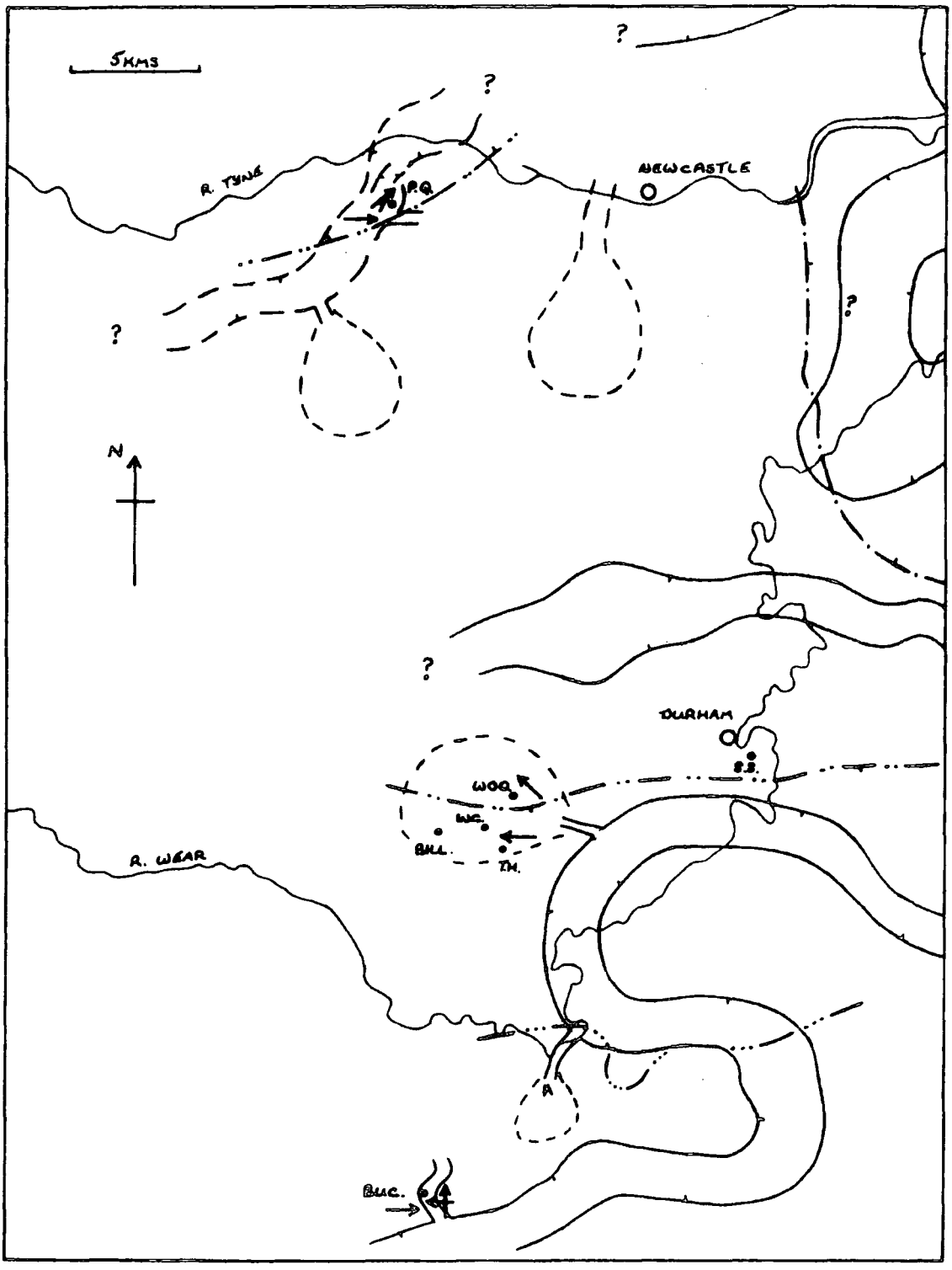


Fig.7.6

COMPOSITE VERTICAL SECTION - PHOENIX QUARRY
(G.R.NZI35628). (BASED ON SECTIONS 390 & 443 :- APPENDIX 1)

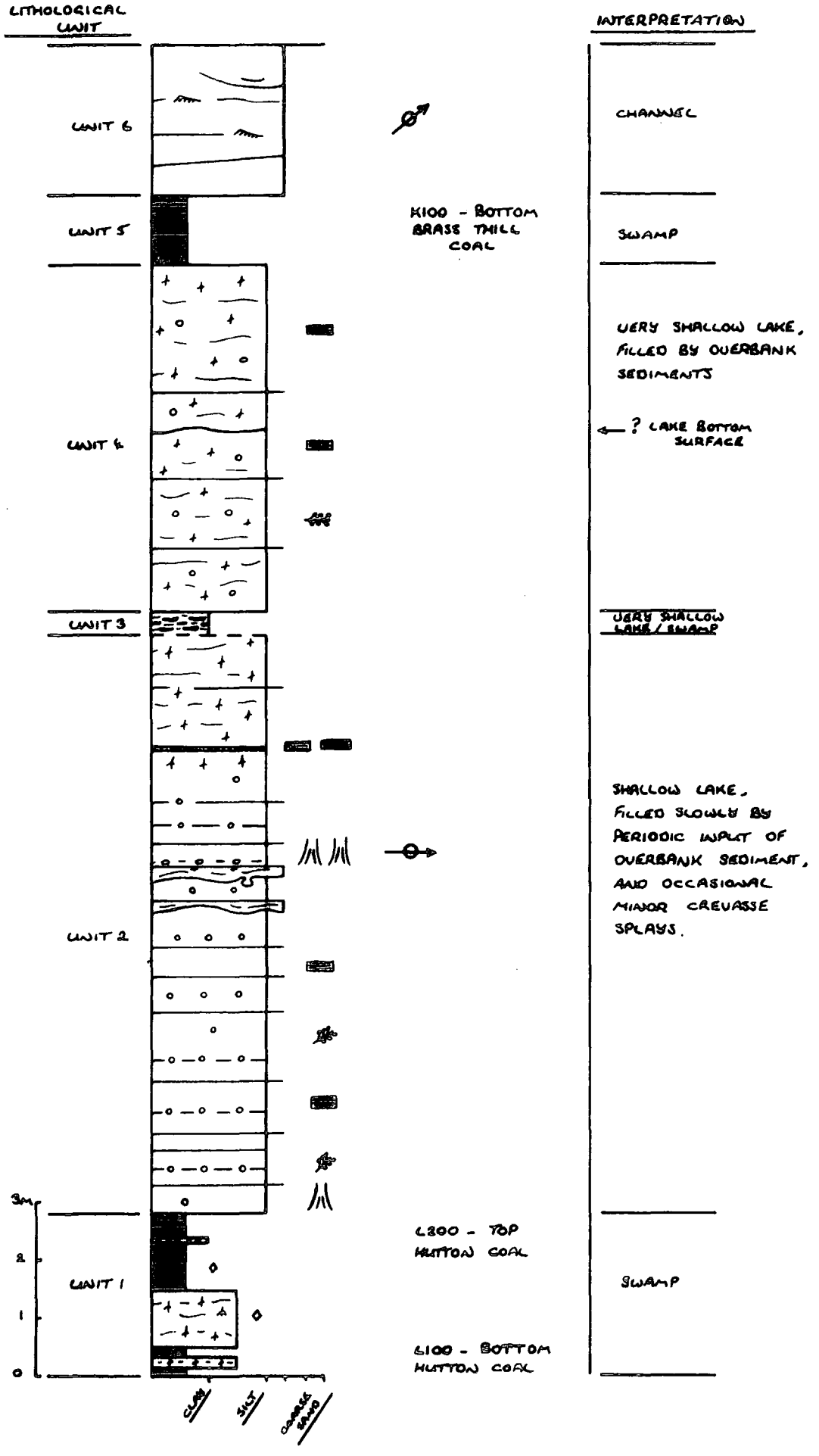


Fig.7.7

COMPOSITE VERTICAL SECTION - INCLINE O.C.C.S.
(G.R.NZI73385), (BASED ON SECTIONS 001 & 005 :- APPENDIX 1)

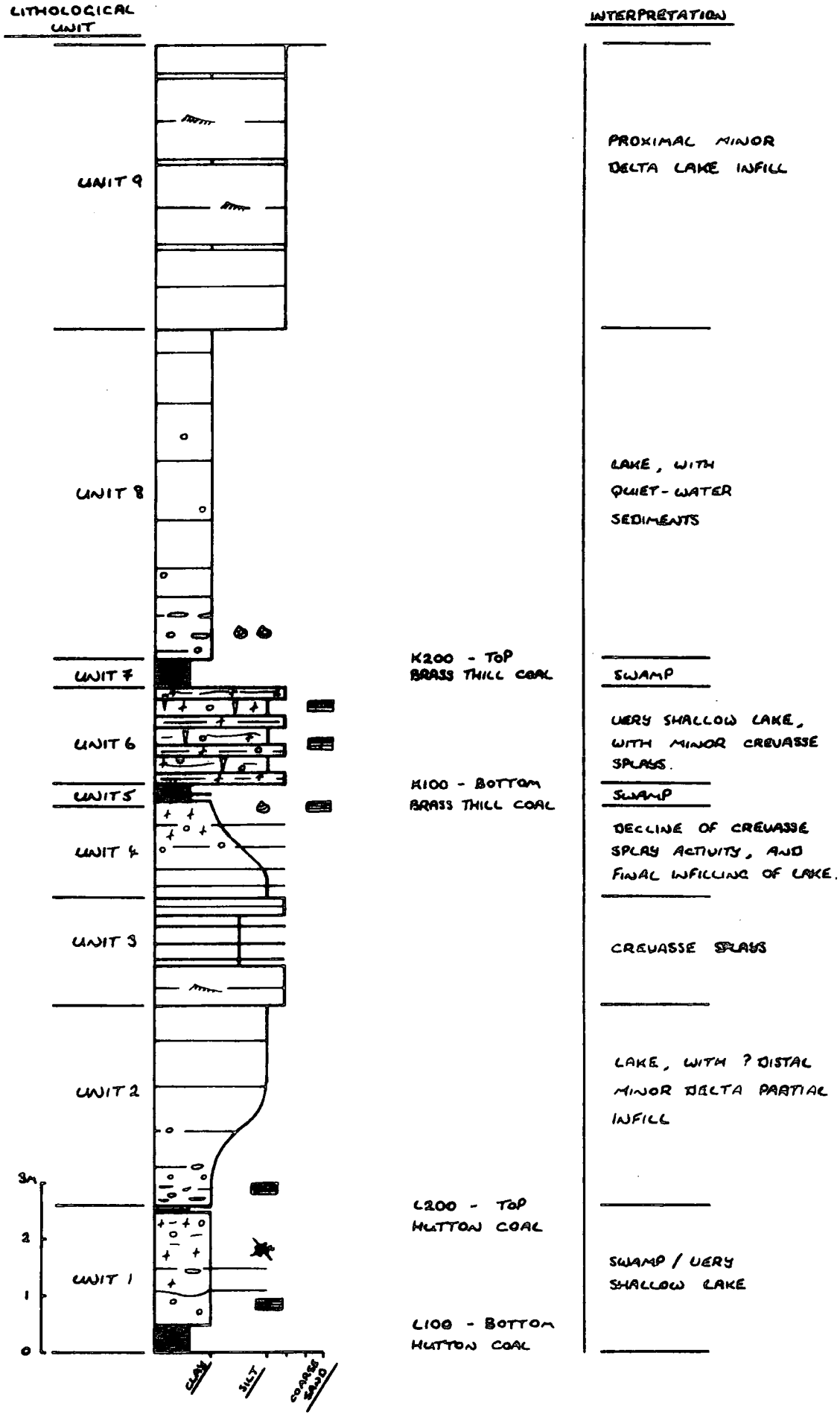


Fig.7.8

MEASURED VERTICAL SECTION - BILLY HILL O.C.C.S.
(G.R.NZI56382), (BASED ON SECTION 421 :- APPENDIX I)

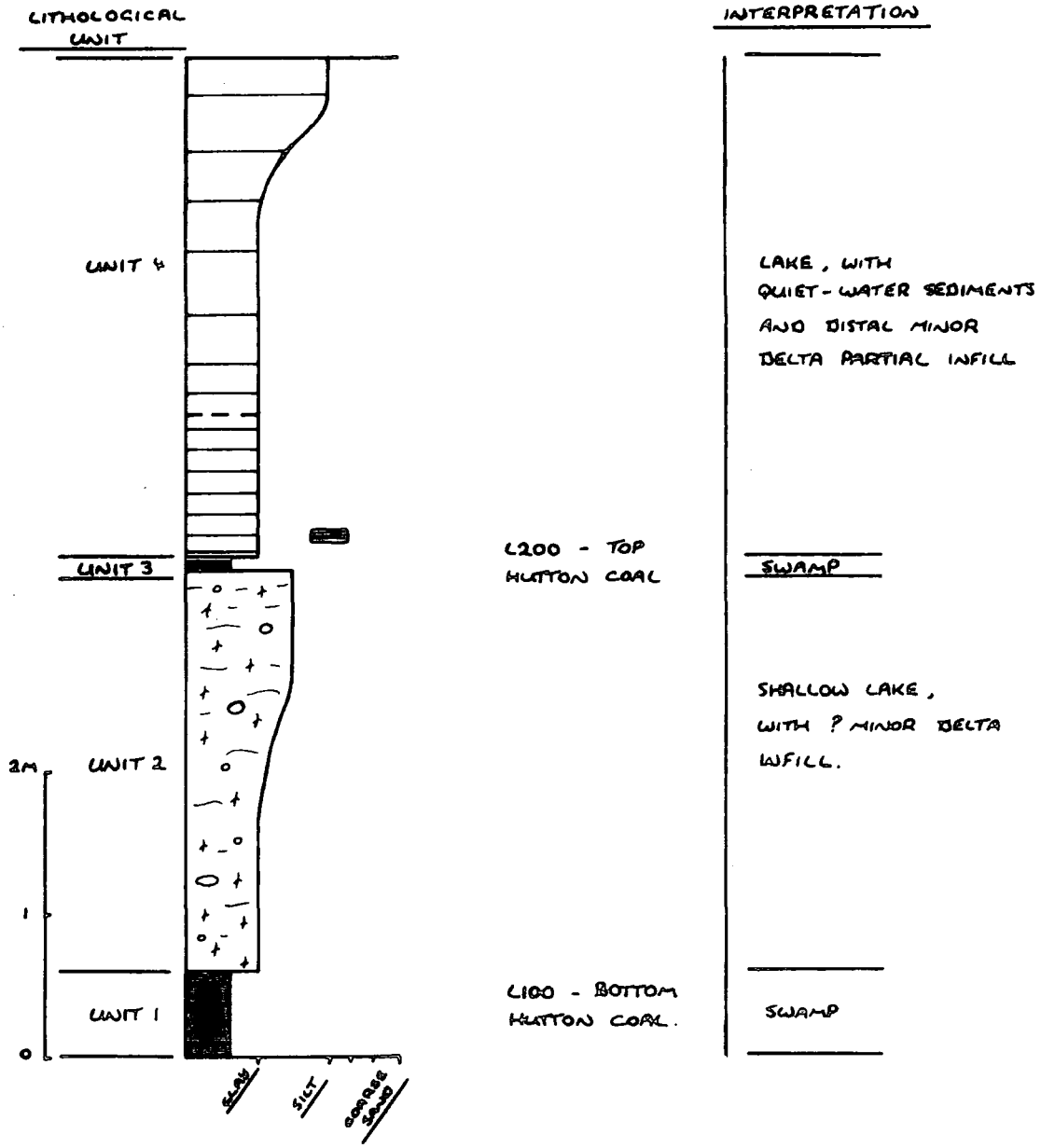


Fig.7.9

COMPOSITE VERTICAL SECTION - TANNERS HALL O.C.C.S.

(G.R.NZI76375), (BASED ON SECTIONS 285, 368, 396, 439, 442 AND OTHERS :- APPENDIX I)

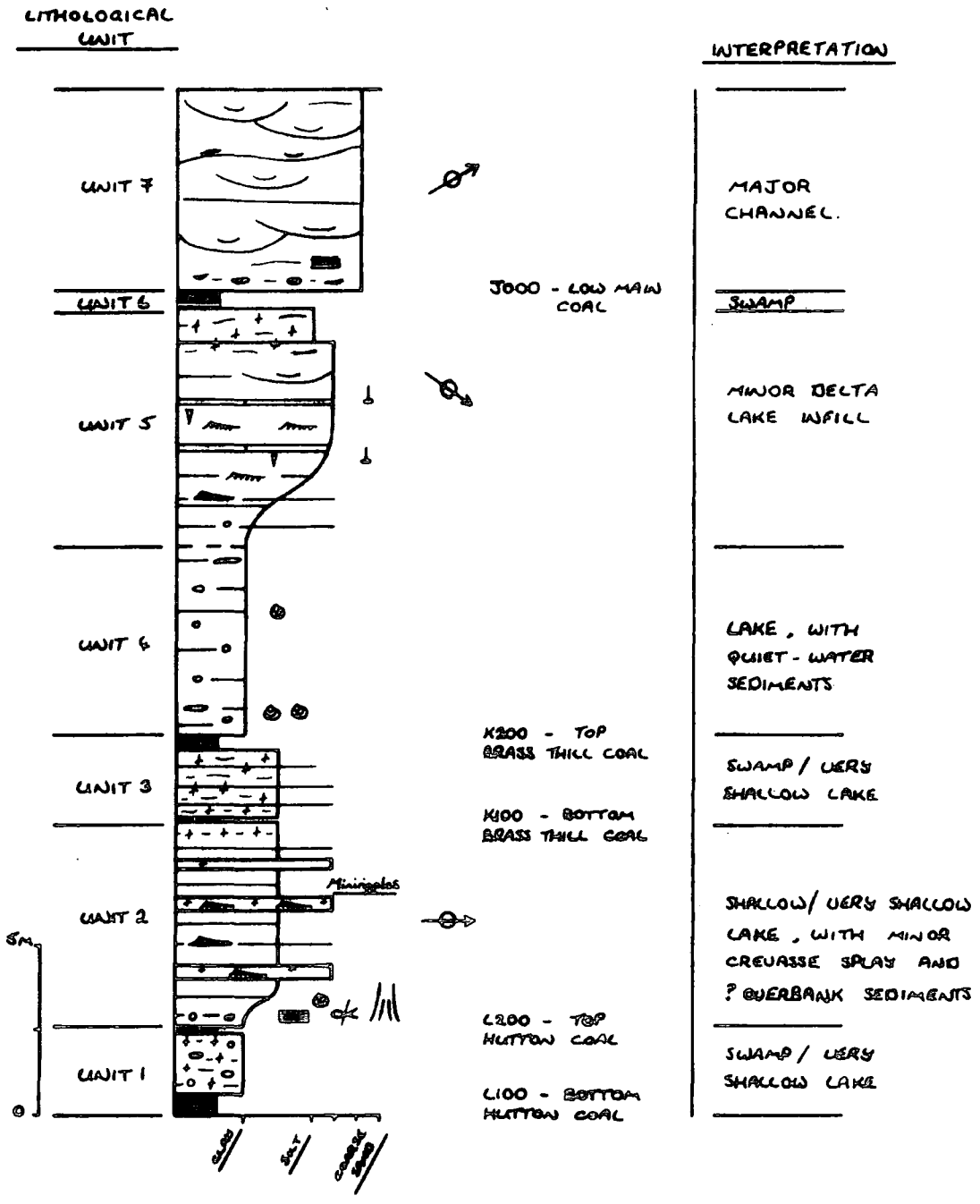


Fig.7.IO

COMPOSITE VERTICAL SECTION - WOOLEY O.C.C.S.

(G.R.NZI83396), (BASED ON SECTIONS 363, 364 & 385 :- APPENDIX I)

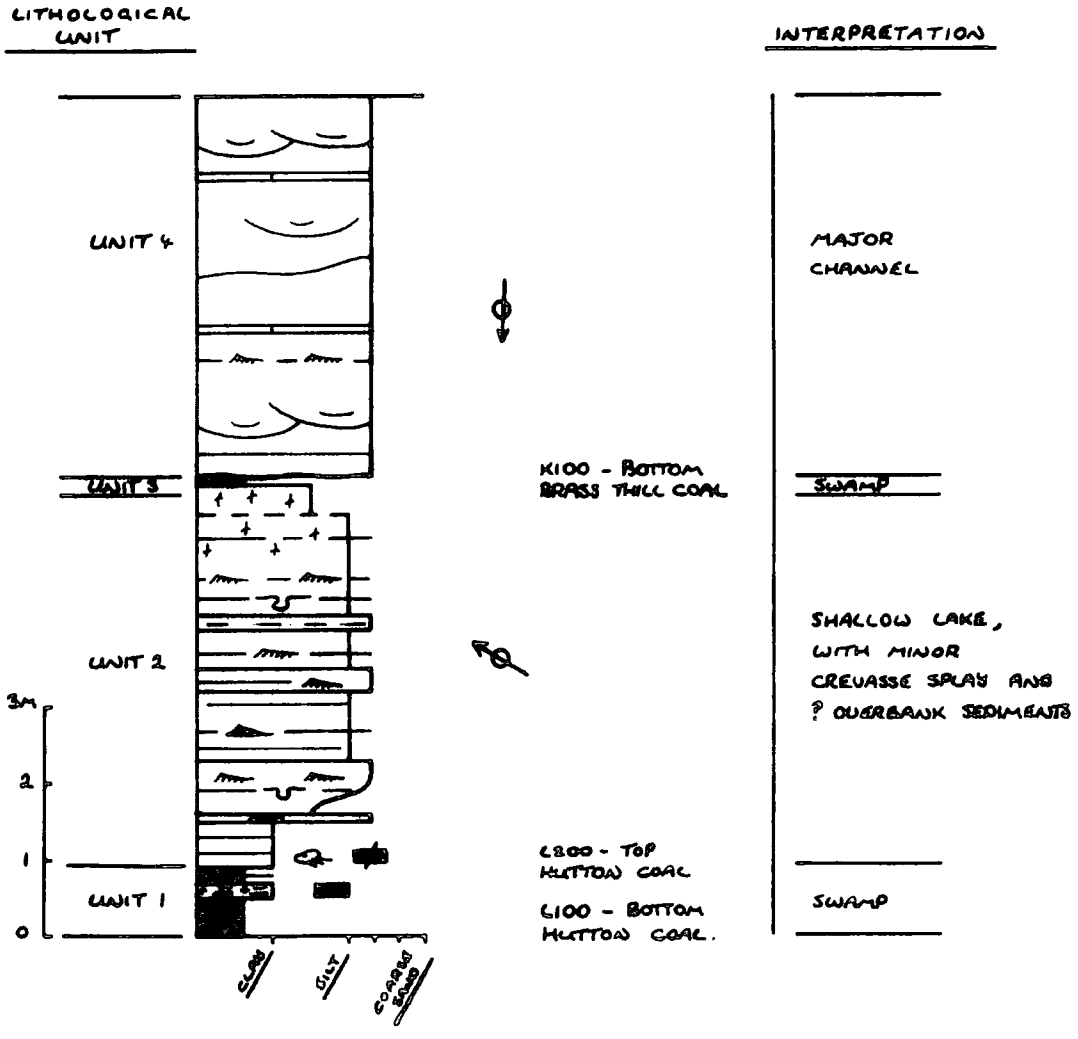
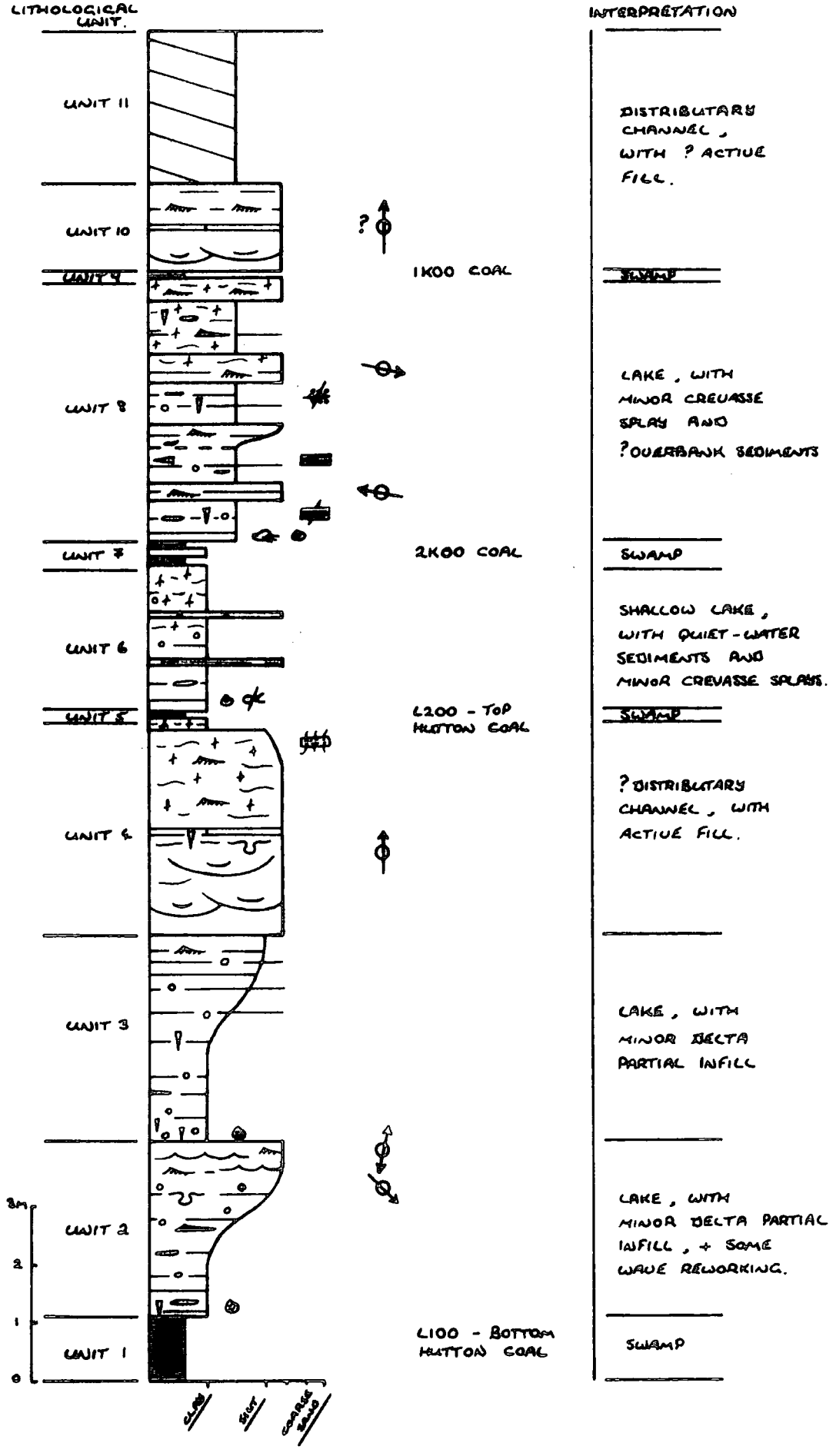


Fig.7.II

COMPOSITE VERTICAL SECTION - BUCKHEAD O.C.C.S.

AREA B (G.R.NZI45243) , (BASED ON SECTIONS 249, 269, 389, 401 :- APPENDIX 1)



7.3.4 Sediments between the Bottom and Top Hutton coals

7.3.4.1 Phoenix Quarry

Description

At Phoenix Quarry, the Bottom Hutton seam, comprising two thin coals, is separated from the thicker Top Hutton by 1.0 m of rootlet-penetrated silty claystones (Fig. 7.6; Unit 1).

Interpretation

The sediments are interpreted, along with the Bottom and Top Hutton coals, as the deposits of a shallow water swamp. Following a period of peat accumulation, this swamp became the site of deposition of fine-grained, possibly overbank-derived, clastic sediment, following which peat-forming conditions were re-established, leading to the formation of the Top Hutton seam.

7.3.4.2 Wooley/Tanners Hall/Incline/Billy Hill O.C.C.S.'s

Description

At Wooley O.C.C.S., a very short distance from a line of splitting in the Hutton seam (Fig. 7.5) the Bottom-Top Hutton parting is represented by only 0.15 - 0.3 m of rootleted clay or shaly claystones with abundant coaly traces (Fig. 7.10), (Plate 7.1). In some areas, these grade laterally into coaly shale or shaly coal.

At distances of 1-3 kms south and south-west of Wooley O.C.C.S., the same interval at Incline, Billy Hill and Tanners Hall O.C.C.S.'s is increased to 2-3m of rootlet-penetrated claystones with siderite nodules (Figs. 7.7, 7.9), (Plate 7.2). Little lateral variation occurs within individual sites, but the parting thickness increases to the south and south-west, between exposures (see also Fig. 7.5).



Plate 7.I - The Hutton coals and overlying sediments at Wooley O.C.C.S. (Cut 3). The sandstone exposed in the upper part of the face is part of the "Low Main Post". Shovel is about Im high.



Plate 7.2 - The Hutton coals and overlying sediments at Tanners Hall O.C.C.S. (Cut I4E), facing south-west. Sandstone beds (light-coloured bands) thin and die out towards the south. Exposed face is about 9m high.

Interpretation

The sediments of the Bottom-Top Hutton parting at Wooley, Tanners Hall, Incline and Billy Hill are interpreted as the result of still water deposition from suspension in shallow lakes. The coaly and rootlet-penetrated nature of the interval at Wooley O.C.C.S. and the thickening of the parting to the south suggest that subsidence of these shallow basins increased southward (Fig. 7.5).

7.3.4.3 Buckhead O.C.C.S.

Description

At Buckhead O.C.C.S.,the Bottom-Top Hutton parting, exposed in Area B (Enclosure 9), comprises some 9-12 m of sediments (Fig. 7.11).

The lower 5.5-8.0 m consists of two sedimentary sequences (Units 2 and 3; Fig. 7.11) which either coarsen upward from laminated claystone to siltstone/very fine-grained sandstone or are composed throughout of laminated claystone with sandy streak (see Sections 269, 389, 401:- Appendix 1). Bivalves and *Spirorbis* (Plate 7.3) are present in the lowermost parts of both sequences, and the upper levels contain abundant ripple cross-lamination, wave-influenced and wave-formed ripples, and some evidence of synsedimentary deformation. Palaeocurrent measurements from ripple cross-lamination in Unit 2 indicate a palaeoflow towards the south-east, and wave ripples indicate motion towards the north-north-east and south-south-west.

Above Unit 3 lies a sharply- or gradationally-based,very-fine-grained sandstone 3-4 m in thickness (Unit 4; Fig. 7.11). This



Plate 7.3 - Close-up of Spirorbis serpulids, found attached to the shell of a Naiadites bivalve, above Bottom Hutton coal, Buckhead O.C.C.S. Length of photo 4mm.

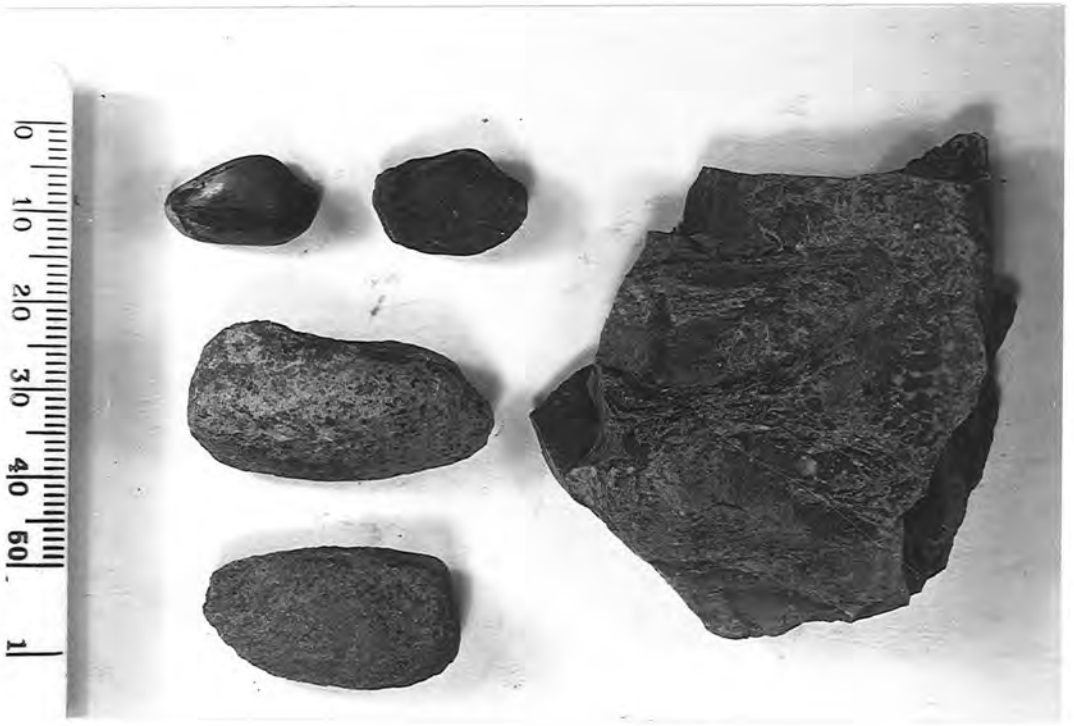


Plate 7.4 - Non-marine bivalves from the Brass Thill Shell Bed and other horizons. Scale divisions in mm.

sandstone fines to siltstone in the uppermost part, and displays an uneven, hummocky upper surface. Much of Unit 4 is penetrated by rootlets, and forms the seatearth to the thin (0.08 m) Top Hutton coal (Fig. 7.11).

Palaeocurrent measurements from ripple cross-lamination and trough cross-bedding in Unit 4 indicate a palaeoflow towards the north.

Interpretation

The sediments of Units 2 and 3 were deposited by a current regime which gradually increased in strength with time, beginning with quiet-water sedimentation from suspension and culminating in high-energy traction current deposition. The sandstone of Unit 4 was evidently deposited by more persistent, though intermittent traction currents, from the contained sedimentary structures and presence of occasional claystone partings. Wave action caused some reworking of sediments.

Units 2 and 3 are interpreted as the products of minor mouth bars which prograded out into a shallow, lacustrine body of water. From palaeocurrent directions and variation in sequence thickness Unit 2 is inferred to have advanced in a south-easterly direction. North-north-east-directed (i.e., onshore) winds caused some re-distribution of current-deposited sediment. A lack of rootlets in the uppermost part of the Unit implies that the minor mouth bar only partially infilled the shallow basin, and the gradational contact between fine and coarse member is taken as evidence for a relatively distal setting with respect to its' source (Fig. 3.2).

Lack of exposure and erosional truncation precludes interpretation of Unit 3 in the same manner, but since Unit 3 was probably deposited in the same sedimentary "episode" as the overlying Unit 4, it may have prograded in a northward direction (see below).

Unit 4 is interpreted as the deposit of a shallow, northward-flowing, minor distributary channel, from the preserved sedimentary structures, presence of bioturbated claystone partings, fining-upward top and "hummocky" upper surface. No channel margins or evidence of lateral accretion were observed, but by comparison with other exposures (e.g., the Middle-Top Tilley parting at Cobey Carr Quarry), the channel exposed at Buckhead was probably of meandering form.

Following abandonment of the distributary channel, plant colonization led to relatively short-lived establishment of peat swamp conditions, and the thin Top Hutton peat accumulated (Unit 5; Fig. 7.11).

The thickness and nature of the preserved sequences (Units 2-4) suggest water depths of the order of 5-6 m in the lacustrine basin before infilling began.

7.3.5 Discussion

Lack of good quality exposure precludes a detailed consideration of the patterns of sedimentation in the Ruler-Hutton interval. However, channel and channel belt patterns have been tentatively identified from subsurface records (Fig. 7.4).

The most striking feature of the channel belt distribution is

the similarity to that of the underlying interval (compare Figs. 7.3 and 7.4), implying that channels operating during earliest Westphalian B times accreted predominantly in the vertical direction, and tended to reoccupy earlier channel courses. This interpretation is borne out by examination of borehole records, many of which show sandstone bodies, up to 30 m+ in thickness, occupying much or even all of the Harvey Marine Band-Hutton interval (see, for example, Plate 11 of Mills and Hull, 1976). In the north, the positions of major channels seem to have been strongly influenced by the presence of thick, underlying Ruler peats, from the inferred presence of a channel belt some 5-10 kms wide(Fig. 7.4), which may in turn have had an underlying structural control (see Ch. 6.4.4). Vertical stacking of channel sand bodies implies tectonic influence on subsidence patterns, since these relatively uncompactable sand units have been shown to subside very slowly under "normal" conditions (Brown, 1979, and see Ch. 6), and the post-Ruler channels show a marked alignment with the regional structural "grain" (Figs. 7.4, 2.7).

The channels and channel belts themselves display some sinuosity, and were probably 1.5 kms in width. Subsurface records also show that channels operated between the time of accumulation of the Bottom and Top Hutton peats in the southern part of the coalfield, but borehole control is insufficient to allow a detailed examination.

The split in the Hutton coal in the southern part of the coalfield (Fig. 7.5) is of a more widespread nature than most of the coal seam splits encountered in the Westphalian A succession. It is possible that splitting in the Hutton seam in the south reflects an increase in basinal subsidence, but seems equally likely to be a

result of accelerated subsidence of thick peat/clay sequences or a response to local structural controls (Fig. 7.5). The "floor split" in the north-east part of the coalfield is difficult to explain in terms of compaction-induced subsidence, and thus possibly reflects a tectonic control.

The nature of the southernmost major split in the Hutton seam allows a calculation of the amount of time represented by the Bottom-Top Hutton clastic fill, by a similar method to that employed in the Deborah O.C.C.S. Bottom-Top Busty example (Ch. 6.6.5). Some 550 m north of the line of split, the single Hutton Seam is 1.70 m thick at a borehole sunk for Wheatley Hill Colliery (C.R. NZ 374413), whereas 1.6 kms south of the line of split, at the nearby Thornley Colliery (G.R. NZ 365395), a Bottom Hutton coal 1.02 m thick is separated by 11.28 m from a Top Hutton of 0.31 m. Applying the procedure of Fig. 4.2, the clastic parting at Thornley Colliery is calculated to have taken of the order of 5000 years to accumulate. This figure is similar to that derived from the Deborah case study, for a clastic interval of approximately the same thickness (10 m).

As with the Deborah example, in certain areas south of the Hutton split the combined Bottom-Top Hutton thickness is greater than that of the single seam further north. This is attributed to local, optimized rates of peat accumulation and subsidence in areas of accelerated subsidence, and indeed, at Deborah, such a feature is interpreted as the cause of the initial split in the Busty seam (Ch. 6.6.4.3).

7.4 HUTTON TO BRASS THILL COALS

7.4.1 Introduction

The interval between the Hutton and Brass Thill seams varies between 3 and 30 m in thickness, the higher values being associated with the presence of major sandstone bodies.

Non-marine mussels and fish remains commonly occur in the roof shales of the Top Hutton coal. Thin coal seams (designated 2KOO, 1KOO) are occasionally found in the Top Hutton-Brass Thill interval.

Strata representing this interval were examined at six localities; Wooley O.C.C.S., Tanners Hall O.C.C.S., Incline O.C.C.S., Billy Hill O.C.C.S., Buckhead O.C.C.S., and Phoenix Quarry. At five of these exposures, the Brass Thill coals were also observed. Additionally, a logged borehole core from the Durham University Science Site (G.R. NZ 275417) contains the Brass Thills (Fig. 7.2).

7.4.2 Sediments between the Top Hutton and Bottom Brass Thill coals

7.4.2.1 Phoenix Quarry

Description

At Phoenix Quarry the Hutton-Bottom Brass Thill parting comprises approximately 16.5 m of laminated siltstones with sandy streak, containing abundant, well-preserved plant remains (Fig. 7.6). Two or three irregularly-based (?loaded) sandstones up to 0.4 m thick occur in the lower part of the sequence, and two thin, carbonaceous or coaly claystones occur higher up. Above the latter, the entire section is rootlet-penetrated. Siderite nodules, which are abundant

throughout much of the sequence, are concentrated on specific horizons with a regular spacing of 30-40 cms.

An upright, *in situ* lycopod tree trunk was found preserved in the roof of the Top Hutton coal, and several more were observed rooted into a horizon immediately above the uppermost sharply-based sandstone. Two of these tree casts, which were about 0.3 m wide and up to 2.0 m in preserved height, were slightly inclined towards the east.

Interpretation

The exposed sediments were probably largely deposited from suspension, at fairly regular (? seasonal) intervals, from the delicate, mode of preservation of plant fossils, lack of traction-derived sedimentary structures and regular spacing of nodule-rich horizons. From the preservation of upright, *in situ* trees, sediment was deposited rapidly, but not too powerfully. The sharply-based sandstones were deposited by more energetic, and probably unconfined, tractional flows.

The sequence exposed at Phoenix Quarry is interpreted as the result of eastward-directed overbank deposition into a shallow, slowly subsiding, lacustrine environment. Lycopods are thought to take root only in very shallow water or emergent settings, and so the presence of lycopod trees enrooted above the sharply-based sandstones, interpreted as the products of minor crevasse splays, implies that the depth of the shallow "floodbasin" was probably no more than 1-2 m at any time (Fig. 7.6).

Flood events, which were possibly seasonally controlled (see discussion in Ch. 6.5.2.2/3.), led to the deposition of 30-40 cm-

thick beds of silt. Quiet-water periods between these floods led to the accumulation of thinner, slightly finer-grained, more carbonaceous units, which later became the site of early diagenetic siderite formation.

The abundant evidence of plant colonization and the presence of carbonaceous horizons in the upper half of the sequence suggest that sedimentation rates declined with time, and that water depths were gradually reduced as the floodbasin was infilled. An undulating, 3 cm thick, clay-rich horizon near the top of the sequence may indicate that the shallow basin floor possessed a somewhat irregular topography. The presence of such a thick sequence of overbank-derived sediment is consistent with the impression of stable channels gained from the underlying interval (Ch. 7.3.5).

7.4.2.2 Wooley/Tanners Hall/Incline/Billy Hill O.C.C.S.'s Description

At Wooley O.C.C.S., the Top Button-Bottom Brass Thill parting comprises approximately 5.0 m of interbedded claystones, siltstones with sandy streak and fine-grained, ripple cross-laminated sandstones (Fig. 7.10),(Plate 7.1). Small-scale (up to 1.0 m thick) and larger-scale (up to 3.0 thick) coarsening-upward sequences are common, possessing sharp upper contacts.

The lowermost part of the sequence, above the Top Hutton coal, is generally composed of fissile, often "flinty", dark-coloured claystone containing fragmentary plant debris, and ostracods. Further up, discrete beds of fine-grained sandstone vary up to 0.50 m in thickness, display either gradational or abrupt basal contacts and have sharp upper contacts. Individual sandstones can often be

traced across the 0.5 sq. km. site, though some gradually thicken southward along cut walls (Appendix 1, Enclosures 12, 13).

Palaeocurrent measurements from ripple cross-lamination in the sandstones indicate palaeoflow towards the north-west, with a minor component to the west.

The uppermost part of the sequence is rootlet-penetrated, forming the seatearth to the Bottom Brass Thill coal.

At Tanners Hall O.C.C.S., the same interval consists of 5.0-7.0 m of similar lithologies to those exposed at Wooley (Fig. 7.9), (Plate 7.2). The lowermost claystones are again fissile and "flinty" or canneloid, contain siderite nodules and occasional fish and non-marine bivalve remains. Coarsening-upward sequences up to 4.0 m thick occur, and are commonly complex in form, containing sharply-bounded sandstones separated by claystone partings. Ripple cross-laminated sandstones vary up to 0.6 m in thickness, and at one locality were seen to contain miniripples (Section 397:- Appendix 1).

In one area the uppermost 3m of the interval comprised a sharply-based, ripple cross-laminated sandstone with occasional finer-grained partings (Section 368: Appendix 1, Enclosure 14). Individual sandstones can often be traced for several hundred metres along cut walls, and correlated confidently between cuts, although some die out gradually (Enclosures 13, 14),(Plate 7.2). Along certain of the north-south-trending cuts in Area E, the outcrop trace of the sandstones defines a broad shallow "channel" profile some 150-200 m wide (Enclosures 13, 14).

At certain localities, the casts of bent-over, *in situ* tree stumps are preserved in the roof of the Top Hutton coal. Rootlets

and *in situ*, inclined *Calamites* casts are occasionally found at several levels within the sequence, and the uppermost levels, composed generally of siltstones or silty claystones, are thoroughly rootlet-penetrated, forming the Bottom Brass Thill seatearth.

Palaeocurrent measurements from ripple cross-laminations and inclined, *in situ* plants indicates a palaeoflow towards the west.

At Incline O.C.C.S., adjacent to Tanners Hall, the Top Hutton-Bottom Brass Thill interval comprises approximately 7 m of similar facies to those at Tanners Hall and Wooley (Fig. 7.7, and see Enclosure 14). The lower half of the interval consists of a simple coarsening-upward sequence (Unit 2; Fig. 7.7) and is overlain by a similar thickness of interbedded, sharply-bounded fine-grained sandstones and silty claystones with sandy streak (Units 3 and 4).

At Billy Hill O.C.C.S., only the lowermost 3.5 m of the Top Hutton-Bottom Brass Thill parting was exposed, due to Pleistocene glacial erosion, and consists of a simple coarsening-upward sequence (Fig. 7.8).

Interpretation

The sediments described above were deposited under a variety of flow conditions, ranging from very low-energy suspension fallout to high-energy tractional flows. Tractional currents seem to have been largely unconfined, from the sheet-like geometry of individual sandstones, but may locally have been channelized (Enclosure 13). Evidence for rapid deposition of these beds exists in the common occurrence of synsedimentary loading.

The rocks comprising the Top Hutton-Bottom Brass Thill parting at Wooley, Tanners Hall, Incline and Billy Hill O.C.C.S.'s are

interpreted as the deposits of a single, shallow, "floodbasin" lake which developed following drowning of the Top Hutton peat swamps, and which filled largely through crevasse splay/minor delta activity. This lake was evidently several kms in diameter, and up to 4 m deep at any time (from the thickness of coarsening-upward sequences; see Enclosures 13, 14 and Appendix 1). The presence of *in situ* plant remains throughout the sequence, however, implies that water depths were probably often less than 1m, and miniripples (Singh and Wunderlich, 1978) indicate deposition in only a few cms water.

Sediments prograded from an assumed channel crevasse source some distance to the east of the present exposures, from palaeo-current measurements and the dominantly corasening-upward nature of major (1 m+ thick) sedimentary units (Enclosure 13).

While it is possible if not likely that some of the preserved sediments were introduced by overbank deposition,the sharply-based sandstones and coarsening-upward sequences are interpreted as the deposits of crevasse splays and minor mouth bars respectively.

Individual crevasse splay sands, though probably some distance from source, display remarkable lateral persistence and uniformity, implying powerful, sheet-like tractional currents. Crevasse splay sandstones decrease in thickness and number towards the west, and probably imply increasing distance from the sediment source. The high width/depth ratio (around 150:1) channel described from Area E of Tanners Hall O.C.C.S. is interpreted as the remnant of a sub-aqueous "crevasse feeder channel", perhaps a more distal type to those described previously from Cabin House O.C.C.S. and Deborah O.C.C.S. (Ch. 6.6.4). They possibly may be distinguished from

shallow submerged or emergent distributary and crevasse channels, which tend to have lower width/depth ratios, show better-developed channel cross-sections, are sandstone filled and display evidence of lateral accretion.

The sharply-based sandstone in the upper part of the sequence in Section 368 (Enclosures 13, 14) is interpreted as a late stage depositional axis, possibly a crevasse channel.

Coarsening-upward sequences, interpreted as the products of westward-prograding minor deltas, occur across the entire area of study, and were largely responsible for the partial and finally complete infilling of the lake. Sequences are more complex, containing sharply-based sandstone beds, towards the eastern end of the study area, reflecting a *relatively* proximal setting (Enclosure 13). Across much of Tanners Hall O.C.C.S., two phases of sedimentation can tentatively be separated, seen best in the stacked coarsening-upward sequences of Section 413 (Enclosures 13, 14, Appendix 1), significantly close to an inferred axis of sediment transport.

Viewed as a whole, the described sequences represent the slow, ? pulsatory infilling of a shallow lake from a relatively distant crevasse source or sources, a situation not described in detail previously in this thesis.

Similar shallow lakes and bays are well-known from modern delta plains (e.g., Coleman, Gagliano and Webb, 1964; Saucier, 1963), and are thought to be infilled predominantly by channel flood sediments (Elliott, 1974), though the detailed mode of infilling is poorly known.

7.4.2.3 Buckhead O.C.C.S.

Description

The Top Hutton-Brass Thill sequence at Buckhead O.C.C.S., exposed in Area B (Enclosure 9), comprises some 12-14 m of sediments of variable character (Fig. 7.11).

The lower part of the sequence is composed of interbedded and interlaminated claystones, silty claystones and fine-grained sandstones, together with two thin and impure coals (Units 6, 9; Fig. 7.11). Discrete sandstone beds, which mostly display sharp boundaries, vary up to 0.7 m in thickness and contain ripple cross-lamination directed both to the east and westward. Claystones, particularly those immediately above the Top Hutton and overlying thin coals (2KOO, 1KOO), contain non-marine bivalves, ? ostracods and fish remains.

The upper part of the sequence (Units 10 and 11) consists of a sharply-bounded fine sandstone with thin partings of carbonaceous claystone, overlain by an interval of poorly-laminated claystones or silty claystones.

The sandstone, directly overlying the 1KOO coal, possesses an undulating top surface which causes considerable variation in the thickness of Units 10 and 11 (Enclosure 9). The undulation is most prominent on east-west rock faces, where a 3 m zone contains low-angle, asymptotically-based surfaces which are inclined towards the east.

Palaeocurrent measurements from trough cross-bedding in the sandstone indicate a local westerly palaeoflow.

Interpretation

The interbedded clastic sediments and thin coals comprising Units 6-9 are interpreted as the deposits of a shallow (? 1-3 m

depth) lake which periodically filled with sediment, allowing peat swamp conditions to become temporarily established.

The sharply-based sandstones were deposited by quite high energy tractional currents, probably crevasse splays. Palaeocurrent measurements suggest that these crevasse splay sands had at least two separate sources, from the east and west.

Finer-grained sediments were probably laid down from suspension, and together with the preserved faunal remains give the impression of a predominantly quiet-water environment.

The sandstone and overlying claystones of Units 10 and 11 are interpreted as in-channel deposits of a meandering, "muddy, fine-grained stream" (Jackson, 1981) which flowed ?northward across the subsiding 1KOO swamp. This interpretation is based on the sedimentary structures and undulating top of the sandstone, and the low-angle accretion surfaces in both the sandstone and claystone. The extend of these "epsilon" cross-sets allow rough estimates of 50 m for channel width and 3-4 m for backfull depth to be made (Leeder, 1973; Ethridge and Schumm, 1978), giving a width/depth ratio of about 15/1.

The complex relief of the Unit 10 sandstone suggests that the depositing channel formed a meander belt by continually switching course across the surrounding floodplain/floodbasin. Palaeocurrent directions are thus likely to be complex, and the recorded directions may bear little relation to the overall direction of the flow.

Similar deposits are described in Ch. 4.7.4, and such channels have been reported from the British Coal Measures by Guion (1978) and Scott (1978), and from Cretaceous rocks of similar environmental affinities to the Coal Measures (Stewart, 1981 a,b).

7.4.3 The Brass Thill Coals

The Brass Thill seam (L000) is not one of the most widely worked coals in the Durham coalfield, owing to its irregular variation in thickness and quality.

In the south and north-east, the Brass Thill is a single, composite seam, but elsewhere is split into the Top and Bottom Brass Thill coals (L200 and L100, respectively), (Fig. 7.12). The combined Brass Thill seam may locally be up to 1.45 m thick, but where split, individual "leaves" are rarely thicker than 1.12 m. In the latter case, the Bottom Brass Thill is consistently thinner than the Top Brass Thill, and is often itself complexly split.

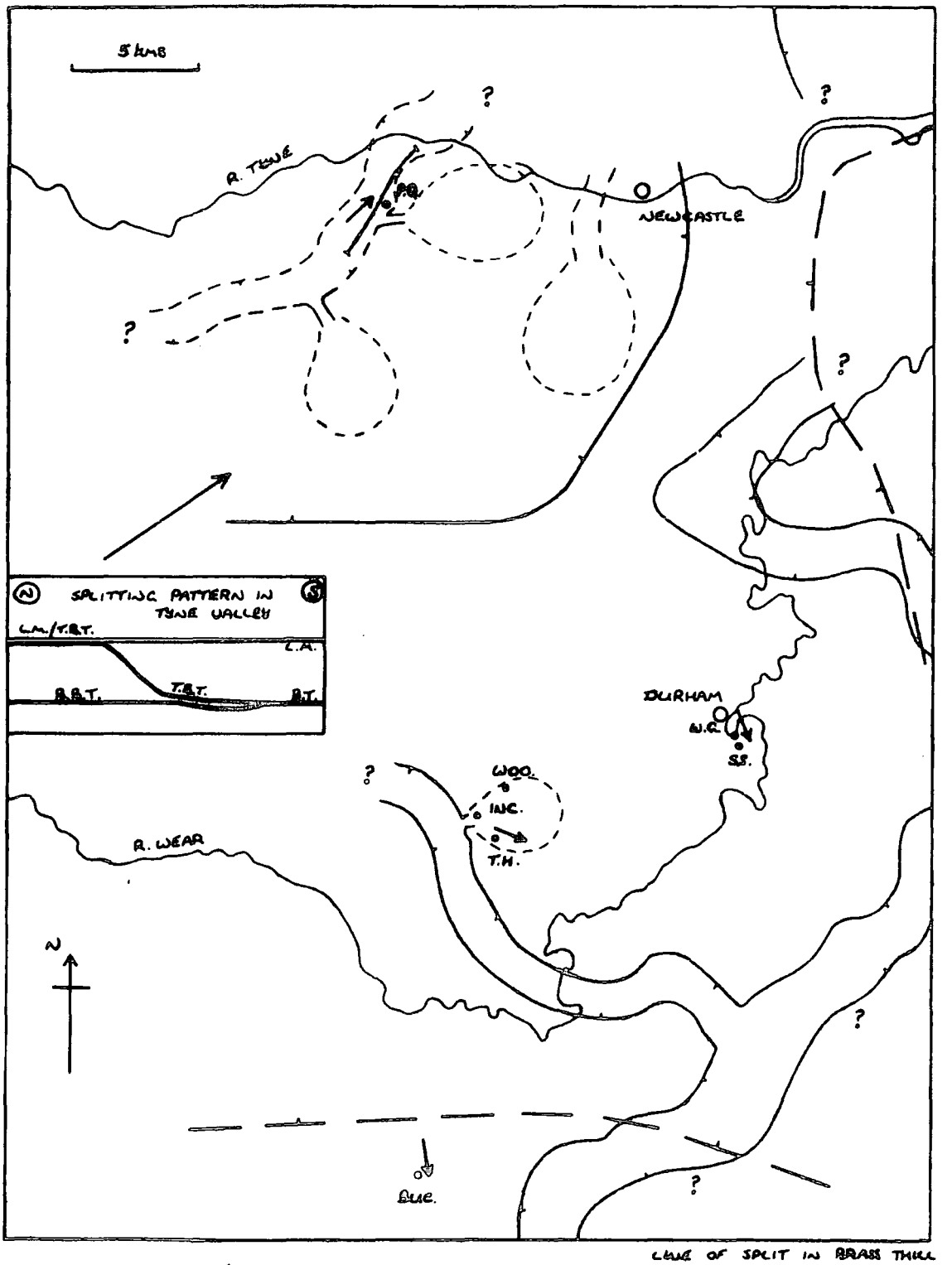
In the northern part of the coalfield (around the Tyne valley), the Top Brass Thill seam rises away from the Bottom Brass Thill to amalgamate with the overlying (Durham) Low Main (J000), (Fig. 7.12). Here, the combined Top Brass Thill/Low Main may be up to 3.17 m thick.

Sulphur values for the Brass Thill coals are highly variable, and values ranging from 0.79 - 4.54% have been encountered.

The Brass Thill coals were examined at six localities; at Buckhead O.C.C.S. in the south, where a single seam was exposed (Area C; Enclosure 9, Appendix 1), Incline O.C.C.S., Tanners Hall O.C.C.S., Wooley O.C.C.S. and the Durham University Science site borehole in the central part of the coalfield where two coals were generally present (Figs. 7.7, 7.9, 7.10, 7.13), and Phoenix Quarry in the north (Fig. 7.6), where the Top Brass Thill coal is amalgamated with the Low Main.

Fig.7.12

THE BRASS THILL COAL, POST-BRASS THILL PALAEOCURRENTS AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS

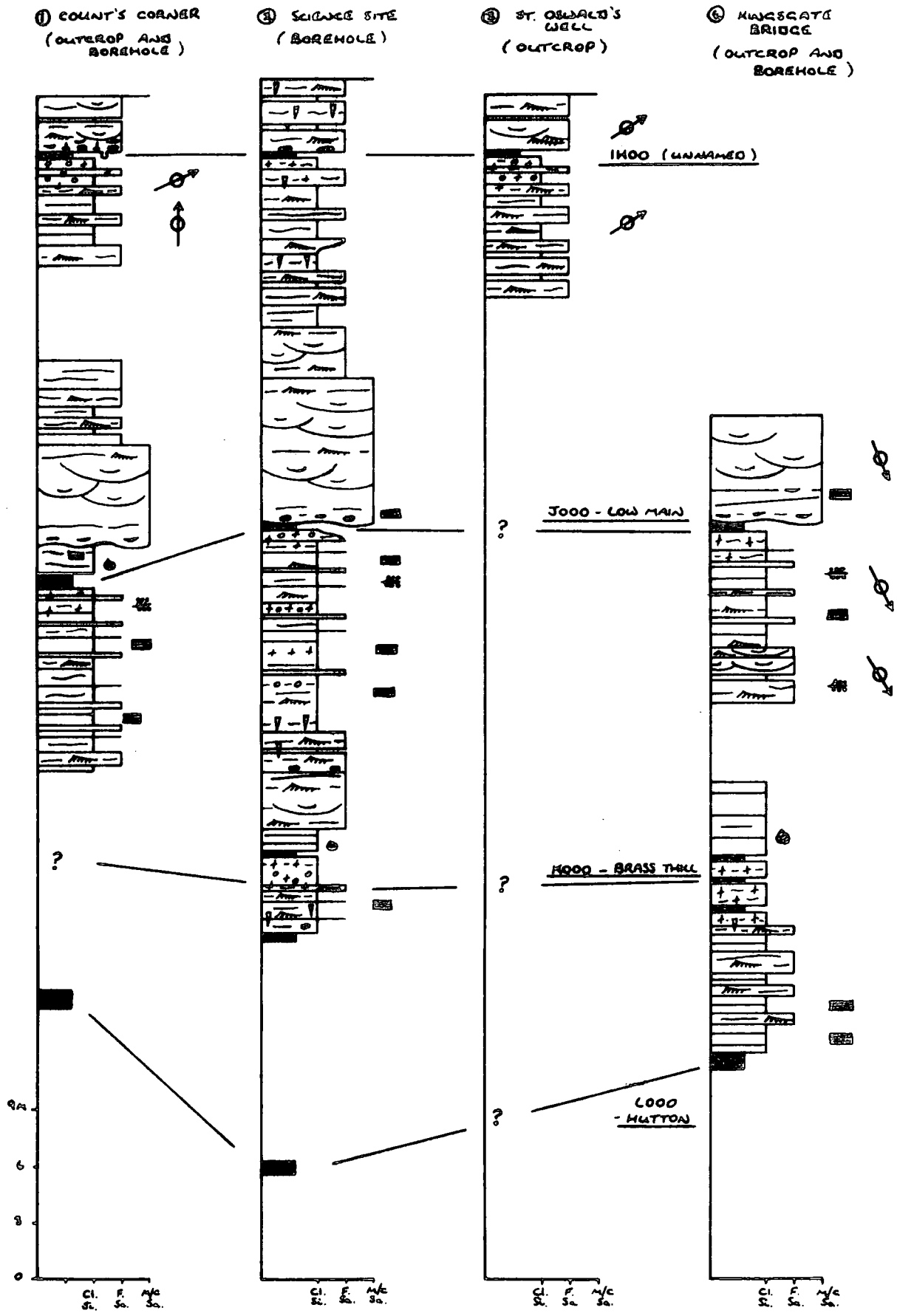


- CHANNEL / CHANNEL BELT MARGINS ("BOTTOM - TOP BRASS THILL INTERVAL")
- CHANNEL / CHANNEL BELT MARGINS (TOP BRASS THILL - LOW MAIN INTERVAL).
- MINOR DELTA LOBE (SCHEMATIC)
- WASHOUT IN BOTTOM BRASS THILL COAL
- PALAEOCURRENT VECTOR MEAN
- LINE OF SPLIT IN BRASS THILL COAL (SEAM SPLIT ON ORNAMENTED SIDE OF LINE)
- LINE OF MAJOR SPLIT IN BRASS THILL COAL (" ") - SEE INSET.

P.Q. - PHOENIX QUARRY (n = 1)
W.C. - WEAR GORGE, DURHAM (n = 12)
T.H. - TANNERS HALL O.C.C.S. (n = 2)
BUC. - BUCKHEAD O.C.C.S. (n = 3)
S.S. - SCIENCE SITE BOREHOLE, DURHAM
INC. - INCLINE O.C.C.S.
WOO. - WOOLEY O.C.C.S.

Fig.7.13

COMPARATIVE VERTICAL SECTIONS OF LOWER WESTPHALIAN B SEQUENCES FROM DURHAM CITY



BASED ON SECTIONS 332, 325, 334 AND 335 RESPECTIVELY, AND I.G.S./UNIVERSITY BOREHOLE RECORDS. DETAILED PALAEOCURRENTS AND SECTION LOCATIONS ON FIG. 5.14.

7.4.4 Sediments between the Brass Thill coals

Description

At the localities mentioned above (other than Buckhead O.C.C.S.), sediments representing the parting between the Bottom and Top Brass Thill coals were exposed.

At Incline O.C.C.S. (Fig. 7.7), Tanners Hall O.C.C.S. (Fig. 7.9) and the "Science Site Borehole" (Fig. 7.13), the interval comprises 1.5-3.0 m of interbedded and interlaminated fine-grained sandstones, siltstones and claystones.

At Wooley O.C.C.S. (Fig. 7.10), (Plate 7.1) a thick (5 m+), trough cross-bedded sandstone overlies and in places erodes the Bottom Brass Thill coal. This is part of a much thicker sandstone body, some 40 m thick over the surrounding area.

At Phoenix Quarry (Fig. 7.6), the Bottom Brass Thill coal is erosively overlain or cut out by a 5 m+ thick sandstone, the top of which is not exposed. From borehole records, this is again seen to be part of a thicker sandstone body.

Interpretation

The interbedded sediments exposed at Incline, Tanners Hall and in the "Science Site Borehole" are interpreted as the deposits of shallow, lacustrine floodbasins, which possibly received sediment from both crevasse and overbank sources.

The thick, erosively based sandstone at Wooley O.C.C.S. is considered to have been deposited after the accumulation of the Low Main peat, since the Top Brass Thill coal is sporadically present across the site, and since the low Main is known to be "washed out" in this area (see Ch. 7.6.2). This sandstone, and that exposed at Phoenix Quarry, are interpreted as major channel deposits.

The Phoenix Quarry sandstone was deposited before the accumu-

lation of the Top Brass Thill peat, since the Top Brass Thill/Low Main coal is known to be preserved in the area. Current ripple cross-lamination indicates a local direction of palaeochannel flow towards the north-east.

7.4.5 Discussion

Conditions of sedimentation during the Hutton-Brass Thill period appear to have been similar to those of underlying intervals; shallow lacustrine basins were crossed by sinuous major and minor distributary channels. The examined exposures are placed in their regional setting on Fig. 7.5, which shows the courses of channels active during this interval. In particular, the channel source of sediment which filled the shallow basin represented by exposures at Phoenix Quarry was only 2-300 m away from the examined outcrops, and that which supplied the basin around Tanners Hall, etc., is identified as being about 3.5 kms distant from Tanners Hall itself. The latter series of exposures provides valuable, previously-lacking data on the detailed mode of infilling of delta plain lakes and bays.

While some uncertainty remains in the identification of palaeochannel courses, due largely to confusion in correlation of seams in subsurface records at this stratigraphical level, there seem to have been comparatively few, high sinuousity channels of up to perhaps 3 kms width operating at this time. Occasionally, these were situated in channel belts up to 5 kms wide. The interpreted setting is very reminiscent of that following accumulation of the Harvey peat (compare Fig. 7.5 with Fig. 6.44).

Channels and channel belts are again situated in similar positions to those of the underlying two intervals (compare Fig. 7.5 with Figs. 7.3 and 7.4), and this channel stability, reflected

in the low areal density of channels and abundance of fine-grained lake fill sequences, perhaps reflects both continued tectonic control of local subsidence and a shortage of sediment supply. It is significant that major channels are preferentially developed in areas where the underlying Hutton coal is split (Fig. 7.5), and not where Hutton peat is likely to have been thickest. This is the opposite of the situation to be expected were compaction-induced subsidence a major influence.

The accumulation of the Brass Thill peats perhaps reflects a slowing down of tectonically-induced subsidence, and the return to a setting where the compaction of peat played an important role in dictating local subsidence patterns. The Brass Thill is represented by a single seam in the areas where rapid, tectonic subsidence is inferred for the underlying interval and conversely is split into several thin seams in the central part of the coalfield where the underlying Hutton coal is thickest.

The splitting pattern of the Brass Thill and Low Main seams in the Tyne valley (see inset on Fig. 7.12) is interpreted as a further example of the "see-saw" pattern of subsidence first seen in the Brockwell/Threequarter coals (Ch. 6.5.4, Fig. 6.23), and is additional evidence for pronounced diachroneity in the Durham coals. Furthermore, "post-Bottom Brass Thill" channels in the Tyne valley are interpreted to have been deposited substantially earlier than their equivalents to the south (Figs. 7.5, 7.12).

7.5 BRASS THILL TO LOW MAIN COALS

7.5.1 Introduction

The Brass Thill-Low Main interval varies between 6 and 20 m,

higher values being associated with thick sandstones. The interval is noted for its' dominantly argillaceous nature, and the roof shales of the Brass Thill or Top Brass Thill coal often contain an abundant and varied fauna of non-marine bivalves (the Brass Thill Shell Bed),(Plate 7.4). This band is up to 2.5 m thick, and forms a persistent marker horizon across much of the coalfield.

Thin coals occasionally occur within the sequence, particularly immediately below the Low Main seam itself ("stringers").

Strata representing the Brass Thill-Low Main interval were examined at five localities; Incline O.C.C.S., Tanners Hall O.C.C.S., Wooley O.C.C.S., Buckhead O.C.C.S. and the Wear Gorge at Durham City (G.R. NZ 272417), (Fig. 7.2). The Durham University Science Site borehole also penetrated this interval.

7.5.2 Sediments between the Brass Thill/Top Brass Thill and Low Main Coals

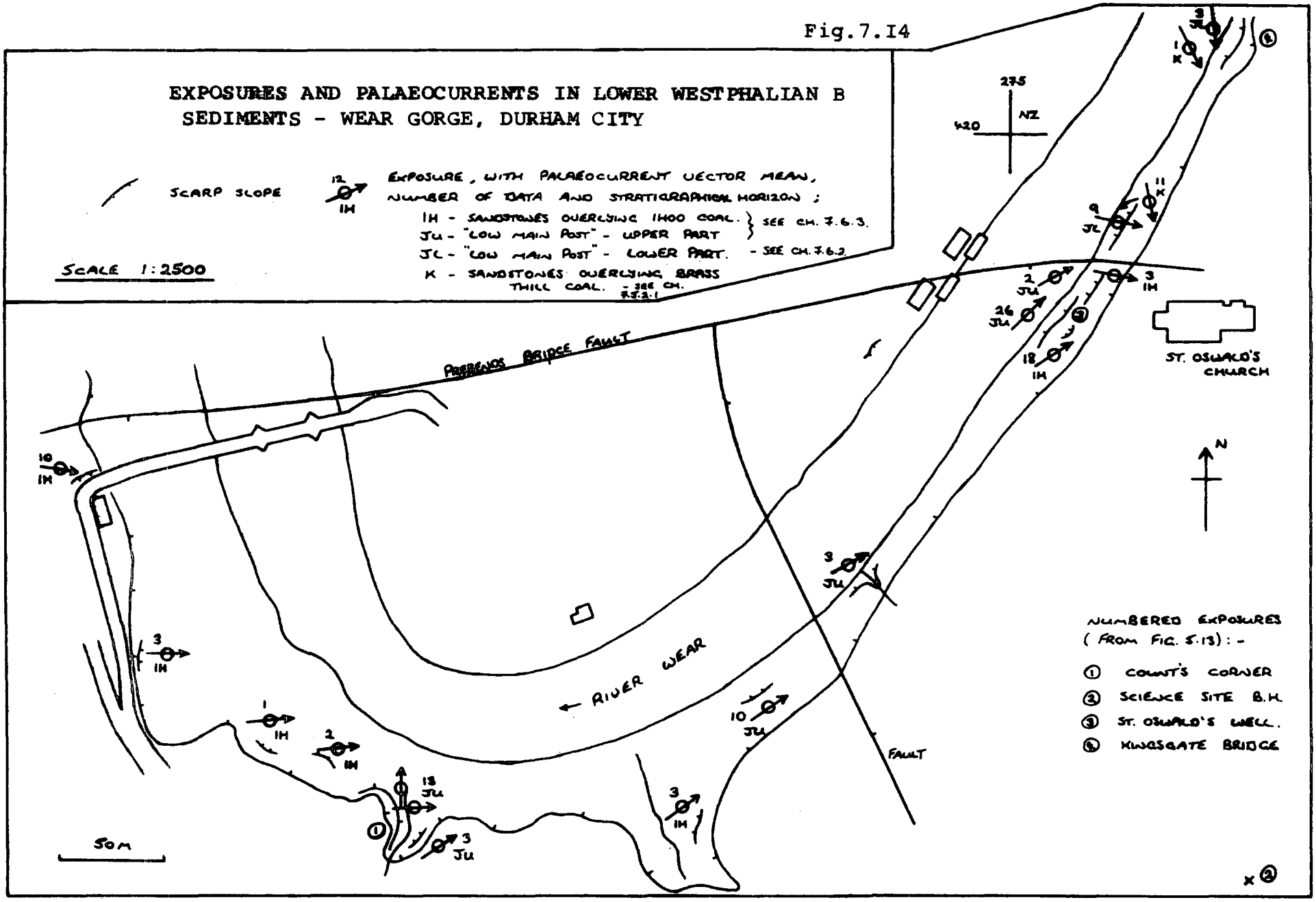
7.5.2.1 Wear Gorge/Science Site Borehole

Description

Part of the Top Brass Thill-Low Main interval is exposed on the south bank of the Wear Gorge in Durham City between St. Oswald's Well (G.R. NZ276419) and Kingsgate Bridge (G.R. NZ 276421). Here, the sequence comprises up to 9 m of interbedded and interlaminated fine-grained sandstones, siltstones and claystones (Fig. 7.13). Palaeocurrent measurements from trough cross-bedding indicate a palaeoflow towards the south-east (Fig. 7.14).

At a locality 50 m north-north-east of St. Oswald's Well, a lens-shaped body of trough cross-bedded and ripple cross-laminated,

Fig.7.14


EXPOSURES AND PALAEOCURRENTS IN LOWER WESTPHALIAN B SEDIMENTS - WEAR GORGE, DURHAM CITY
SCARP SLOPE
EXPOSURE, WITH PALAEOCURRENT VECTOR MEAN, NUMBER OF DATA AND STRATIGRAPHICAL HORIZON;
1H - SANDSTONES OVERLYING 1H00 COAL. } SEE CH. 7.6.3.
Ju - "LOW MAIN POST" - UPPER PART }
JL - "LOW MAIN POST" - LOWER PART. - SEE CH. 7.6.2.
K - SANDSTONES OVERLYING BRASS THILL COAL. - SEE CH. 7.5.2.1
SCALE 1:2500
275
420
NZ
PRESSENS BRIDGE FAULT
ST. OSWALD'S CHURCH
RIVER WEAR
FAULT
50M
N
NUMBERED EXPOSURES (FROM FIG. 5.13):-
① COUNT'S CORNER
② SCIENCE SITE B.H.
③ ST. OSWALD'S WELL.
④ KINGSGATE BRIDGE

fine-grained sandstone some 3-4 m in thickness and 40 m wide is exposed. Palaeocurrent measurements again indicate a palaeoflow towards the south-east (Fig. 7.14).

Similar sequences to those exposed have been recorded from nearby boreholes including the Science Site borehole (Fig. 7.13, Section 325; Appendix 1).

Interpretation

The interbedded/interlaminated sediments are interpreted as the deposits of a shallow, lacustrine floodbasin, fed by overbank and/or crevasse-derived clastic detritus. The lens-shaped sandstone near St. Oswald's Well is interpreted as an oblique section through a minor crevasse/distributary channel. This channel flowed towards the south-east, and claystone partings between units of sandstone (interpreted as slack-water sediments) suggest it was filled by a number of sedimentary events. Low angle surfaces dipping towards the south-west are possible evidence of lateral accretion in this channel deposit.

A similar sandstone, with claystone partings, occurs in the Science Site borehole (Fig. 7.13, Section 325; Appendix 1), sunk some 400 m south of the St. Oswald's Well exposure, and may represent the same channel slightly further downcurrent.

The well-developed structure of the channel deposit is considered to be a result of sustained activity over considerable period of time, perhaps aided by progradation through very shallow water. This interpretation is supported by the presence of rootlets at several horizons, and in this respect the channel is similar to those described previously from Binchester Crags (Ch. 6.7.2.5) and Cobey Carr (Ch. 6.9.2.3), and different from those seen at Deborah

O.C.C.S. (Ch. 6.6.4.3) and Tanners Hall O.C.C.S. (Ch. 7.4.2.2), which record channelized flows in somewhat deeper water.

The observation that palaeocurrent directions in the crevasse channel and floodbasin sediments coincide (Fig. 7.14) probably implies that the interbedded sediments are predominantly crevasse-derived. Comparison of such palaeocurrent directions may be one of the few ways of distinguishing thinly interbedded crevasse- from overbank-derived sediment in shallow floodbasins.

7.5.2.2 Tanners Hall/Incline/Wooley O.C.C.S.'s Description

On the adjoining Tanners Hall and Incline sites, the Top Brass Thill-Low Main interval is 10-15 m thick, divisible into a lower fine-grained member and an upper coarse-grained member.

Over the southern half of Tanners Hall O.C.C.S., the fine-grained member consists of 4.5-6.0 m of poorly-laminated ironstone-bearing claystones and silty claystones containing abundant remains of non-marine bivalves in the lower part (Unit 4; Fig. 7.9), (Plate 7.5). Bivalves are preserved in several conditions:

(1) as flattened, disarticulated impressions,

(2) as articulated but opened "clappers", and

(3) as articulated, closed shells, none of which are in life position.

In the south-east part of the site, a thin unit (or occasionally two such units) of very fine-grained sandstone or ironstone (up to 0.15 m thick) occurs part way up the sequence, dying out towards the north and west (Enclosure 14, Appendix 1).



Plate 7.5 - The Top Brass Thill - Low Main interval in the southern part of Tanners Hall O.C.C.S. (Cut 3W), showing coarsening-upward sequence in the upper part of the face. Height of exposure about 8m.



Plate 7.6 - The Top Brass Thill - Low Main interval in the northern part of Tanners Hall O.C.C.S. (Cut 9N), showing sharply-based sandstone in the upper part of the face. Height of exposure about I3m.

In one area (Section 399:- Appendix 1), a channel-like depression some 50 m wide and 3 m in height was observed in the claystone sequence on a north-south-trending cut wall (Enclosure 14).

The fine member is overlain in the south by a 5-7 m thick coarsening-upward sequence, which is commonly complex in form, containing numerous intercalations of sandstone and finer-grained sediments (Unit 5; Fig. 7.9). Most commonly-occurring sedimentary structures are ripple cross-lamination, uneven lamination and parallel lamination. Palaeocurrent measurements from ripple cross-lamination indicate a palaeoflow towards the south-east.

The uppermost part of the interval comprises up to 1.0 m of rootlet-penetrated well-laminated siltstones, and forms the seat-earth to the Low Main coal.

In the north of Tanners Hall O.C.C.S., and in the southern part of the adjacent Incline Site, a fine-grained member similar in lithology and thickness to that exposed in the south is abruptly overlain by a 5 m thick fine-grained sandstone, containing trough cross-bedding and low-angle cross-bedding surfaces, in addition to those structures characteristic of the coarse member in the south (Plate 7.6), (Fig. 7.7),(Enclosure 14, Appendix 1). The sandstone generally fines upward into about 2.5 m of siltstones and silty claystones, the upper part of which forms the Low Main seatearth.

Towards the north-west end of Tanners Hall site, the sandstone member decreases in thickness to 2.5 m and contains abundant low-angle cross-bedding surfaces. Simultaneously, the overlying fining-upward unit increases to about 4 m, the upper 2.5 m of which is rootlet-penentrated.

Interpretation

The exposed sequences are interpreted as the fill of a single, lacustrine body of water which formed as a result of subsidence of the Top Brass Thill peat swamp. The fine member claystones were deposited from suspension, and probably represent a considerable period of time when little or no traction current - derived sediment was introduced to the lake. The mode of preservation of the non-marine bivalves indicates a limited amount of entrainment by low-energy currents. The thin sandstone/ironstone is interpreted as a distal ? crevasse splay deposit which, from its' geometry, probably emanated from a source to the south-east.

The channel-shaped depression examined on Cut 6W (Enclosure 14) is considered to be of primary sedimentary origin since no evidence of glacial, tectonic or mining disturbance was observed in the area. This feature is interpreted as an orthogonal section through a lake bottom "feeder channel" similar to that described from the underlying interval at the same site (Ch. 7.4.2.2), though the claystone-dominated nature of the fine-grained member would suggest a slightly more distal aspect.

The coarsening-upward sequence exposed over the southern half of Tanners Hall is interpreted as a crevasse-initiated, minor delta infill, which prograded in a south-easterly direction across the lake-bottom sediments. The general coarsening-upward indicates an increase in current strength with time, but the interbedded nature of the sequence and the presence of bivalve escape traces implies that sedimentation was intermittent, possibly periodic.

The sharply-based sandstone exposed in the north is interpreted as a result of erosion and deposition in a more axial position on the minor delta system. In this area, the sharp base of the unit, higher

proportion of sand and assemblage of sedimentary structures indicate that transporting currents were stronger and more persistent than further south.

The thinning of the coarse member towards the north-west may be the result of a lessening of water depth towards the lake edge. Indeed the channel source of the (crevasse-initiated) minor delta system may lie in the extreme western part of the site, not yet excavated at the time of writing.

The fine-grained sediments overlying the sandstone member across the entire study area are interpreted as the result of waning flow in the minor delta system, presumably as a result of abandonment. This period of fine-grained sedimentation completed the infilling of the lake, and led to the establishment of peat swamp conditions.

From the thickness of the coarse member deposits and overlying fines, the depth of water in the lake immediately before the commencement of minor delta progradation was of the order of 6-8 m, possibly varying somewhat irregularly as a result of lake bottom topography. In the north-west, water depths were probably less, perhaps 5-6 m. Borehole data shows that the interval thickens from 10 to about 15 m northwards across Tanners Hall site, implying that the minor delta prograded into the deepest part of the lake.

The inferred depth of water in the "Tanners Hall lake", thickness of claystone and presence of bivalves at various levels suggest that lake bottom subsidence was virtually unchecked by sedimentation for a long time.

The environment and sedimentation history of the Brass Thill-Low Main interval at Tanners Hall and adjoining sites may be similar to those of the shallow lakes well-known from modern coastal plains (Coleman, Gagliano and Webb, 1964; Elliott, 1978), infilling of which is believed to be initiated by crevassing of a channel bank

(Arndorfer, 1973; Elliott, 1974).

7.5.2.3 Buckhead O.C.C.S.

Description

The Brass Thill-Low Main parting was exposed in two areas of Buckhead O.C.C.S.:- Area L (G.R. NZ 140238) and Area C (G.R. NZ 148247), (Enclosure 9).

In Area L, 7.0 m of ironstone-bearing claystones coarsen upward in the uppermost 1.0 m into fine-grained, rootlet-penetrated sandstone (the Low Main seatearth), (Section 293; Appendix 1). The claystones are poorly laminated and even canneloid in places, and contain horizons with abundant, flattened impressions of the non-marine bivalves *Carbonicola* and *Anthracosia*.

In Area C, a sequence of similar thickness and lithology was exposed (Sections 298, 426; Appendix 1). Bivalve remains were concentrated here 0.7 m above the roof of the Brass Thill seam, and comprise mostly flattened, disarticulated impressions with some "clappers" and articulated, *in situ* shells.

The uppermost part of the succession differs slightly from that in area L, in being composed of claystone (Section 426) or a series of sharply-bounded sandstones interbedded with linsen-bedded claystones containing ? partly rounded sandstone clasts (Plate 7.7), (Section 298; Appendix 1). The sandstones thicken and split to the south-east, and also split and die out to the south-west (Plate 7.7). Ripple cross-lamination also indicate a palaeoflow towards the south-south-west.

Interpretation

The claystone sequences preserved at Buckhead are interpreted as deposits from suspension in a shallow floodbasinal lake. The presence



Plate 7.7 - Panorama of Buckhead O.C.C.S. Area C (facing north-west), showing the Brass Thill-Low Main interval, Low Main coal (dark band) and "Low Main Post" sandstone. Thin sandstones beneath the Low Main coal thin and split along both faces away from the face corner (F). Height of exposure about 30m.



Plate 7.8 - Trough cross-bedded sandstone of the "Low Main Post" at Hilltop Quarry. Face is about 5m high.

of high organic matter content (inferred from sediment colour) and the existence of canneloid beds point to an almost total lack of tractional current-derived sediment.

The coarsening-upward sequence at the top of the interval in Area C was deposited by traction currents which became more powerful through time, and is interpreted as a crevasse lobe/minor delta infill of the lake. Water depth in the lake, before infilling, was probably about 1-2 m, from the thickness of the coarsening-upward sequence.

The sharply-based sandstones which comprise the uppermost part of the interval in Area C were deposited by erosive tractional currents, and the interbedded finer-grained sediments evidently laid down by less energetic currents. The geometry and palaeocurrents suggest that the sandstones are south-eastward-prograding crevasse splays.

The claystones with linsen bedding between sandstone beds are interpreted as having been deposited by gentler currents which operated between crevasse splay pulses.

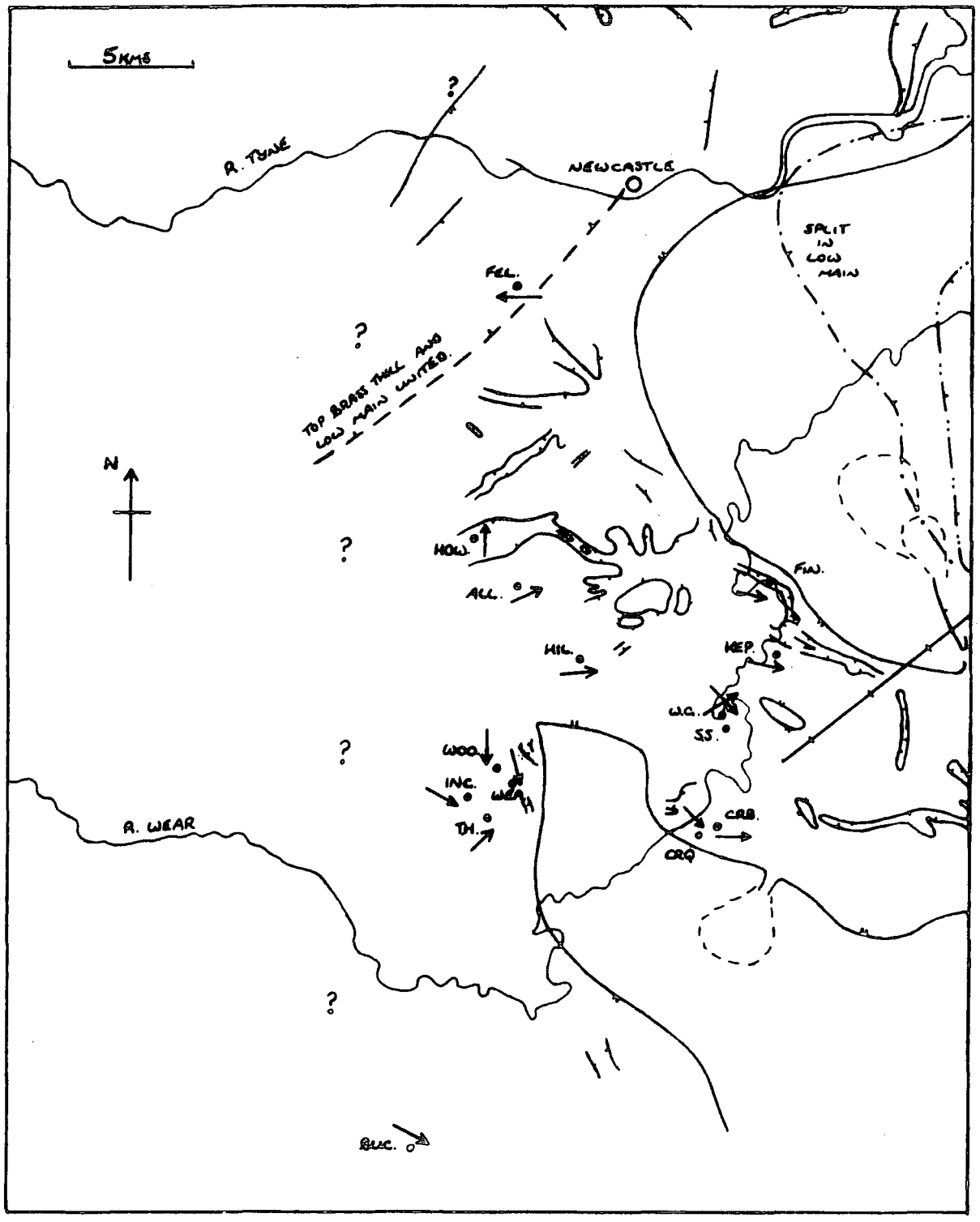
The crevasse splays filled the shallow lake, giving a *maximum* water depth of about 2 m before splay sedimentation began.

7.5.3 The Low Main coal

The Low Main coal (Durham Low Main, JOOO), is highly variable in thickness, ranging up to 2.29 m, or exceptionally up to 3.17 m where united with the Top Brass Thill seam in the area of the Tyne Valley, (Fig. 7.15). The Low Main is only locally banded, and much of the variation in seam thickness is a result of erosive "washouts" and partial "washouts" (Fig. 7.15). Isopachs for the Low Main show a

Fig.7.15

THE LOW MAIN COAL, POST-LOW MAIN PALAEOCURRENTS AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS



CHANNEL / CHANNEL BELT MARGINS

WASHOUTS IN LOW MAIN COAL.

MINOR DELTA LOBE (SCHEMATIC)

PALAEOCURRENT VECTOR MEAN

TOP LOW MAIN AND MAUDLIN SEAMS UNITED (ON ORNAMENTED SIDE)

FEL. - FELLSIDE QUARRY ($\wedge$ = 7)
HOW. - HOWDEN CLL ($\wedge$ = 36)
ALL. - ALLOTMENT QUARRY ($\wedge$ = 6)
HIL. - HILLTOP QUARRY ($\wedge$ = 29)
FIN. - FINCHALE GORGE ($\wedge$ = 26)
KEP. - KEPIER QUARRIES ($\wedge$ = 23)
W.C. - WEAR GORGE, DURHAM CITY ($\wedge$ = 69)
S.S. - SCIENCE SITE BOREHOLE
CRB. - CROXDALE BECK ($\wedge$ = 75)
CRQ. - CROXDALE QUARRY ($\wedge$ = 25)
WOO. - WOOLEY O.C.C.S. ($\wedge$ = 1)

INC. - INGLINE O.C.C.S. ($\wedge$ = 21)
T.H. - TANNERS HALL O.C.C.S. ($\wedge$ = 4)
BUC. - BUCKHEAD O.C.C.S. ($\wedge$ = 44)
WEA. - WEATHER HILL QUARRIES ($\wedge$ = 18)

APPROXIMATE LINE OF SECTION OF FIG. 7.18

pronounced relationship to the pattern of washouts discernible from mining records (Fig. 11 of Smith and Francis, 1967). Indeed, Smith and Francis (*op. cit.*) state that "washouts ... are more abundant in the Durham Low Main than in any other seam in the district".

The Low Main appears to generally increase in thickness northward across the coalfield, but the positive identification of this relationship is hindered by frequent erosion of the upper part of the seam.

The Low Main splits into two separate coals in the north-east of the coalfield, and in one area east of Hetton-le-Hole (G.R. NZ 380480), is united with the overlying Maudlin seam (Figs. 7.15, 7.16).

The sulphur content of the Low Main seam varies considerably, like that of underlying seams, and values ranging from 0.85-2.42% have been reported.

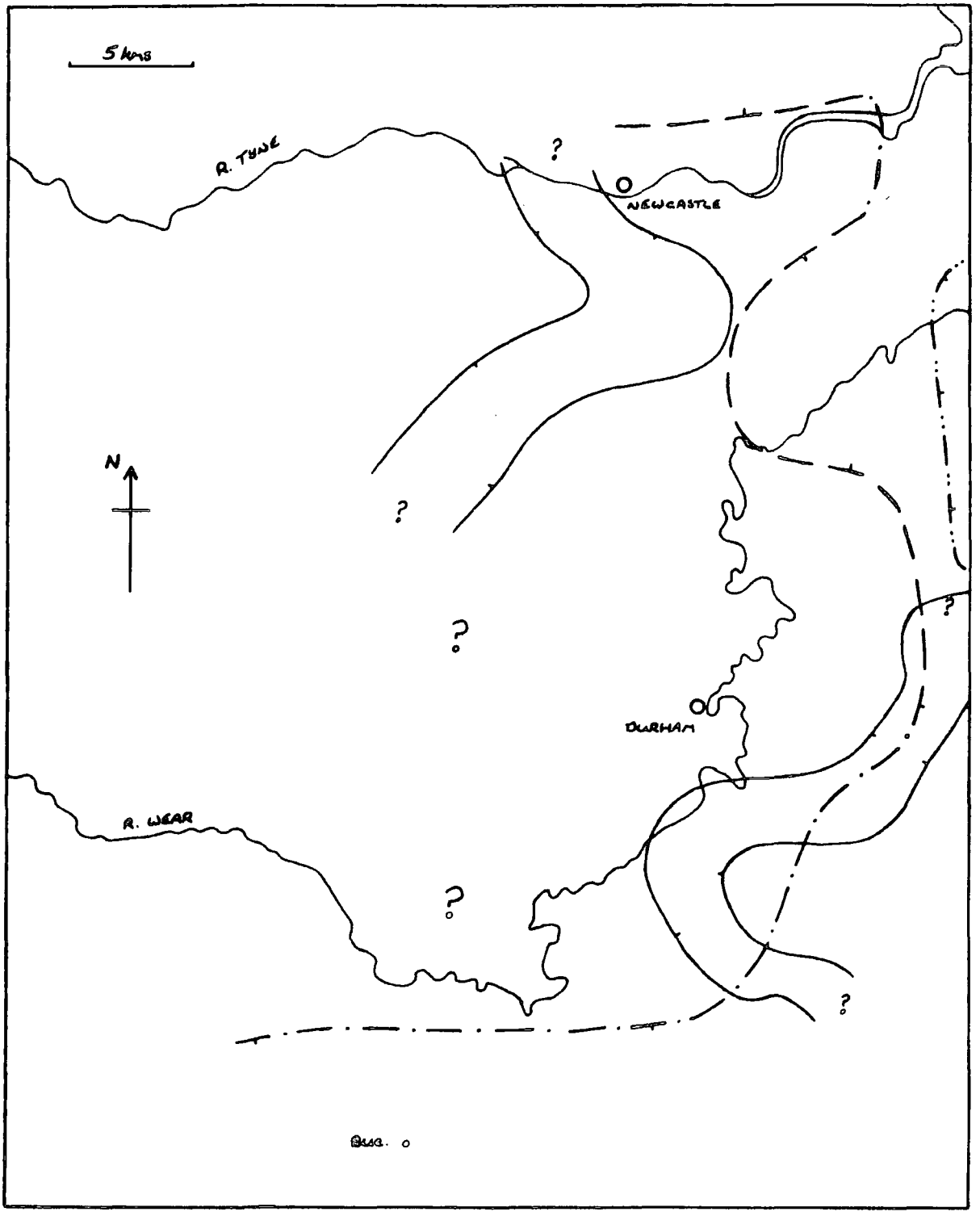
The Low Main coal was examined at five surface exposures, (Incline O.C.C.S., Buckhead O.C.C.S., Tanners Hall O.C.C.S., the Wear Gorge and Finchale Gorge (G.R. NZ 293473) and also in the core of the "Science Site Borehole" (see Sections 006, 402, 286, 335 and 325:- Appendix 1).

7.5.4 Discussion

As with the previous interval, there seem to have been few major channels operating during Brass Thill-Low Main times (Fig. 7.12, and compare with Fig. 7.5). The pattern is complicated by the amalgamation of the Top Brass Thill and Low Main seams in the Tyne Valley (Ch. 7.4.5, Fig. 7.12), but does show that channel systems in the northern and central/southern parts of the coalfield are "mutually exclusive".

Fig.7.16

THE MAUDLIN COAL AND SPECULATIVE POST-MAUDLIN CHANNEL/CHANNEL BELT TRENDS



CHANNEL/ CHANNEL BELT MARGINS

NB SEPARATION OF POST-MAUDLIN FROM POST - LOW MAIN CHANNELS IS DIFFICULT TO ACHIEVE, PARTICULARLY IN THE SOUTH.

Buc. - BUCKHEAD O.C.C.S.

MAUDLIN COAL OF WORKABLE THICKNESS (ON ORNAMENTED SIDE OF LINE)

MAUDLIN COAL SPORADICALLY OF WORKABLE THICKNESS (" " ")

MAUDLIN AND LOW MAIN COALS UNITED (" " ")

This in turn forms further support for the concept of a "see-saw" effect in the pattern of subsidence (Ch. 7.4.5), whereby peats were able to accumulate in one part of the coalfield at the same time as enhanced subsidence led to lacustrine and channel sedimentation (see also Ch. 6.5.4 and Fig. 6.23).

The "later" channels in the central/southern area seem to bear little relationship with the lines of splitting shown (Fig. 7.12). However, these are relatively unimportant splits, since the thickness of the Bottom-Top Brass Thill parting south of latitude NZ50 rarely exceeds 3 m, and are therefore unlikely to have had any major effect on channel locations. Channels seem to show evidence of avoiding earlier courses in some areas, and of "vertical stacking" in others, perhaps indicating the influence of both tectonically-induced and compaction-induced subsidence (Figs. 7.12, 7.5).

As far as it is possible to tell, channels are of similar size and form to those of underlying intervals, i.e., sinuous, and 1-3 kms wide.

The apparent low density of channels in the Brass Thill-Low Main interval is considered to result from increased channel stability and/or a diminished rate of sediment supply (A decrease in time available is discounted, since the interval is comparable in thickness and lithology to those below). Additionally, local tectonic movements probably influenced the distribution of channels.

The channel source of the crevasse-initiated minor delta system which filled the Tanners Hall lake is seen from borehole records to be less than 1 km from the examined exposures (Fig. 7.12).

The difference between lake depths inferred for the Tanners Hall and Buckhead sequences, despite the preservation of similar

thicknesses of claystones beneath coarse lake fill sediments, may be explained either by variable rates of subsidence or by variation in water turbulence and suspended sediment fallout.

The split in the Low Main coal in the north-east of the coalfield is possibly a result of accelerated subsidence induced by compaction of the underlying (thick) composite Brass Thill peat. The amalgamation, in the same area, of the Top Low Main with the overlying Maudlin seam probably requires a later slight decrease in this subsidence. This will be considered again in Ch. 7.6.5.

7.6 LOW MAIN TO MAUDLIN COALS

7.6.1 Introduction

The Low Main-Maudlin interval varies from 0.10 m to 37 m, occupied in part or in whole across much of the Durham coalfield by a thick sandstone, known as the "Low Main Post". In places, the base of this sandstone has cut through the Low Main coal itself, forming a "washout", but elsewhere is separated from the Low Main seam by argillaceous sediments. Where claystones are preserved above the Low Main seam, these have been found to contain remains of non-marine bivalves.

While the entire Low Main-Maudlin interval is often occupied by the "Low Main Post", the uppermost part is more commonly composed of finer-grained lithologies. Thin coals occasionally occur in these upper levels.

Sandstones of the Low Main Post were examined at thirteen surface exposures, and in the Science Site Borehole core. Finer-grained sediments representing the uppermost part of the interval were examined at one surface exposure and also in the core.

7.6.1 The "Low Main Post"

Description

The "Low Main Post" is probably the most areally persistent sandstone in the Durham coalfield, and outcrops extensively in the area around Durham City, forming the foundation and building material for Durham Cathedral (Johnson and Dunham, 1982), (Frontispeice).

The Low Main Post (LMP) was examined at the following localities:- Incline O.C.C.S., Buckhead O.C.C.S., Tanners Hall O.C.C.S., Wooley O.C.C.S., Wear Gorge, Croxdale Beck (G.R. NZ 271377), Croxdale Quarry (G.R. NZ267372), Hilltop Quarry (G.R. NZ216443), Howden Gill Quarry (G.R. NZ 172492), Kepier Banks (G.R. NZ 295442), Finchale Gorge (G.R. NZ 292473), Weather Hill Quarries (G.R. NZ188392), Allotment Quarries (G.R. NZ 190471), Fellside Quarry (G.R. NZ 193591) and in the core of the "Science Site Borehole" (Fig. 7.2).

The LMP has been described and interpreted in detail by Haszeldine (1981a, b) who discusses particularly the exposures at Hilltop Quarry (Plate 7.8) and Finchale Gorge, and only a brief description is necessary in the present work.

The base of the LMP is most commonly either a short distance above the Low Main coal or in direct contact with the coal seam itself. Occasionally, however, the Low Main coal is "washed out", and the sandstone may occur down to the level of the Brass Thill coals, as at Wooley O.C.C.S (Plate 7.1).

Though generally composed of fine-to-medium-grained sandstone, the LMP varies in grain size from claystone to pebble conglomerate.

Intraformational pebble conglomerates are common at the base of the LMP, though may occur at any position within the unit. Conglomerates contain partly-rounded pebbles of shale, sandstone, ironstone and coalified peat, occasionally showing a subtle imbrication, and generally supported in a matrix of fine-grained sandstone. The proportion of clasts in these conglomerates is usually quite high (about 30%).

Sandstones are most commonly trough cross-bedded (Plate 7.8), in sets up to 3.0 m thick, though tabular cross-bedding and ripple cross-lamination may be common locally. Sets are often organized in cosets, or display superimposition of small-scale (e.g., 0.15 m) cross-sets on larger ones (e.g., 0.5 m), (Plate 7.9). Thin partings of mica-rich, carbonaceous siltstone commonly occupy major bounding surfaces, many of which are laterally persistent over several 10s of m and display an irregular topography. Other common features include primary current lineation (Plate 7.10), drag folds and oversteepened cross-sets, water escape structures, chaotically-bedded horizons, rafts of shale and coalified peat, and sandstone clasts (Plate 7.11).

Siltstones and claystones may occur at any level within the unit, but are most common in the uppermost levels. Such sediments commonly contain "linsen bedding", ripple form sets and ripple cross-lamination. The uppermost few m of the LMP are usually composed of interbedded sandstone and finer-grained sediments, as at Howden Gill Quarry (Plate 7.12).



Plate 7.9 - Cosets of cross-strata showing superimposition of small sets over larger ones. "Low Main Post" sandstone, Hilltop Quarry. Exposure is about 3.5m high.



Plate 7.IO - Primary current lineation oriented down the axis of a trough cross-set, "Low Main Post" sandstone, Howden Gill Quarry. Hammer is 30cms long.



Plate 7.II - Sandstone clast (S) embedded in "Low Main Post" sandstone, Howden Gill Quarry. Hammer is 30cms long.



Plate 7.I2 - Uppermost part of the "Low Main Post" at Howden Gill Quarry, showing interbedding of fine-grained sandstone and silty claystone. Hammer (H) is 30cms long.

Palaeocurrent measurements from cross-bedding and other structures in the LMP show moderate variation within individual localities, but on a regional scale "box the compass" (Fig. 7.15, and see also Fig. 44 of Haszeldine, 1981a). Directional structures in the uppermost, interbedded part of the LMP show considerable variance from those of lower levels. Interference ripples are occasionally developed near the top of the unit (Plate 7.13).

In thin section, the LMP is quite distinctive (particularly in the area surrounding Durham City) in containing a very high proportion of kaolinite/illite cement (Plate 7.14), (Appendix 2).

Interpretation

From a detailed consideration of internal structure at a small number of localities and a study of regional geometry, etc., Haszeldine (1981a) concluded that the "Low Main Post" was the deposit of low sinuosity fluvial channels 1-2 kms wide, contained within braided channel belts 10-20 kms wide. According to Haszeldine (*op. cit.*), the complex internal architecture of the exposed LMP shows the preserved remnants of medial and bank-attached clannel floor bars (*cf.* Bluck, 1976), among other features, and palaeocurrent and geometrical relationships were used to support his argument.

From the assemblage of preserved sedimentary structures, internal structure and thickness of the sandstone, and lateral extent of the LMP, a channel interpretation is upheld.

Little direct indication of channel size or morphology is given by surface exposures, and the sandstone body is of sheet geometry. However, the wide spread in palaeocurrent directions



Plate 7.I3 - Interference ripples in the uppermost part of the "Low Main Post" sandstone at Hilltop Quarry. Lens cap is 4cms wide



Plate 7.I4 - Photomicrograph of the "Low Main Post", showing abundance of kaolinite/illite cement. Length of photomicrograph I.2mm. (Crossed polars).

between exposures and in washout orientations (Fig. 7,15), and the relatively high proportion (up to 50%) of fine grade sediment in the sequence (reflected in the sediment petrography; Appendix 2) seem atypical of other documented braided channel deposits (e.g., Campbell, 1976; Miall, 1977; Collinson, 1978).

The LMP is similar in character to the other major sandstones of the Durham Coal Measures, particularly to those of the lowermost Westphalian A (the so-called "Third Grit"). Evidence exists for at least a 10 m scour depth in the LMP channels and this, together with the size of preserved structures and lateral extent of the sandstone, suggest deposition in large channels. However, the general lack of evidence of emergence and of rootlet-penetrated sediments, and the presence of coarsening-upward cycles within the LMP, some of which may be interpreted as lacustrine delta deposits, suggest that the LMP was deposited as part of a distributary, rather than fluvial, channel system. This topic will be discussed further in Chs. 7.6.5, 9 and 10.1, as will that of channel morphology and density.

The fine-grained interbeds towards the top of the LMP may be interpreted either as slack-water channel abandonment or "fine member" in-channel deposits (Jackson, 1978, 1981).

7.6.3 Sediments above the "Low Main Post"

Sediments representing the interval between the top of the "Low Main Post" and the Maudlin coal were examined in the Wear Gorge, Durham City (G.R. NZ 271419-276419) and in the core of the nearby Science Site Borehole.

Description

The sediments comprise up to 13 m of interbedded sharply- and gradationally-bounded, fine-grained sandstones, siltstones and claystones (Fig. 7.13). Bioturbation is common, and at one horizon, present in both the examined sections, a rootleted horizon is overlain by a thin coal (1HOO).

In both surface and subsurface exposures, the sequence for 4 m or more above the 1HOO seam is dominated by sharply-bounded sandstones, which at the base are often trough cross-bedded and display load casting into the roof of the coal.

Palaeocurrent measurements from trough cross-bedding and ripple cross-lamination in sediments both beneath and above the 1HOO coal indicate a palaeoflow towards the east and east-north-east (Fig. 7.14).

Interpretation

The exposed sediments seem to have been deposited under a variety of conditions, varying from quiet-water suspension fallout to high energy tractional flows, and are interpreted as deposits of a shallow floodbasin lake developed over the subsiding, abandoned, "Low Main Post" channel sediments.

Most of the sandstones, and almost certainly all of those greater than 1 m in thickness, may be interpreted as the deposits of crevasse splays which prograded across the shallow lakes in east-north-easterly and easterly directions. The exact role, if any, of overbank-derived sediment in this system is not certain, although the relatively low palaeocurrent variance between localities suggests that overbank input was subsidiary to crevasse splays (Fig. 7.14; see "JU" and "IH" palaeocurrents). A persistent contrast in palaeocurrent direction with respect to the underlying

major sandstone confirms the idea of a cessation of channel activity *at this locality*.

Water depths in these lacustrine basins were probably no more than 5 m, from a comparison with other similar sequences.

While the examined sequence is sandstone-dominated, considerable evidence of quiet-water conditions exists in the form of burrows and laminated carbonaceous claystone horizons, indicating that sediment input to the basin was sporadic, or possibly periodic.

7.6.4 The Maudlin Coal

The Maudlin coal (H000) is of relatively minor importance in the Durham coalfield, being laterally impersistent and subject to rapid lateral changes in quality and thickness.

The Maudlin reaches workable thickness in the north-east, where it may be up to 2.18 m thick, and in some southern parts, where the seam varies up to 1.96 m in thickness. Where workable, it is most commonly banded or split into Top (H200) and Bottom (H100) Maudlin seams. Also, in the south, the coal is of comparatively low grade, containing high proportions of ash and sulphur (e.g., 8.5-14.5% and 3% respectively at Buckhead O.C.C.S.).

The seam is, however, largely thin or absent from the central part of the coalfield, and has rarely been worked in this area (Fig. 7.16).

The thickness variation of the Maudlin coal is inversely related to the thickness of the underlying "Low Main Post" (Fig. 7.15, 7.16, and see also Fig. 12 of Smith and Francis, 1967).

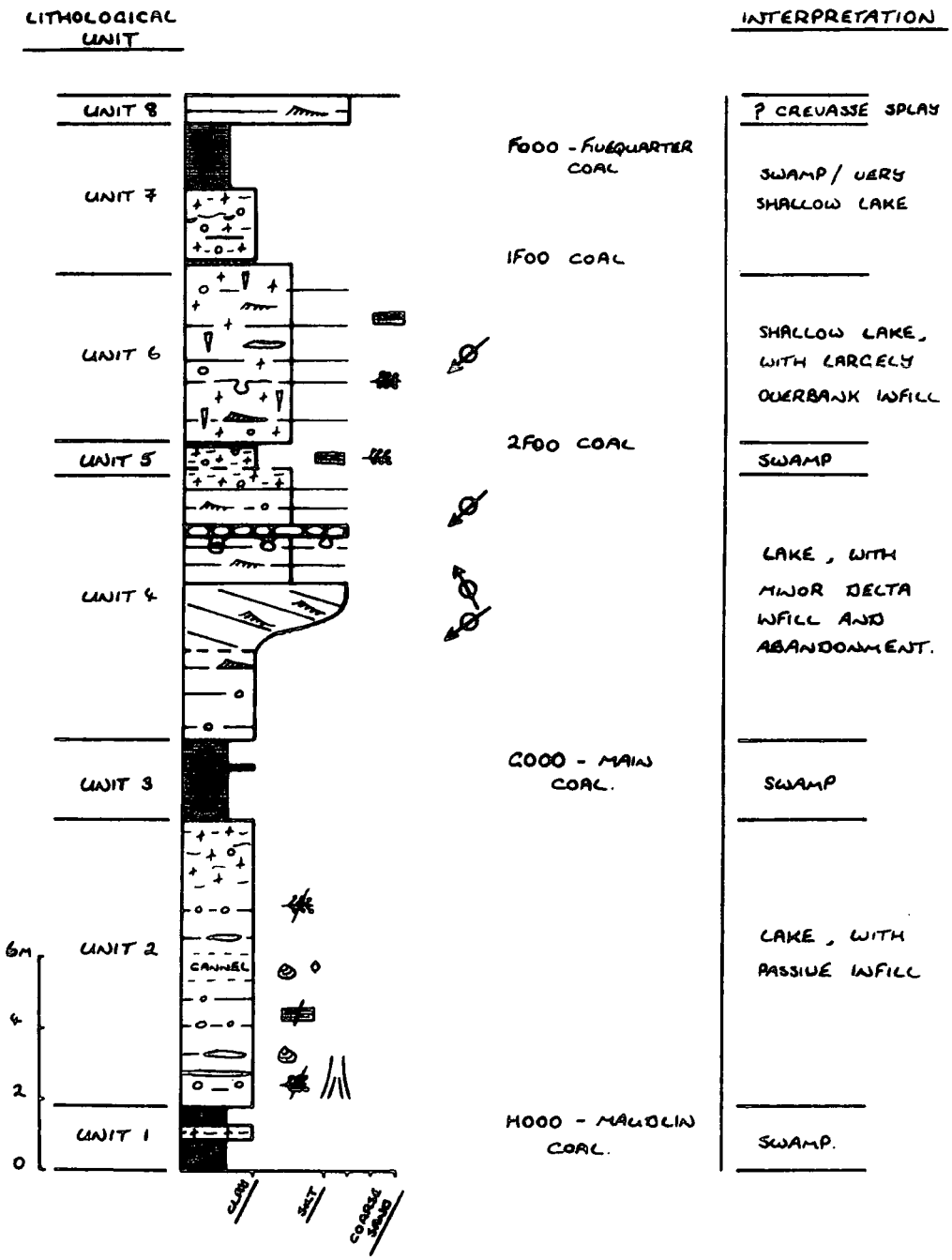
The Maudlin coal was examined at one locality; Buckhead O.C.C.S. (Area H and laundry Extension; Enclosure 9, Fig. 7.17).

Fig.7.17

COMPOSITE VERTICAL SECTION - BUCKHEAD O.C.C.S.

AREA H/L.E. (G.R.I33243)

(BASED ON SECTIONS 205, 229, 294, 348 AND OTHERS - APPENDIX I)



At this exposure, minor synsedimentary faults were observed in the upper part of the coal (Section 327; Appendix 1).

7.6.5 Discussion

The distribution of major channel belts active during the Low Main-Maudlin interval is shown on Fig. 7.15, from which it is clear that much of the Durham coalfield was covered by channel belts of perhaps up to 20 kms width. What is less clear, however, is the type of channel or channels which were responsible for the deposition of the "Low Main Post".

Haszeldine and Anderton (1980) interpreted the Low Main Post, along with certain other major sandstones in the Westphalian B sequence of N.E. England, as the products of sandy braidplains which swept southwards across the Coal Measures plain. The braidplains were initiated by local tectonic uplift of separate source areas, which liberated large quantities of recycled sands. This interpretation was challenged by Heward and Fielding (1980) on three accounts:

(1) widely varying palaeocurrent means between individual localities were considered inconsistent with a model of braided rivers flowing down tectonically tilted palaeoslopes,

(2) there appears to be little petrographic distinction between the "Low Main Post" and other major sandstones as might be expected if they were derived from separate source areas (Appendix 2), and

(3) there does not seem to be any evidence for wholesale recycling of sediment.

More recently, Haszeldine (1981a, b) has described exposures in the "Low Main Post" as the deposits of sandy, braided rivers, which he believes to be controlled by source area rejuvenation and also by local tectonic movements.

The interpretations of Haszeldine are based primarily on consideration of only three intervals within the Westphalian B sequence (Hutton-Brass Thill, Low Main-Maudlin and Maudlin-Main), and will probably give an *unbalanced* view of the Coal Measures depositional system. The author disagrees with certain aspects of Haszeldine's interpretations:

(1) hard evidence for source area basement control is lacking; incised valleys cannot be shown to have formed, no significant change in palaeoslopes, sediment source or climate can be discerned and separate sources cannot reliably be identified from sandstone petrography (Appendix 2),

(2) while it seems plausible that braided or low sinuosity rivers were responsible for depositing the "Low Main Post", the available palaeocurrent data suggest a degree of sinuosity in the depositing channels (Fig. 7.15). Haszeldine (1981a) asserts that all the major Westphalian B channels in the Pennine coalfields were of low sinuosity, a thesis which is not in accord with the findings of this study (see Chs. 9-11),

(3) the average grain-size (fine sand) of, and the high proportion of finer sediment in, the "Low Main Post" is consistent with other Coal Measure deposits, and

inconsistent with a model of braided rivers and tectonic source area rejuvenation, and

(4) a humid, tropical, coastal plain with virtually no palaeoslope does not seem a likely setting for the development of braided river systems (Miall, 1977).

The author believes that the approach adopted in this thesis, leading to a broad understanding of the Coal Measures depositional setting, is more conducive to solving the difficult problem of interpreting the Low Main Post.

Two points which are of relevance in this respect emerge from Ch. 7.6.2:

(1) areas containing major sandstones, i.e., channel belts, show an overall low sinuosity, but within, palaeocurrent vectors at individual localities show an extremely wide spread (Fig. 7.15), and

(2) the LMP is similar in many respect to the other major sandstones of the Durham Coal Measures (e.g., in overall thickness, preserved sedimentary structures, internal architecture), particularly those in the basal Westphalian A, interpreted as the deposits of trunk distributaries.

Discounting the concept of a braidplain, for the reasons discussed above, two other possibilities remain for the "Low Main Post"; that it represents:

(1) several small, ? sinuous channels up to 1 km wide, migrating within a channel belt over a long period of time, and

(2) a single, larger (? 2-5 kms wide) channel of moderate sinuosity, or possibly two such channels, which

migrated only to a limited extent over a period of time.

The first alternative is considered unlikely because:

(1) no channel margins are apparent within the sandstone body, and

(2) preserved structures, and the thickness of the LMP imply that large channels deposited these sediments.

The "Low Main Post" is thus considered to be best interpreted as the stacked deposits of either one or two large channels of possibly 5 kms width and at least moderate sinuosity, which were probably very important avenues of sediment transport across the Coal Measures plain at this time, having presumably avulsed from a former, distant course. These channels underwent limited lateral migration, building up a thick,sheet-like sandstone body, and eventually avulsed to an alternative course, causing widespread channel abandonment.

The pattern of variation in the Maudlin coal is clearly related to the thickness of the underlying "Low Main Post".

The thinning of the Maudlin coal across the central part of the Durham coalfield seems probably due to very slow compactional subsidence of the thickest channel sand accumulations. The area of combined Maudlin and Top Low Main coal in the east is explained by diachroneity of peat development (see Fig. 6.23) and persistent peat-forming conditions to the east of the "Low Main Post" channel belts.

To explain the geometry of the Low Main and Maudlin coals, and the Low Main Post, Haszeldine (1981a; pp. 138-146) invoked the

existence of a "palaeotopographical high" in the eastern part of the coalfield, related to a rejuvenation of the "Alston Block" of lower Carboniferous times (see Ch. 2.2), which allowed accumulation of thick Low Main/Maudlin peat simultaneous with deposition of the "Low Main Post" channel sands to the west.

However, thick peat accumulations have been shown in this study to compact/subside at moderately rapid rates, and thick channel sand bodies to be characterized by slow compaction/subsidence (see also Brown, 1969), and the Low Main coal is split into two "leaves" in the area of combined Low Main/Maudlin, another feature generally initiated by increased, rather than subdued, subsidence rates.

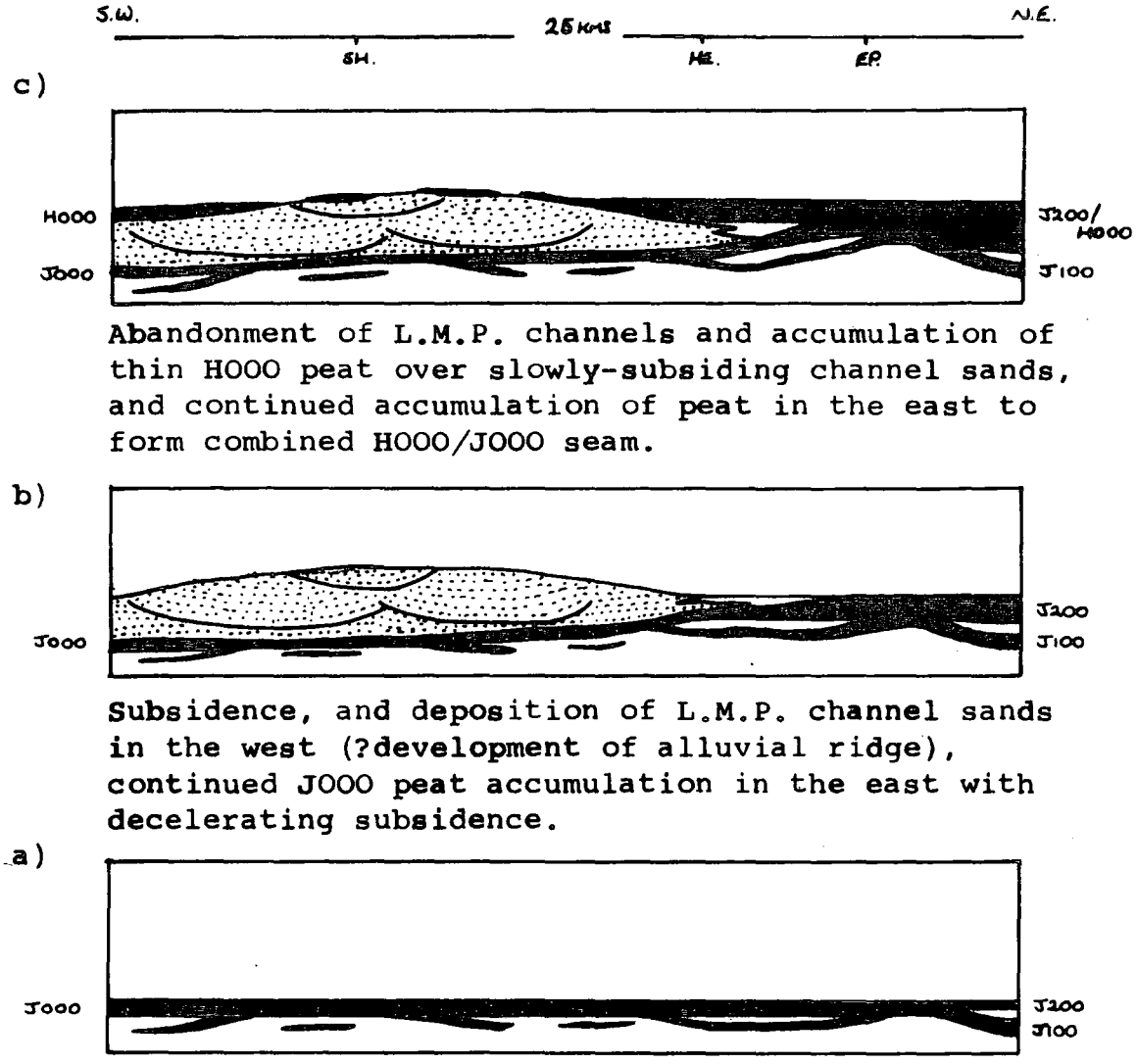
The area of amalgamated Low Main/Maudlin coals is considered to be better explained as a backswamp area adjacent to the LMP channel belts which subsided at a rate similar to, or possibly even greater than, that of the LMP sands, allowing more or less continuous peat accumulation in the east. As was suggested in Ch. 7.5.4, the rate of subsidence may have been decreasing slightly at this time.

The relatively uncompactable channel sands subsided slowly, perhaps building up an?alluvial ridge, and following channel abandonment were succeeded by thin accumulations of peat-forming vegetation (the Maudlin coal). In the east peat formation continued throughout, giving rise to the westward splitting in the Low Main and Maudlin seams (Fig. 7.18). There thus seems no need to invoke "block and basin" tectonics to explain the observed variation; initial siting of the LMP channels may have been influenced by the presence of thick or multiple, rapidly compacting Low Main peats

Fig.7.18

DEPOSITIONAL MODEL FOR THE LOW MAIN COAL (JOOO), "LOW MAIN POST" SANDSTONE AND MAUDLIN COAL (HOOO) IN THE CENTRAL PART OF THE DURHAM COALFIELD

(SEE ALSO FIG. 7.15).



Abandonment of L.M.P. channels and accumulation of thin HOOO peat over slowly-subsiding channel sands, and continued accumulation of peat in the east to form combined HOOO/JOOO seam.

Subsidence, and deposition of L.M.P. channel sands in the west (?development of alluvial ridge), continued JOOO peat accumulation in the east with decelerating subsidence.

Accumulation of JOOO peat, and early accelerated subsidence in the west and east, causing "seam splits".

"LOW MAIN POST" CHANNEL SANDS (L.M.P.)

NB PROFILES A-C ARE SCHEMATIC.

CALCULATION OF LIFESPAN OF L.M.P. CHANNEL SYSTEM FROM RELATIVE THICKNESSES OF JOOO & HOOO COALS.

EP. - EPPLETON COLLIERY - J200/HOOO = 2.44 m

2.5 kms

9.5 kms

HE - HETTON COLLIERY - JOOO = 1.24 m, HOOO = 0.46 m, PARTING = 13.66 m.

SH. - SHINCLIFFE COLLIERY - JOOO = 1.02 m, HOOO = 0.18 m, PARTING = 28.02 m.

∴ 28.02 m OF CLASTIC SEDIMENTS AT SHINCLIFFE ≡ 1.24 m COAL AT EPPLETON, (2.44 m − (1.02 m + 0.18 m)).

USING THE METHOD DESCRIBED IN Fig. 4.2, THIS INTERVAL IS CALCULATED TO REPRESENT APPROXIMATELY 15,000 YEARS' PEAT ACCUMULATION.

(FOR DETAILS OF LOCALITIES, SEE SMITH & FRANCIS (1967) AND C.N.E.I.M.M.E (1878))

(later perhaps partly eroded), or may have been controlled by other local palaeotopographical or structural features. It may be significant that thin coal "stringers" commonly underlie the Low Main Coal in the central area.

Using relative thicknesses of the Low Main and Maudlin coals across the area of splitting, and the method described in Fig. 4.2, the life span of the "Low Main Post" channel system, including its' "abandonment phase", may be roughly estimated as 15,000 years (Fig. 7.18).

7.7 MAUDLIN TO MAIN COALS

7.7.1 Introduction

The interval between the Maudlin and Main coal seams varies between 8 and 25 m, and is highly variable in character.

In the central part of the coalfield, a thin coal commonly occurs midway up the sequence, and in the north several seatearths or coals may be present (Land, 1974).

A prominent non-marine fossil horizon is commonly present in the upper part of the interval, containing a fauna of bivalves, *Spirorbis*, *Estheria* and fish (the "Blackhall Estheria Band"; Magraw, Clarke and Smith, 1963). This band generally represents the lowermost occurrence of *similis-pulchra* zone fossils in the coalfield.

The Maudlin-Main interval was examined at only one exposure, and the Main coal itself in three places.

7.7.2 Sediments between the Maudlin and Main Coals

7.7.2.1 Buckhead O.C.C.S.

Description

At Buckhead O.C.C.S., the Maudlin-Main interval was exposed in Area H, and in the Laundry Extension (Enclosure 9).

The sequence comprises 6.5-7.0 m of medium and dark grey, often canneloid, claystones (Fig. 7.17; Unit 2), decreasing in thickness slightly towards the east.

The claystone-filled cast of an upright, *in situ* tree stump was seen at one locality, and at another, three thin sandstone bands were observed (Sections 327 and 310 respectively:- Appendix 1).

Interpretation

The sediments exposed at Buckhead seem to have been deposited largely from suspension, and are interpreted as the deposits of a shallow, stagnant lake which developed as a result of subsidence of the Maudlin peat. The preservation of an *in situ* tree trunk suggests that sedimentation must have been rapid at times.

The uppermost part of the interval, which is heavily rootlet-penetrated, displays no evidence of coarsening-upward or any other signs of a coarse-grained lake fill. However, such fine-grained lake infills are common throughout the Durham Westphalian, in some cases demonstrably adjacent to coarser deposits (for example, the Brass Thill-Low Main interval at Buckhead O.C.C.S.; see Ch. 7.5.2.3), and it is thus evident that increased water turbulence, associated perhaps with crevasse splay activity, could have caused deposition of fine-grained lake fills.

7.7.3 The Main Coal

The Main coal (G000) is, as the name suggests, one of the most widely worked seams in the Durham coalfield, varying up to 3.35 m in thickness.

The seam is thickest in the extreme south, where it is commonly banded and known to change rapidly in thickness laterally (Fig. 7.19). Further north, however, it is generally thinner, though commonly banded, and in the far north of the coalfield becomes uniform in thickness and character (Land, 1974).

In certain areas, notably around Burnhope (see accounts of Ibbetsons O.C.C.S. Extension) and near the coast, west of Blackhall Colliery (Fig. 13 of Smith and Francis, 1967), the Main coal is united with the overlying Fivequarter seam (Fig. 7.19).

Sulphur values for the Main coal are moderately low, and seem to display less variation than those of stratigraphically adjacent seams, the range encountered being 0.88-1.62%.

The main coal was examined at Buckhead O.C.C.S., Ibbetsons O.C.C.S. (G.R. NZ 192485) and Langley O.C.C.S. (G.R. NZ 212467), (Plate 7.15), (Figs. 7.17, 7.20 and Enclosure 15/Appendix 1 respectively, Fig. 7.2). At Langley O.C.C.S., the Main coal was underlain in one area (? 1-200 m in width) by up to 1 m of impure shaly coal.

7.7.4 Discussion

Major channels believed to have been active during the interval between accumulation of the Maudlin and Main peats are shown on Fig. 7.16. However, due to uncertainty in stratigraphical correlation where the Maudlin coal is thin or absent, it is emphasized that identification of these channels is only tentative.

Fig.7.19

THE MAIN COAL, POST-MAIN PALAEOCURRENTS AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS

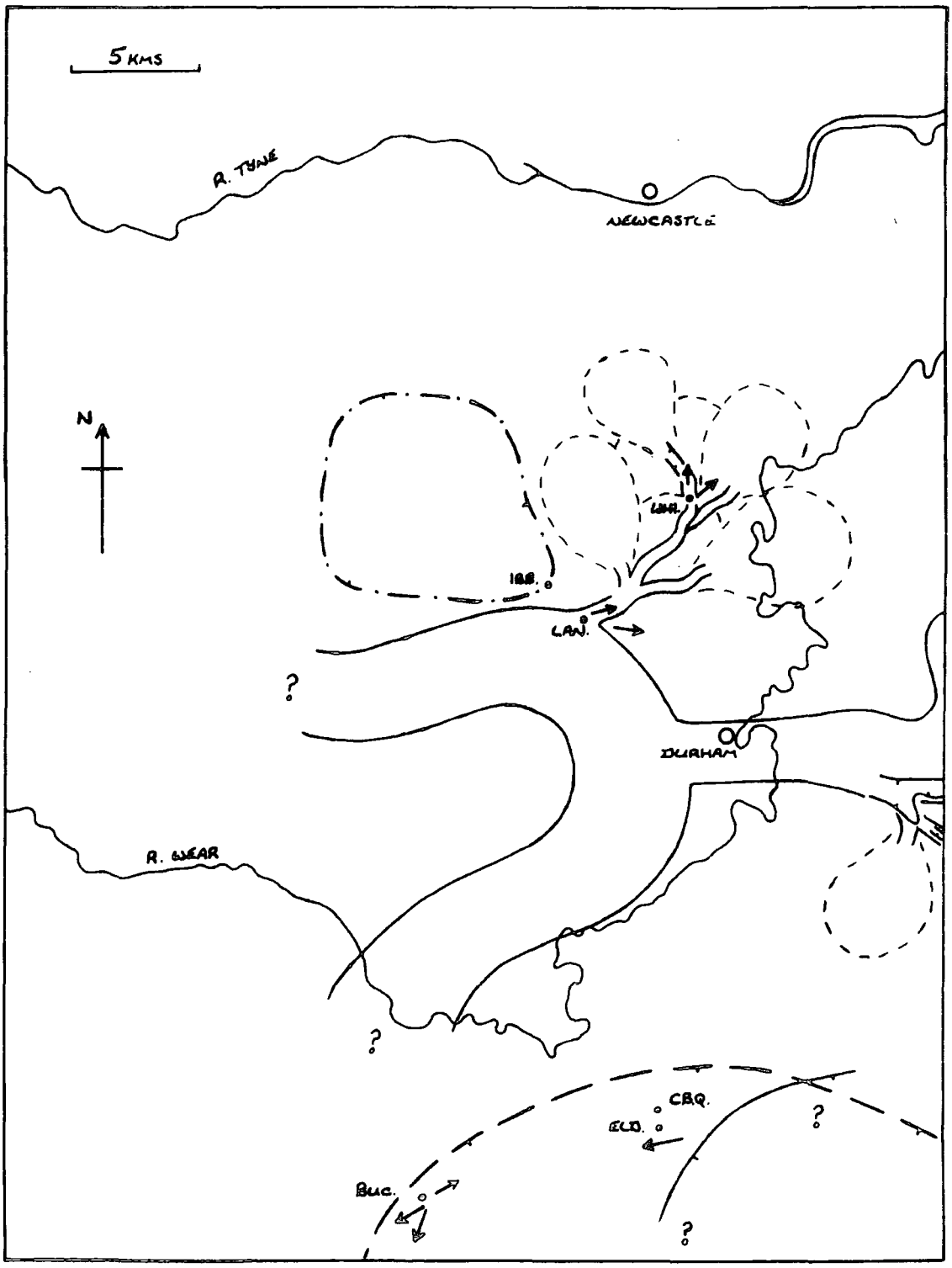




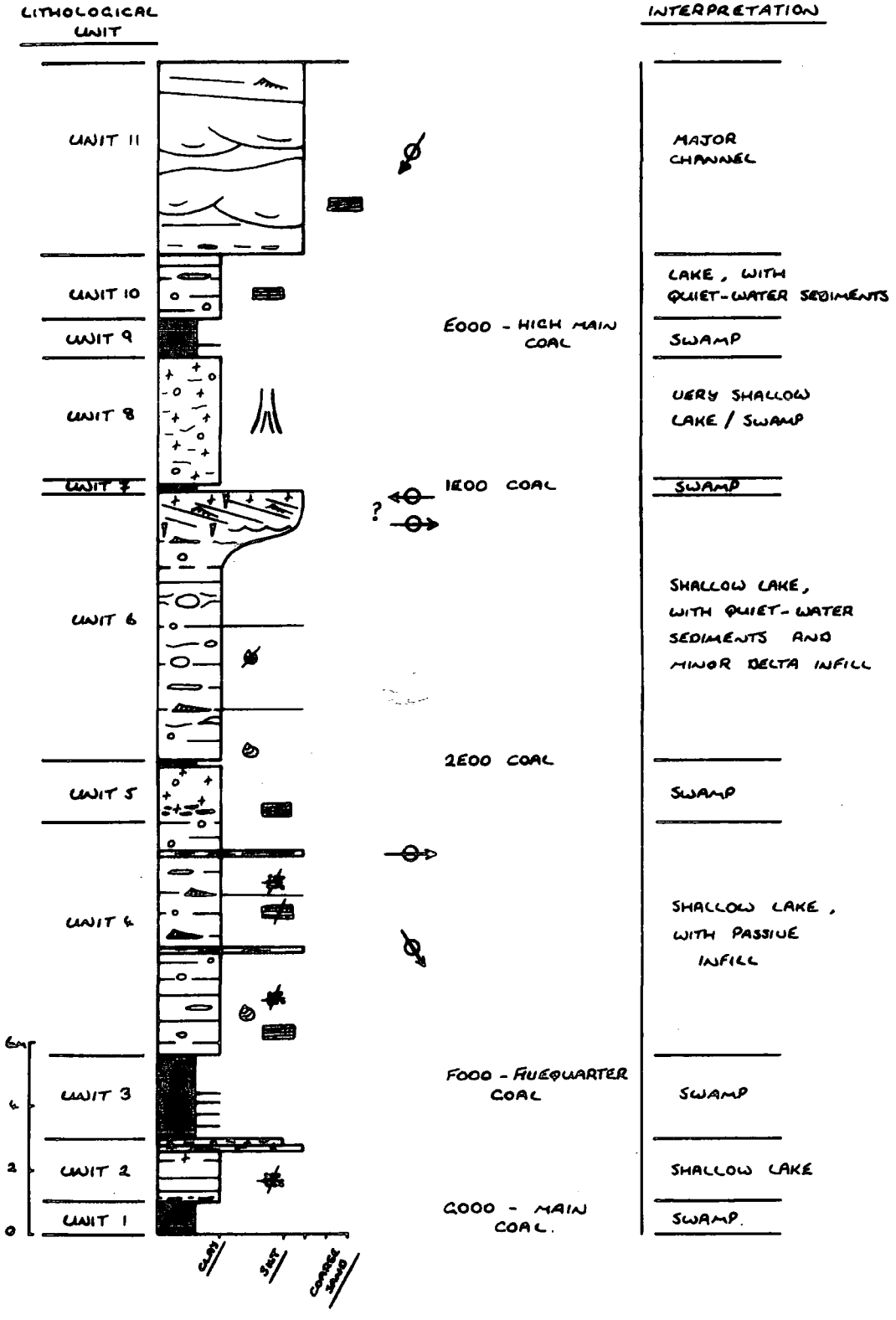
Plate 7.I5 - View of the Main coal and overlying sediments at Langley O.C.C.S., facing east. A unit of thinly interbedded sediments, thinning and displaying low-angle depositional dips towards the east, is overlain by a similar thickness of trough cross-bedded sandstone. Height of exposure about 8m.



Plate 7.I6 - The Main-Fivequarter interval at Whitehall Shale Quarry, showing discontinuous, ?minor channel sandstones (S) within a thick siltstone sequence. Height of exposure about I2m.

Fig.7.20

COMPOSITE VERTICAL SECTION - IBBETSONS O.C.C.S. EXTENSION (G.R.NZI92485), (BASED ON SECTIONS 219, 264, 280, 321 - APPENDIX 1)



For the same reason, it is possible that some of the "uppermost" channel deposits shown previously in the Low Main-Maudlin interval (Fig. 7.15) may have accumulated with or after the Maudlin peat.

Despite this uncertainty, it appears that the Maudlin-Main interval was characterized by a diminished sediment supply, reflected in a low areal density of major channels. This may have resulted from the complete avulsion of the trunk distributary system which had flowed across the area during the previous interval, causing wholesale re-direction of sediment toward other parts of the Coal Measures plain. The author has found little evidence for the "zone of thick sand" inferred by Haszeldine (1981a; Fig. 29) as representing continuation of the "Low Main Post" channel system, though it is evident from Haszeldine's work that major channels are more important at this level further north, in Northumberland.

The irregular pattern of thickness variation in the Main coal is attributed to local variation in subsidence rates, caused perhaps by a combination of differential compaction/palaeo-topography and local structural controls. The area characterized by amalgamation of the Main and Fivequarter coals will be considered in the following section (Chs. 7.8.2 and 7.8.4).

7.8 MAIN TO FIVEQUARTER COALS

7.8.1 Introduction

The interval between the Main and Fivequarter coals varies between less than 1 m and 40 m, thicker partings being associated with major sandstones.

Thin, impersistent coals may occur at several levels, and in northernmost part of the coalfield a quite persistent seam of variable thickness occurs near the middle of the sequence (the Bentinck; G200 or 1F00). In the north, and more so in the adjacent Northumberland coalfield, the coal seams above the Main display a complex pattern of splitting and rejoining (see Fig. 56 of Land, 1974).

Sediments representing the Main-Fivequarter interval were examined at six surface exposures and the Fivequarter coal at six localities.

7.8.2 Sediments between the Main and Fivequarter Coals

7.8.2.1 Langley O.C.C.S.

Description

At Langley O.C.C.S., the Main-Fivequarter parting comprises 10-17 m of sandstone-dominated sediments.

Over much of the site, the interval consists of interbedded fine-grained sandstones and carbonaceous claystones, erosively overlain by a sequence of more continuous fine-grained sandstone (Plate 7.15),(Enclosures 15, 16).

The lower unit consists of 5-15 cm thick beds of sandstone alternating with 0.5-2 cm partings of dark-coloured, carbonaceous claystone. Individual beds may be traced laterally for 100s of m in an east-west direction. From the centre to the eastern end of the site (a distance of about 750 m), the interbedded unit increases in thickness to a maximum of about 4.0 m, and then decreases again, display a very low-angle "draping" towards the east-south-east (Enclosure 16, Plate 7.15).

Occasionally *Pelecypodichnus* and *Planolites* burrows are present, in addition to more indeterminate traces. Synaeresis cracks were observed at one locality (Section 436:- Appendix 1, Enclosure 15). Palaeocurrent measurements from ripple cross-lamination and rare trough cross bedding indicate a general palaeoflow towards the east and east-south-east (Enclosure 15).

The overlying trough cross-bedded unit has an eroisve basal contact, and varies inversely in thickness with the underlying sediments. Trough cross-sets, arranged in a complex mosaic, vary up to 2.0 m in thickness and one cross-set of 2.0 m thickness often comprises the basal part of the sandstone, traceable in a downcurrent direction for at least 100 m. Palaeocurrent measurements from trough cross-bedding indicate a palaeoflow towards the east and east-north-east (Enclosure 16).

The uppermost 1.0 m or so of the interval shows upward fining to well-laminated siltstone or silty claystone, which is rootlet-penetrated and forms the seatearth to the Fivequarter coal.

In the western part of the site, the entire sequence, increased in thickness to as much as 16 m, is composed of continuous, large-scale trough cross-bedded sandstone, with a thin rootlet-penetrated siltstone again underlying the Fivequarter coal (Enclosures 15, 16). Trough cross-sets in this area are often complex in form, and may show a basal lining of dark claystone up to 0.2 m thick. Palaecurrent measurements from trough cross-bedding indicates a local palaeoflow towards the east (Enclosure 16).

Borehole information shows that this lithology occupies the entire interval for at least 1 km east-west, up to the western boundary of the site.

Interpretation

The trough cross-bedded sandstone with claystone partings and drapes, which comprises the entire Main-Fivequarter interval in the west, and the upper half of the interval elsewhere on the site, was probably deposited by strong, though not continuous, traction currents. The thickness and lateral extent of the sandstones, combined with their traction-dominated nature, suggest that they represent the deposit of a fluvial or distributary channel. The fine-grained sediments beneath the Fivequarter coal may then be interpreted as ? in channel abandonment deposits.

The interbedded sediments were deposited by an alternation of quite energetic tractional currents and suspension fallout conditions. From this, the lateral continuity of individual beds and the geometry of the unit as a whole, (Enclosure 16) the interbedded sequence is interpreted as the deposit of a channel levee. Judging by the apparent lack of rootlets, and abundance of bioturbation (including evidence of bivalve colonization), the levee was subaqueous and, from extrapolation of unit thickness, was about 1 km in "width".

From the paleocurrent distribution and geometry of the interbedded and continuous sandstone units, the levee is interpreted as having developed at the eastern margin of a major channel which was at least 1 km wide, and flowed towards the east where channel deposits were examined, but changed direction towards the south (Enclosure 16). Interesting in this respect are observations from Enclosure 16 that the predominant palaeoflow direction was oblique to the "levee contours", and that the levee widened towards the presumed downcurrent end of the curved channel reach. Instantaneous

channel depth is uncertain, but must have been at least 2.0 m from the thickness of cross-sets.

The presence of a substantial and well-developed levee sequence and the total thickness of the channel sandstone deposit in the west implies long-term stability of the channel course, and a dominantly vertical mode of accretion *at this margin*. However, the occurrence of channel sandstones directly overlying the levee sequence, with structures indicating east- and east-north-east-directed palaeoflow, implies eventual breaching of the concave (i.e., erosional) channel bank, causing a diversion in the course of the channel (Enclosure 16). Complete avulsion of the channel evidently does not seem to have occurred, since channel sandstones in the "western belt" persist almost up to the level of the Five-quarter coal.

The low-angle, downcurrent-persistent cross-set present in the base of this sandstone superficially resembles the "epsilon cross-stratification" associated with lateral accretion. However, the cross-set in question dips in the same direction as the trough cross-bedding, and is therefore interpreted as the result of infilling of the shallow-water overbank environment prior to full-scale establishment of the diverted channel.

The rootlet-penetrated abandonment deposits immediately below the swamp peat accumulation of the Fivequarter coal attest to the eventual abandonment of the entire channel system, presumably by upstream avulsion. The thickness of the fine-grained sediments indicates abandonment to have been fairly rapid.

Channel levee deposits are common in modern-day delta plain and alluvial plain settings, and may build up to several metres height above low flow-stage water level (Coleman, Gagliano and

Webb, 1964; Singh, 1972). However, levee deposits are very poorly-described from the ancient record, exceptions including Gjelberg (1977), Guion (1978) and Ethridge, Jackson and Youngberg (1981). This is seen as a result of:

(1) the poor preservation potential of levees in channel sequences, and

(2) the exceptional quality of exposure required to display the characteristics of these deposits adequately, and the difficulty in interpreting poorly-exposed sequences.

Preservation of the Langley levee sequence was probably achieved as a result of *partial* abandonment of the initial channel course, which divided the erosive power of the channel and led to rapid burial of levee sediments without erosive removal by the diverted channel.

The superbly-exposed Main-Fivequarter parting at Langley O.C.C.S. thus records the evolution of a major ? distributary channel erosional margin (concave bank), a setting very rarely observed during this study, and indeed poorly-known from the stratigraphical record. The identification of a subaqueous channel levee and evidence for downcurrent channel bifurcation forms support for a deltaic distributary, rather than fluvial channel, interpretation (see Chs. 9 and 10).

7.8.2.2 Buckhead O.C.C.S.

Description

At Buckhead O.C.C.S., a Main-Fivequarter parting of some 15 m. including two thin coals (2FOO and 1FOO), was exposed in Area H and the Laundry Extension (Enclosure 9), (Fig. 7.17).

The coarsening-upward sequence (Unit 4; Fig. 7.17) which comprises the entire Main-2FOO parting over much of the Area contains low-angle, ?tabular depositional cross-surfaces up to 4.0 m in height, most of which dip at 5-10 degrees towards the south-west, with a smaller number inclined towards north-north-west and north-east. Palaeocurrent measurements from ripple cross-lamination and ripple form sets indicate a similar diversity in palaeoflow direction. At the western end of the Area, the uppermost 3 m or so of the Main-2FOO parting is composed of silty claystones with sandstone laminae, and occasional load-casted sandstone/ironstone layers, in which ripple form sets indicate a palaeoflow towards the south-west (Fig. 7.17).

The overlying 2FOO-1FOO and 1FOO-Fivequarter partings (Units 6 and 7; Fig. 7.17) are of similar character, being entirely composed of rootlet-penetrated silty claystones with sandy streak and laminae. Evidence of synsedimentary deformation is contained in slump folds with near-horizonal axial planes, and palaeocurrent measurements from ripple cross-lamination within the 2FOO-1FOO interval indicate a palaeoflow towards the south-west.

Interpretation

The coarsening-upward sequence was deposited under gradually increasing, though fluctuating, energy conditions. From this, and the presence of large-scale dipping surfaces, the sequence is interpreted as the product of a prograding lacustrine delta, or from the palaeocurrent pattern, two or three such deltas. The lake into which this delta prograded developed as a result of drowning of the Main peat swamp, and from the thickness of the coarsening-upward sequence was about 5-6 m deep immediately prior to commence-

ment of infilling. From the presence of fine-grained sediments at the top of the sequence in the west, the dominant axis of sedimentation on the minor delta system is inferred to have lain towards the eastern end of the examined area (Enclosure 9), and to have transported sediment into the lake towards the south-west.

Peat swamp conditions eventually developed on the near-emergent surface of the abandoned minor delta, leading to accumulation of the 2FOO seam, until subsidence once again overtook peat accumulation.

The sediments of the 2FOO-1FOO and 1FOO-Fivequarter partings were deposited by fluctuating flow conditions in a very shallow-water environment, from the frequent variation in sediment grain-size and ubiquitous presence of rootlets. These are interpreted as shallow floodbasin deposits, fed by overbank material from distant channels. Periodically these filled completely, allowing peat swamp conditions to be established. The presence of slump folds in the 2FOO-1FOO parting implies the presence of a ? south-ward-inclined depositional slope, although borehole information indicates a thinning in the 2FOO-1FOO sequence only towards the east.

The fairly consistent direction of palaeoflow throughout the Main-Fivequarter parting at Buckhead implies the persistence of the channel source of sediment throughout this time, and taken together with the development of 6 m water depth in floodbasinal lakes, is a further indication of increased channel stability and/or decreased sediment supply.

7.8.2.3 Ibbetsons O.C.C.S.

Description

Excavations of the Main-Fivequarter interval at Ibbetsons O.C.C.S. Extension revealed a parting which varies between 1.4 and 3.75 m (Fig. 7.20). An isopach map shows that the two seams converge towards the north-west across the site, and more or less unite in the extreme north-west (Fig. 7.21). For the most part, the interval consists of claystones or silty claystones with sandy streak, but sharply-based beds of sandstone are occasionally present.

Interpretation

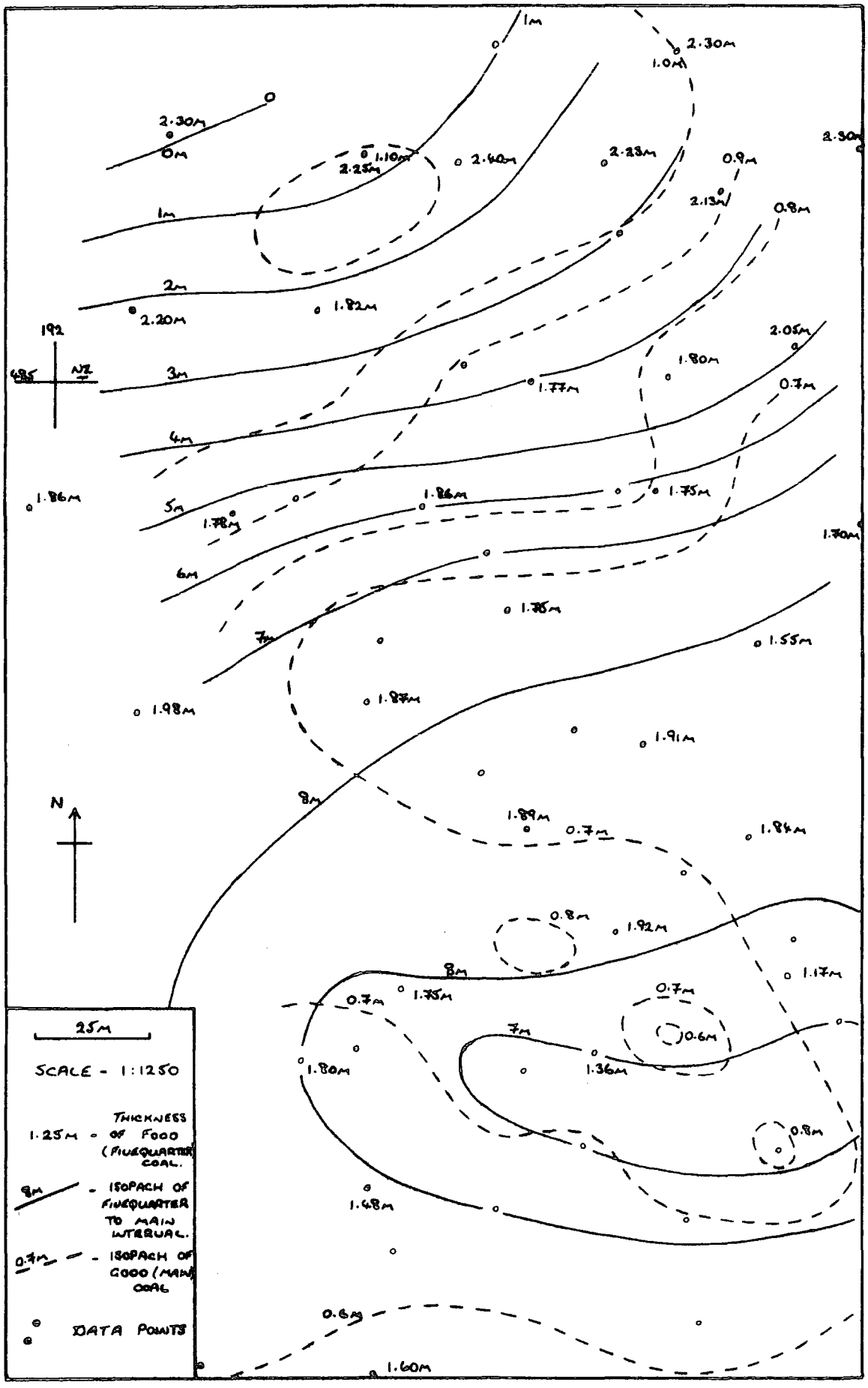
The sediment exposed at Ibbetsons O.C.C.S. were deposited under fluctuating energy conditions, and are interpreted as the deposits of a shallow floodbasinal lake, developed as a result of subsidence of the Main peat swamp. Sedimentation was achieved probably by a combination of crevasse splay and overbank processes, though the balance of influence is not clear.

The divergence of the Main and Fivequarter coals is interpreted as a result of enhanced subsidence to the south-east, perhaps initiated by a thickened Main peat deposit in that direction. The area to the north-west is seen as an area of moderate subsidence, where peat accumulation continued virtually uninterrupted for perhaps 50,000 years (Fig. 4.2). The life span of the shallow lake fill may be estimated from the variation in thickness of the Main seam across the area (Fig. 7.21) and using the method of Fig. 4.2. A period of about 6000 years is considered to have been required for the development and filling of the 10 m clastic sequence.

Evidence for the persistence of this area of localized

Fig.7.21

THICKNESS RELATIONSHIPS BETWEEN THE MAIN AND FIVEQUARTER SEAMS, AND THE MAIN - FIVEQUARTER INTERVAL AT IBBETSONS O.C.C.S. EXTENSION



accelerated subsidence lies in the thickness of the overlying Fivequarter coal seam, which varies inversely with that of the Main-Fivequarter parting (Fig. 7.21).

7.8.2.4 Whitehall Shale Quarry

Description

Whitehall Shale Quarry (G.R. NZ 248518; Fig. 7.2) exposes 20 m of mainly fine-grained sediments, representing virtually the entire Main-Fivequarter parting, although neither of these seams were exposed when the quarry was visited (Fig. 7.22),(Plate 7.16).

Much of the interval comprises poorly-laminated siltstones rich in drifted plant debris, though in the middle of the succession two fine-grained sandstones occur (Units 2 and 4; Fig. 7.22), and in the uppermost part a 2.5 m thick coarsening-upward sequence is sandwiched between two thin coals (Units 6, 7 and 8).

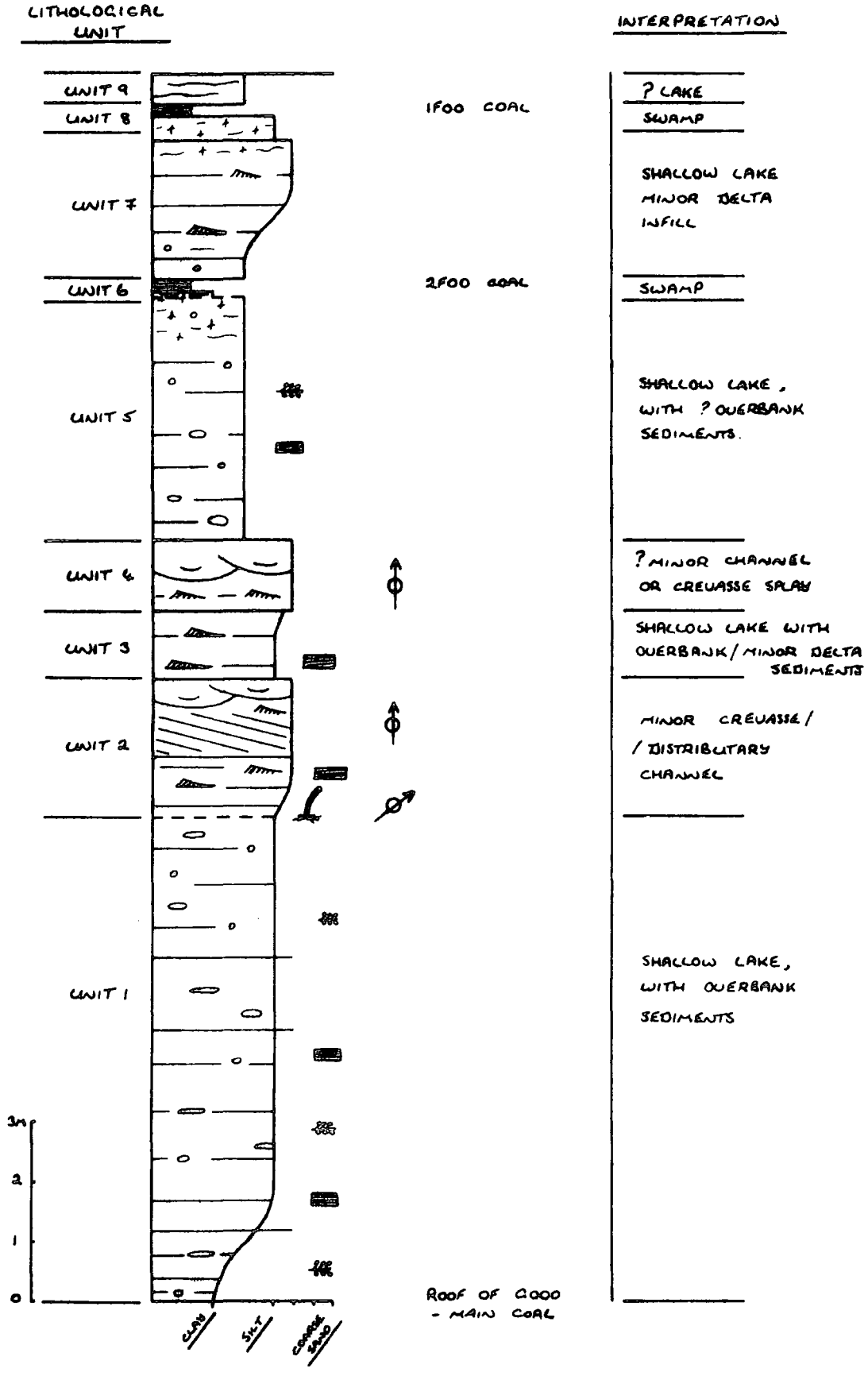
The lowermost of the two sandstones (Unit 2) displays a number of low-angle bedding surfaces inclined towards the east-south-east, whereas other directional structures in both sandstones (trough cross-bedding and ripple cross-lamination) indicate a palaeoflow towards the north. Bent-over, *in situ Calamites* casts and drifted plant debris immediately below the lower sandstone indicate palaeoflow towards the north-east (Fig. 7.22).

The uppermost sandstone (Unit 4) can be seen to wedge out to the east along a 50 m - long stretch of the quarry wall. The overlying silty claystones contain a series of sharply-bounded sandstones which die out to the west.

Fig.7.22

MEASURED VERTICAL SECTION - WHITEHALL SHALE QUARRY

(G.R.NZ248518). (BASED ON SECTION 420 - APPENDIX I)



Interpretation

The thick sequence of "massive" and poorly-laminated siltstones exposed at Whitehall Quarry was probably a result of rapid suspension fallout, from the lack of traction-derived sedimentary structures and delicate preservation of plant fossils, and is interpreted as the products of overbank deposition into a shallow-water, floodbasinal lake. This style of sedimentation was sustained over a long period of time, interrupted by two periods of higher-energy current activity, which led to the deposition of the two sandstones. From the ? lenticular nature of the upper sandstone, the depositing flows may have been confined, and the sandstones are tentatively interpreted as the deposits of northward-flowing minor channels (although the upper unit might merely represent a proximal crevasse splay deposit.).

The presence of low-angle cross-bedding, inclined at about 120^{o} from the palaeflow direction determined from other structures implies that the channels were laterally accreted, in turn suggestive ofa meandering channel morphology. The process of lateral accretion indicates that the "lower channel" was active for some time, may thus be termed a minor distributary and distinguished from shorter-lived crevasse channels which possess a simpler internal architecture (see, for example, Ch. 6.7.2.3), though it is evident that the two channel types were probably formed in the same way. No impression of channel width could be gained from the available exposure, but, from a comparison with previously-described minor channels, the thickness of channel units implies that these channels were probably not more than 100 m wide. From the general consistency in palaeocurrent direction between overbank and crevasse-derived sediments, the

same ultimate sediment source is implied (the sharply-based sandstones in the eastern part of the quarry face are interpreted as crevasse splay deposits possibly from another source).

The presence of *in situ* plant remains implies that the depth of water in the overbank fed basin cannot have been much more than 1-2 m at most times. The basin was eventually filled sufficiently to allow peat swamp conditions to develop, leading to the accumulation of the 2FOO peat.

The overlying coarsening-upward sequence is interpreted as similar sequences elsewhere, as a minor delta infill of a shallow lake established due to peat swamp subsidence. The lake is interpreted to have been 2.5-3.0 m deep before commencement of infilling.

7.8.2.5 Eldon Hill Quarry/Crossley Brickworks Quarry

Description

At Eldon Hill Quarry (G.R. NZ 241274) an 8 m sequence exposes the lower part of the Main-Fivequarter interval, whereas at the nearby Crossley Brickworks Quarry (G.R. NZ 240278) almost the entire interval (about 16 m) was seen (Appendix 1:- Sections 366 and 411 respectively, Fig. 7.2).

The Eldon Hill sequence, exposed in a single 4o m long quarry face, comprises a series of interbedded siltstones and fine-grained sandstones, of which the latter display both sharp and gradational bases and sharp tops. Abundant evidence of syn-sedimentary deformation is present in the form of load casts and detached load balls. Near the top of the sequence, a thin coaly shale is present, with *in situ* rootlets.

The sandstones thin and pinch out towards the south-west apart from the uppermost one, which thins in the opposite direction. Palaeocurrent measurements from trough cross-bedding and ripple cross-lamination indicate a consistent direction of palaeoflow towards the west-south-west, while structures in the uppermost sandstone imply palaeoflow towards the north (Section 366: Appendix 1).

At the adjacent Crossley Brickworks Quarry, a thick sequence of siltstones and claystones, occasionally containing a sandy streak, and up to 0.05 m thick sandstone layers, was exposed, with no evidence of the thicker sandstones occurring only 400 m away at Eldon Hill Quarry (Section 411:- Appendix 1).

Interpretation

The sequence exposed at Eldon Hill Quarry was deposited by an alternation of high and low energy traction current flows, while the Crossley sediments were probably all laid down under relatively low-energy conditions, and occasionally only from suspension.

The sequences are interpreted as the deposits of a shallow-water floodbasinal lake, which received sediment from both overbank and crevasse sources in the case of Eldon Hill, or predominantly from overbank flooding in the case of the Crossley Quarry. The shallowness of this lake (perhaps 2-3 m water depth) is attested to by the development of the Fivequrater seatearth and coal at the top of the sequence without any corase-grained lake-fill sediments, and by the ability of crevasse splays in the upper part of the Eldon Hill sequence to all but completely fill the basin, allowing plant colonization to take place and peaty material to accumulate.

Fig.7.23

MEASURED VERTICAL SECTION THROUGH THE FIVEQUARTER COAL AND OVERLYING STRATA AT LANGLEY O.C.C.S. (2I2467NZ)

(AREA A, CUT 2)

(BASED ON SECTION 432 :- APPENDIX I)

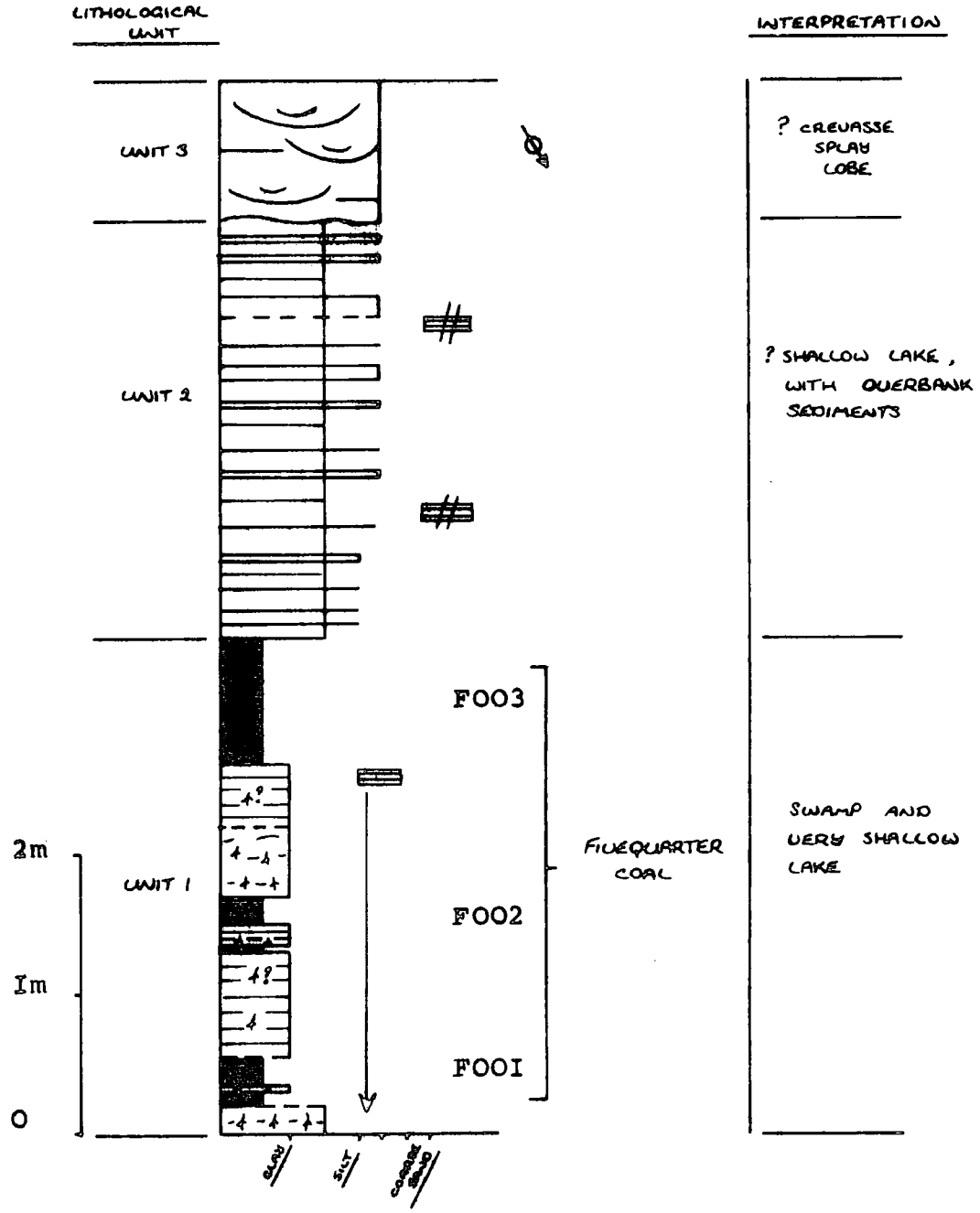




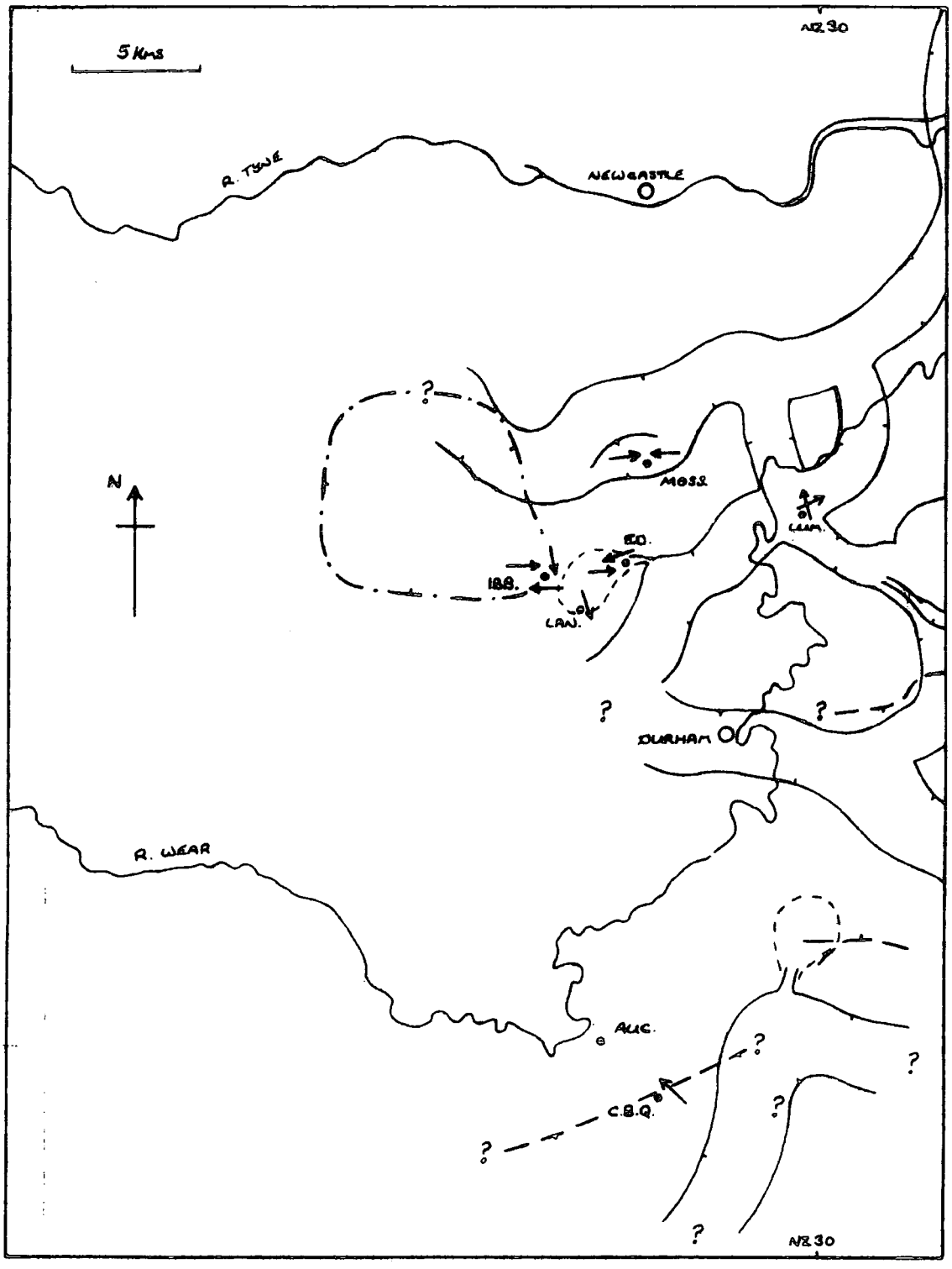
Plate 7.I7 - The complex Fivequarter coal at Langley O.C.C.S., showing disturbance by old workings. Geologist is I.7m high.



Plate 7.I8 - The Fivequarter coal and overlying interbedded sediments at Edmondsley O.C.C.S. Geologist is I.9m high.

Fig.7.24

THE FIVEQUARTER AND METAL COALS, POST-FIVEQUARTER PALAEOCURRENTS AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS



CHANNEL/CHANNEL BELT MARGINS

WASHOUTS IN FIVEQUARTER COAL

MINOR DELTA LOBE (SCHEMATIC)

PALAEOCURRENT VECTOR MEAN

NB METAL COAL VARIES UP TO 2.5m THICK, EAST OF LONGITUDE NZ 30, AND GENERALLY UP TO 0.30m TO WEST.

FIVEQUARTER AND METAL COALS UNITED (ON ORNAMENTED SIDE).

FIVEQUARTER AND MAIN COALS UNITED (" " ").

MOSS. - MOSS CLOSE O.C.C.S. (∧ = 9)
LUM. - LUMLEY PARK BURN (∧ = 30)
ED. - EDMONDSLEY O.C.C.S. (∧ = 16)
IBB. - IBBETSONS O.C.C.S. (∧ = 18)
LAN. - LANGLEY O.C.C.S. (∧ = 6)
C.B.Q. - CROSSLEY BRICKWORK QUARRY (∧ = 21)
ALIC. - AUCKLAND PARK

From the palaeocurrent distribution and sandstone bed geometry, the crevasse splays prograded west-south-west-wards across the lake, with a minor component of northward motion, perhaps indicating separate sources. From the lateral thinning and impersistence of the sandstones, and rarity of erosive bed bases, these are considered to be relatively minor splay deposits. Abundant load casting does, however, imply rapid deposition of these beds.

The occasional claystones present at Eldon Hill represent periods of little coarse sediment input, when only clays settled from suspension.

7.8.3 The Fivequarter Coal

The Fivequarter coal (F000) is widely worked across the Durham coalfield, ranging generally up to 2.3 m in thickness, and exceptionally up to 3.18 m.

The seam is characterized by frequent lateral changes in thickness and quality (see Fig. 7.21, and compare Ibbetsons O.C.C.S. Extension with Langley O.C.C.S.:- Figs. 7.20, 7.23, Plate 7.17). There is little evidence of regional variation over and above this local irregularity, although the Fivequarter coal does seem to be generally thinner in the extreme north (Land, 1974).

The Fivequarter coal usually occurs as a single, unbanded seam, though bands occur locally. In some parts the Fivequarter seam is united with the underlying Main (see previous passage), and in certain areas unites with the overlying Metal seam (2E00 or 1E00), (Fig. 7.24).

The Fivequarter seam was examined at Ibbetsons O.C.C.S. Extension, Moss Close O.C.C.S. (G.R. NZ 235525), Langley O.C.C.S. (Plate 7.17), Edmondsley O.C.C.S. (G.R. NZ 225490), (Plate 7.18),

Fig.7.25

COMPOSITE VERTICAL SECTION - MOSS CLOSE O.C.C.S.
(G.R.NZ235525), (BASED ON SECTION 698 :- APPENDIX 1)

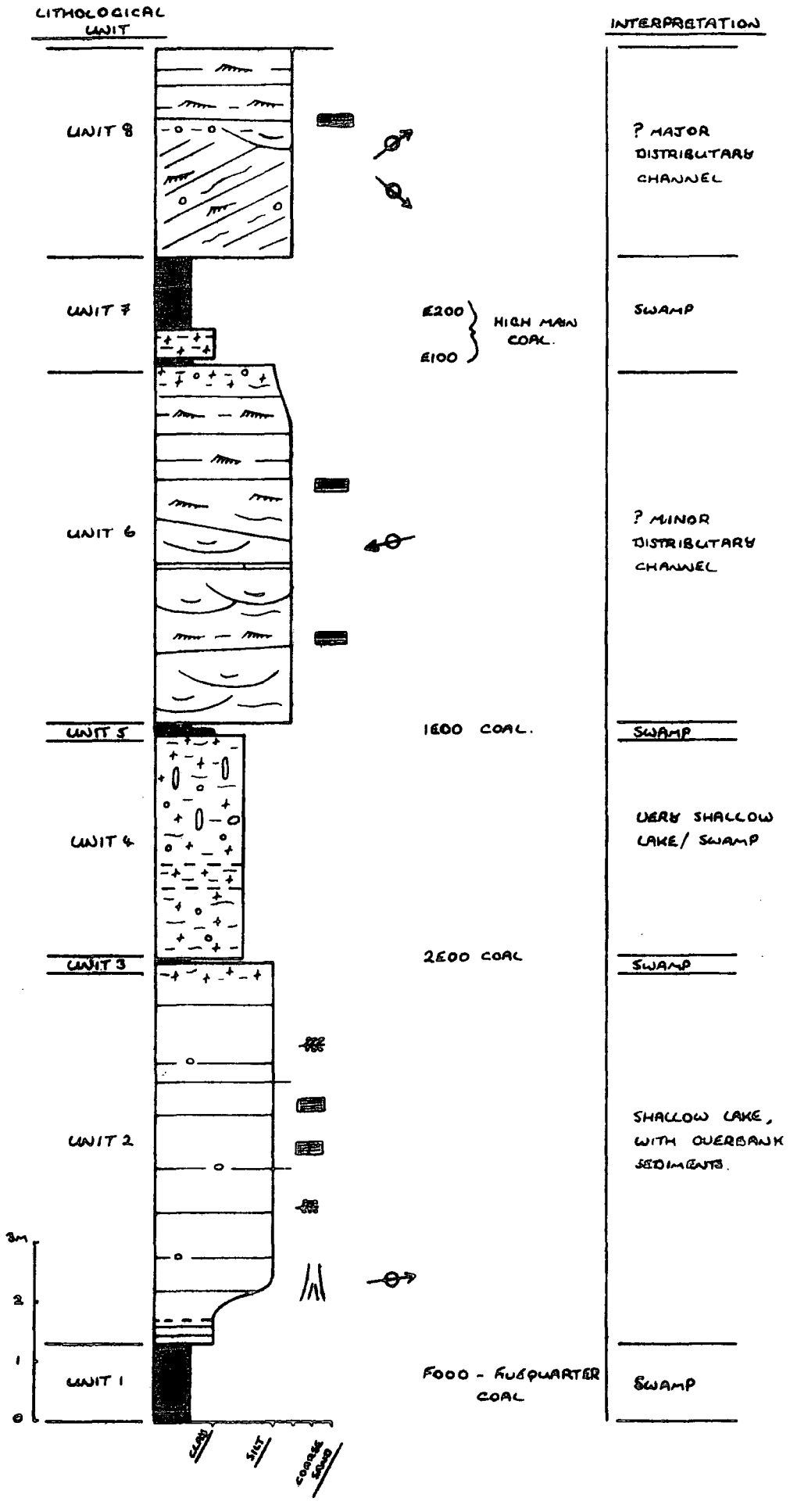
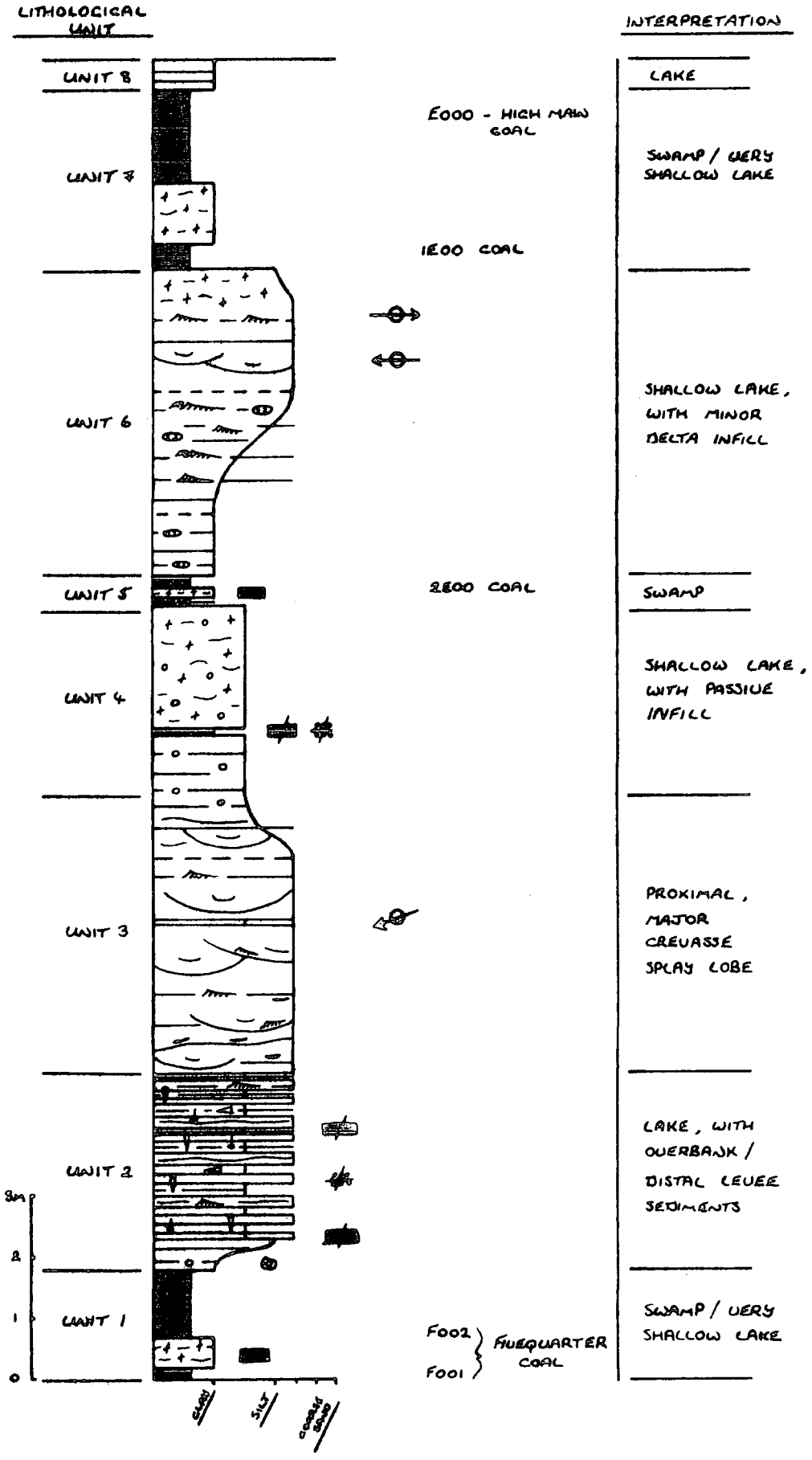


Fig.7.26

COMPOSITE VERTICAL SECTION - EDMONDSLEY O.C.C.S.

(G.R.NZ225490), (BASED ON SECTIONS 265, 365, 393 & 405 - APPENDIX 1)



Crossley Brickworks Quarry and Buckhead O.C.C.S. (Figs. 7.17, 7.20, 7.23, 7.25, 7.26 and Section 411:- Appendix 1), (Fig. 7.2).

7.8.4 Discussion

Locations of major channels active during deposition of the Main-Fivequarter interval, and the regional setting of examined exposures, are presented on Fig. 7.19. This shows that, as with the underlying interval, comparatively few major channels were active through this period, separated by shallow, floodbasinal lakes. These lakes were filled by overbank sedimentation, and by the progradation of crevasse-initiated minor deltas which were commonly fed by minor distributary channels. Comparison of Figs. 7.16 and 7.19 shows that the post-Main channels avoided courses taken by earlier (post-Maudlin) channels.

The channels themselves were probably similar to those of underlying intervals, i.e., sinuous and 2-4 kms wide, and from the apparent lack of wide channel belts, were probably stable in position through time. This idea is supported by the substantial levee development on a major channel margin at Langley O.C.C.S., although at this locality also, evidence for major crevassing is preserved (Ch. 7.8.2.1, Fig. 7.19).

Once again, the implications are for increased channel stability and decreased channel density (relative to Westphalian A) and together with the occurrence of relatively deep freshwater lakes (6 m+) probably indicate a reduced sediment supply to the Durham area. However, subsidence was, as ever, variable on a local scale, as evidenced by the lateral variability in the Fivequarter

seam, and the common amalgamations between stratigraphically adjacent coals (Figs. 7.19, 7.21, 7.24). Evidently, local tectonic and palaeotopographical controls were also important in some areas.

7.9 FIVEQUARTER TO HIGH MAIN COALS

7.9.1 Introduction

The interval between the Fivequarter and High Main coal seams, varies between 12 and 50 m, and is also highly variable in character.

The interval contains a coal which, while laterally somewhat impersistent, is commonly of workable thickness, and is known as the Metal seam (F200, 2E00 or 1E00). The Metal coal may be as much as 2.54 m thick, is often banded, and in various parts of the coalfield may be united with either the underlying Fivequarter or overlying High Main seams (Fig. 7.24), (Figs. 14 and 15 of Smith and Francis, 1967). Further thin coals are often present, notably beneath the High Main Seam (1E00 or E100:- "High Main Stringer"), and may locally be workable.

Accumulations of non-marine fossils occur locally throughout the interval in many areas, but none form useful marker horizons.

Sediments representing the Fivequarter to High Main interval were examined at eight localities, and the High Main coal itself at three of these exposures.

7.9.2 Sediments between the Fivequarter and High Main Coals

7.9.2.1 Preamble

Seven of the eight localities exposing the Fivequarter-High Main interval which were visited are described below, the eighth (Buckhead O.C.C.S.) not being of sufficient quality to merit consideration. No distinction could consistently be made between sediments above and below the intermediate Metal seam (1EOO or 2EOO), since records of this seam *as such* are rare in some parts of the coalfield. For this reason, the Fivequarter-High Main interval is treated as a single depositional unit.

7.9.2.2 Moss Close O.C.C.S.

Description

At Moss Close O.C.C.S. a sequence some 16 m thick representing the entire Fivequarter-High Main interval was examined (Fig. 7.25).

The lower part, between the Fivequarter and thin 2EOO coal, is almost entirely composed of poorly-laminated siltstones (Unit 2; Fig. 7.25) containing abundant plant debris, often delicately-preserved (Plate 7.19). Towards the base, an upright tree cast at least 1.60 m high slightly inclined towards the east-north-east was found preserved (Plate 7.20). The base of this tree was obscured by rubble, but, if it was rooted in the Fivequarter roof, is preserved at least 3.60 m in height.

The 4 m sequence between the 2EOO and 1EOO coals (Unit 4) is entirely rootlet-penetrated, and in the upper part contains elongate siderite nodules/concretions concentrated around rootlets.

The parting between the 1EOO and High Main coals (Unit 6) is



Plate 7.I9 - Delicately-preserved plant remains from siltstones overlying the Fivequarter coal at Moss Close O.C.C.S. Scale divisions in mm.



Plate 7.20 - Upright, <u>in situ</u> tree cast preserved in siltstones above the Fivequarter coal at Moss Close O.C.C.S. Hammer is 25cms long.

entirely composed of fine-grained sandstone with thin silty claystone partings which become more abundant upward.

Trough cross-bedding and ripple cross-lamination indicate palaeoflow towards the west.

Interpretation

The poorly-laminated siltstones of Unit 2 were probably deposited from suspension, from the lack of traction-produced sedimentary structures, and the delicate mode of preservation of plant fossils (Plate 7.19). However, rates of sedimentation were sufficiently rapid to entomb an upright tree to possibly 2.6 m depth before the woody tissue could decompose. The siltstones are interpreted as overbank flood deposits from a nearby channel, and the tilting of the upright tree may suggest that the channel supplying overbank sediment lay a short distance to the west-south-west. This suggestion is supported by the fact that the interval thickness increases to the west.

The channel eventually was abandoned and the sediment surface became a temporary site for peat accumulation. The modest thickness of the 2EOO coal implies that subsidence quickly overtook the rate of peat accumulation, though the sediment surface never dropped below the depth limit for plant colonization, and plants continued to grow as fine-grained sediment (Unit 4) was deposited in a shallow floodbasin environment.

The 1EOO coal records infilling of this shallow basin and gradual re-establishment of peat swamp conditions. Alternatively, the presence of an impure, shaly coal in the lower part of the 1EOO seam might imply that peat accumulation became possible largely as a result of a failure in the supply of clastic sediments rather

than by basin infilling, direct evidence for which is lacking.

The sandstone overlying the 1E00 coal (Unit 6) was deposited by quite high energy traction currents, though from the presence of claystone partings, current energy varied. The thickness of the sandstone, presence of internal erosion surfaces, large-scale trough cross bedding (0.6 m thick sets) and palaeocurrents suggest that this sandstone is the deposit of a westward-flowing channel. Lack of lateral control prevents further determination of size or morphology, but from its' thickness, the channel was probably of minor ? distributary type.

The abandoned surface of the channel deposit was colonized by vegetation and the peats of the High Main Stringer (E100) and High Main (E200) seams were allowed to accumulate.

7.9.2.3 Ibbetsons O.C.C.S. Extension

Description

The Fivequarter-High Main parting at Ibbetsons O.C.C.S. comprises 20-24 m of predominantly argillaceous sediments (Fig. 7.20),(Plate 7.21), and contains two thin coals (2E00 and 1E00).

The lowermost 8-11 m, between the Fivequarter and 2E00 coals, is almost entirely composed of laminated claystones with occasional sandy streak and thin bands of fine-grained sediment (Units 4, 5; Fig. 7.20). Palaecurrent measurements from ripple cross-lamination indicate palaeoflow towards the east and south-south-east.

The roof of the Fivequarter coal and that of the 2E00 coal are locally composed of cannel coal, or canneloid claystone.

The sequence between the 2E00 and 1E00 coals is similar in character and thickness to the underlying parting but culminates in a 3-4 thick coarsening-upward sequence (Unit 6),(Plate 7.21), the



Plate 7.2I - Panorama of Ibbetsons O.C.C.S. Extension, showing the Fivequarter coal(at base of section), 2EOO (2) and IEOO (I) coals, High Main (H) and overlying sandstone. Other coaly or carbonaceous horizons also stand out as dark bands. Height of exposure about 35m.



Plate 7.22 - Large trough scours in the upper part of the Fivequarter - 2EOO interval at Edmondsley O.C.C.S. Height of exposure about 6m.

upper part of which forms the seatearth to the 1EOO coal. Palaeocurrent measruements from trough cross-bedding and ripple cross-lamination are ambiguous, indicating palaeoflow directed towards both the east and west. However, wave-formed ripples are common and many sets of ripple cross-lamination seem wave-influenced.

Between the 1EOO and High Main coals lie 3.3-4.0 m of thoroughly rootlet-penetrated claystones which, at one locality, contained the 0.6 m-high cast of a upright tree rooted into the sediments some 1.5 m above the 2EOO coal (Unit 8).

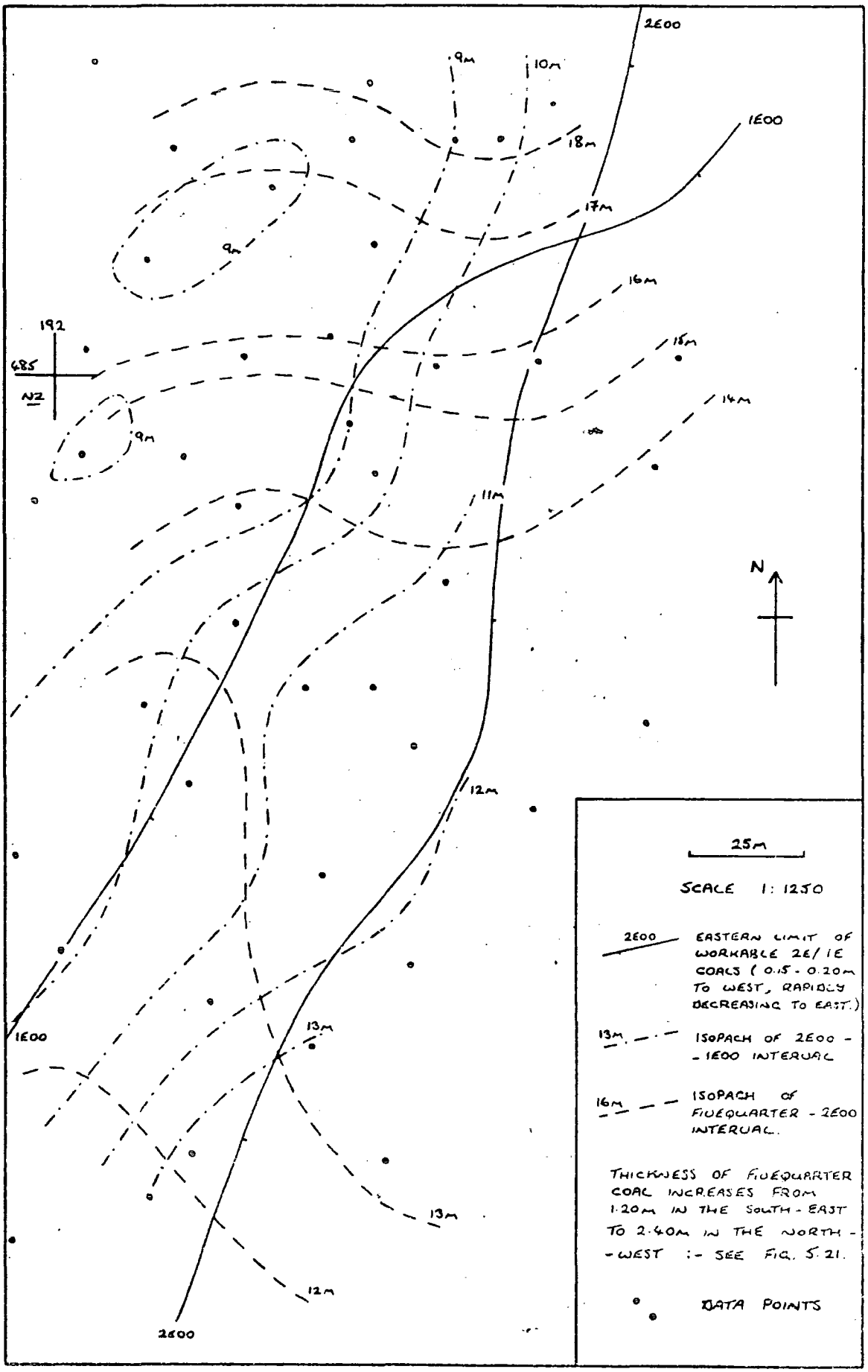
Lateral variation in the thickness of the Fivequarter, 2EOO and 1EOO coals, and inter-seam partings, is shown on Fig. 7.27, and both direct and inverse relationships are displayed between successive units. Any variation in the 1EOO and High Main seams is impossible to determine due to lack of adequate lateral control.

Interpretation

The FOOO-2EOO parting (Unit 4) was deposited predominantly from suspension, with occasional contributions from tractional flows, and is interpreted as the deposits of a shallow floodbasin lake which received, at first, very little sediment, from the locally canneloid nature of the Fivequarter roof, and later, occasional crevasse and/or overbank sediment from a distant channel source to the west or north-north-west. As with the Moss Close example, the presence of coaly, plant-rich horizons beneath the 2EOO coal (Fig, 7.20, Plate 7.21) and the colonization by rootlets without any coarse-grained "lake fill" sediments is a probable indication that at any time during the deposition of the unit, discrete layers of peat were only prevented from accumulating by the dilution effect of slow clastic sedimentation.

Fig.7.27

THICKNESS RELATIONSHIPS BETWEEN THE FIVEQUARTER, 2E00 AND 1E00 COALS, AND INTER-SEAM PARTINGS, AT IBBETSONS O.C.C.S. EXTENSION



Peat was eventually allowed to accumulate (2EOO seam), and this was followed by drowning of the swamp with continued lack of clastic sediment supply (as indicated by the canneloid nature of the 2EOO roof) and the development of a further shallow lacustrine basin, represented in the overlying claystone sequence (Unit 6). Quiet-water conditions were again established and sustained for some time, following which the lake was filled by a coarsening-upward, minor delta sequence. The thickness of this sequence indicates the lake to have been about 4.0 m deep. Wave ripples show that wind-driven waves moved either towards the east or west, that water depths were 2-3 m and wave fetches were of the order of 2- 20 kms (P. Allen, 1981).

Having filled the shallow lake, the minor delta system was abandoned, and peat deposits were again able to accumulate, forming the 1EOO seam. The 1EOO-High Main parting is interpreted similarly to the 2EOO-1EOO parting at Moss Close, as the deposits of a very shallow floodbasin which never subsided below the threshold for plant colonization. Reduction of clastic sediment supply is again thought responsible for the recommencement of peat accumulation, on this occasion sustained over a long period, eventually to form the High Main coal seam.

Relationships between the thicknesses of the Fivequarter, 2EOO and 1EOO coals, and those of inter-seam partings (Fig. 7.27) are interpreted as further evidence of differential subsidence initiated by variations in peat thicknesses, and subsequence "see-saw" effects induced by this pattern of variable subsidence (see Ch. 6.6.4.3 for a more detailed case study of this phenomenon).

7.9.2.4 Edmondsley O.C.C.S.

Description

The Fivequarter-High Main parting exposed at Edmondsley O.C.C.S. comprises some 14.5-20 m of sediments including two thin coals, the unnamed 2E00 and High Main Stringer (1E00) seams (Fig. 7.26).

The basal part of the Fivequarter-2E00 interval,10-13 m in total thickness, comprises a thin, well-laminated claystone containing occasional casts of non-marine bivalves. This lithology coarsens rapidly upward into a sequence of regularly and thinly interbedded fine-grained sandstone and carbonaceous silty claystone with occasional "sandy" streak (Unit 2; Fig. 7.26).

Individual depositional units 1-2 cms thick can often be traced laterally for 100s of metres, although correlation is made difficult by collapse of strata around old workings (Plate 7.18).

Occasional low-angle scours and ripple cross-lamination are present in the sandstone, particularly in the upper part of the sequence, where the proportion of sandstone present increases from about 50% to 80% or more. The proportion of sandstone also increases generally towards the east across the site. Comminuted plant debris are common in the silty claystones, and occasional evidence of faunal bioturbation includes *Pelecypodichnus*, *Planolites* and indeterminate burrows.

The thinly interbedded sequence passes upward either gradationally or abruptly into a 7 m thick, fine-grained sandstone (Unit 3). Where gradational, the passage is achieved by thickening of individual sandstone beds in the interbedded unit, rather than by a general "coarsening-upward".

The sandstone is most commonly parallel- or evenly-laminated, but also displays ripple cross-lamination and trough cross-bedding (in sets up to 1.0 m thick). An elongate, west-south-west-to east-north-east-trending belt some 75-150 m wide contains abundant large-scale trough scours and undulating bounding surfaces (Plate 7.22), (Enclosures 17, 18). These large scours are commonly 2 m deep and 20 m wide, and display highly variable fills, which may be partly composed of silty claystone, chaotically bedded or ripple cross-laminated sandstone. Thin partings of silty claystone are almost ubiquitous, and are occasionally so abundant that they give the rocks an interbedded appearance.

The base of the sandstone unit varies irregularly in nature, but is generally erosive in the "central belt" mentioned above, downcutting to the west and then levelling out at the west end of the site (Enclosures 17, 18). Trough cross-bedding and large trough scours indicate palaeoflow towards the west-south-west (Enclosure 18).

The uppermost part of the sandstone contains silt-filled trough cross-sets, fines rapidly upward and passes into a thin, laterally persistent claystone, in turn overlain by a variable thickness of rootleted silty claystone which forms the 2EOO seatearth (Unit 4).

The Fivequarter-2EOO parting as a whole varies around 11 m in thickness across much of the site, but increases sharply at the eastern end to more than 13 m (Enclosure 18).

The sequence beteen the 2EOO and 1EOO/High Main coals is highly variable, but generally consists of claystones overlain by a coarsening-upward unit of 2-5 m thickness (Unit 6). The overall

thickness of the parting increases eastward across the site (from 4.5 to 7 m), although borehole control at this level is somewhat scattered. Palaeocurrent measurments from ripple cross-lamination and small-scale trough cross-bedding indicate palaeoflows towards the east and west in different areas.

Interpretation

The basal, bivalve-bearing claystones of the Fivequarter-2E00 parting were deposited under quiet-water conditions, and are interpreted as deposits from suspension in a lake formed by drowning of the Fivequarter peat swamp.

A rapid coarsening into the overlying regularly interbedded sequence implies the introduction of coarse-grained sediment at periodic, possibly regular, intervals into the lake by means of traction currents. Unit 2 (Fig. 7.26) is interpreted as overbank flood deposits (see discussion in Ch. 6.5.2.2/3), from a channel which, from the sediment grain-size, was probably only a short distance away. Certainly, in comparison to similarly interbedded/inter-laminated sediments described previously from Cobey Carr Quarry (Ch. 6.7.2.4) and Woodland O.C.C.S. (Ch. 6.5.2.2), the Edmondsley lithology indicates a more proximal location with respect to the channel source.

This interpretation of a proximal setting is supported by the occurrence,in the upper part of Unit 2, of a lithology very closely comparable to the sediments exposed above the Main coal at Langley O.C.C.S., interpreted as subaqueous levee deposits (Ch. 7.8.2.1). Preservation of subaqueous levee deposits overlying "proximal" overbank sediments might be expected from the gradual progradation of overbank material away from a channel (Elliott, 1974; Heward, 1976, Fig. 3.2).

Occasional erosive scours and discrete sandstone beds up to 0.8 m thick may be interpreted as the result of minor crevasse splays across the overbank/levee deposits.

The fact that the Edmondsley sediments are so uniformly interbedded, as are the Cobey Carr and Woodland lithologies, suggests that sediment was introduced by regularly-spaced floods, which is in turn suggestive of a seasonal control on sedimentation. The overbank deposits exposed at these localities are in marked contrast to those exposed at Phoenix Quarry (Ch. 7.4.2.1) and Moss Close (this section), which display little regularity in bedding, indeed, little bedding at all. In the latter cases, overbank deposition is believed to have taken place more rapidly, in greater volumes, largely from suspension, and possibly also from relatively minor, distributary channels. The latter hypothesis might explain the predominance of silt-grade sediment in the Phoenix Quarry and Moss Close sequences.

The sandstone of Unit 3 was deposited by rapid, though intermittent, tractional flows, from the present of high-energy bedding structures, erosion surfaces and fine-grained partings. The sandstone is interpreted as a major crevasse splay lobe prograding in a west-south-westward direction across and through previously-deposited overbank sediments, presumably from the same channel source. The "central belt" containing large-scale scour structures and internal erosion surfaces (Plate 7.22) is interpreted as the axis of sediment transport across the proximal part of the crevasse splay lobe. The absence of channel margins suggest that flow was possibly not truly channelized. Interestingly, the "axial zone" of

the major crevasse splay lobe corresponds to the area where trough scours and minor crevasse splay sandstones are present in the underlying unit, and it is possible that channel bank breaching was achieved at a point of inherent bank weakness, created and exploited by previous crevasses (Enclosure 18).

The scale of the large trough scours in the axial zone is seen as the result of:

(1) proximity to channel source, and

(2) progradation into relatively deep water (possibly as much as 8-10 m, from the thickness of the sandstone unit).

These factors help explain the difference between the Edmondsley sediments and deposits of a similar,though shallower water setting exposed at Cabin House/Mown Meadows O.C.C.S. (Ch. 6.8.2.2).

From an isopach plot of Unit 2 thickness (Enclosure 18), it seems that the crevasse splay lobe eroded a spoon-shaped hollow in the overbank sediments during the initial stages of its' progradation. This is interpreted as a result of an initially highly erosive current losing power as it ripped through levee and overbank sediments adjacent to the channel from which it originated.

All available evidence points towards a channel source for the Edmondsley sediments in close proximity to the site, and indeed, the thickening of the Fivequarter-2E00 parting at the extreme eastern end of the site may represent the channel margin (Enclosure 18).

The fining-upward in the uppermost part of the sandstone is interpreted as the result of crevasse lobe abandonment after incomplete infilling of the lacustrine basin, and the overlying thin claystone as quiet-water deposits in the residual, shallow lake, preceding final infilling by ? overbank silty clays, and peat swamp establishment (Units 4 and 5).

The 2EOO-High Main interval (Unit 6) is again interpreted as the infill of a shallow lake (2-5 m in depth) formed as a result of subsidence of the 2EOO peat, aided by the loading effect of underlying sands into the Fivequarter peat deposit. This is supported by the increase in interval thickness across the site to the east, towards inferred major channel deposits.

The lake was filled predominantly by minor delta progradation which, from the preserved lithologies and palaeocurrent distribution, appears to have emanated from at least two directions (east and west). However, data is limited.

Once the shallow lake was filled by minor delta sedimentation, the abandoned sediment surface was once again heavily colonized by plants, and peat swamp conditions were established, leading to the accumulation of the High Main peat.

In conclusion, the overbank, levee and channel bank crevasse sediments exposed at Edmondsley represent a similar, but more distal, setting to that preserved above the Main coal at Langley O.C.C.S. (Ch. 7.8.2.1). Whereas the undoubted levee deposits at Langley lay between 0 and 750 m from the margin of the supplying channel, the Edmondsley deposits were probably 400 m - 1 km distant from their source.

7.9.2.5 Langley O.C.C.S.

Description

The sediments overlying the Fivequarter seam at Langley O.C.C.S. are very similar in aspect to those described from Edmondsley (Figs. 7.23, 7.26), comprising 3 m of thinly interbedded fine-grained sandstone and carbonaceous silty claystone (Unit 2; Fig. 7.23), abruptly overlain by trough cross-bedded sandstone (Unit 3). Trough cross-bedding in Unit 3 indicates a palaeoflow towards the south-south-east.

Interpretation

The Langley sediments are interpreted similarly to those exposed at Edmondsley, as overbank-derived, ? seasonally introduced, lake bottom sediments, overlain and partly eroded into by a crevasse splay lobe deposit. The distance between Langley and Edmondsley (about 2.5 kms) and the height of the sandstone above the Fivequarter seam suggest that the sandstone does not represent the same depositional event, but the overbank sequences are probably related. Lack of palaeocurrent data and information on lateral variability preclude more detailed analysis.

7.9.2.6 Lumley Park Burn

Description

At Lumley Park Burn (G.R. NZ 298507), an 18 m sequence is exposed, representing the strata immediately above and below the Metal coal (Section 371; Appendix 1).

The lower part of the sequence, comprising fine-grained sandstones, passes upward through rootlet-penetrated silty claystones into the Metal coal. Palaeocurrent measurements from ripple cross-

lamination in the sandstones indicate palaeoflow towards the east-north-east.

The sequence above the Metal coal comprises 11 m of fine-grained sandstones, with occasional siltstones in the upper part. The sandstone is ripple cross-laminated throughout and also contains occasional small-scale trough cross-bedding and internal erosion surfaces. Ripple cross-lamination indicate a palaeoflow towards the north-north-west.

Interpretation

The sediments beneath the Metal seam are tentatively interpreted as the ? active channel, abandonment and post-abandonment deposits of a channel. The thick sequence of rootlet-penetrated sediments implies that plants colonized the channel-fill sediments soon after abandonment, and continued to do so for some time subsequently.

The sandstone above the Metal coal is interpreted as the deposit of a north-north-westward-flowing channel, the dimensions and morphology of which are not discernible. The interbedded sediments near the top of the exposed section may be interpreted either as channel abandonment deposits or active channel "fine member" deposits (Jackson, 1981).

7.9.2.7 Auckland Park

Description

On the east bank of the River Gaunless in Auckland Park (G.R. NZ 218301) a 15 m sequence again exposes the strata around the level of the Metal coal (Section 412; Appendix 1), (Fig. 7.2).

Above a basal seatearth and "flinty" shale, the lower part of the sequence is largely composed of laminated siltstones with

occasional fine-grained sandstones, containing non-marine bivalve remains. The sequence fines rapidly to claystone beneath the Metal coal, which at this locality is a cannel coal lacking a seatearth.

Above the Metal coal, the lower 6 m of a coarsening-upward sequence is exposed.

Interpretation

The basal seatearth and "flinty" shale are interpreted as the result of rapid subsidence of a ? peat swamp surface, to such an extent that before any discrete peat deposits could form, organic material became diluted by clastic detritus.

The siltstones are interpreted as ? overbank flood sediments which periodically poured into the lake, and the rapid fining-upward to bivalve-bearing claystones beneath the Metal implies a failure of sediment supply, leading to further subsidence and deposition only of clays from suspension.

The cannel Metal coal is interpreted as an allochthonous deposit of this stagnant and sediment-starved lake, whereby water-logged plant debris and microfloral material were allowed to slowly accumulate in the almost complete absence of any clastic sediment input.

The coarsening-upward sequence is tentatively interpreted as a minor delta infill of a 6 m+ deep lake.

7.9.2.8 Crossley Brickworks Quarry

Description

Above the combined Fivequarter/Metal coal at the Crossley Quarry an 8 m sequence of varied lithologies is exposed (Section 411;

Appendix 1). 4 m of silty claystone, with a sandy streak towards the top, is overlain by stacked, erosively-based, fine-grained sandstones, each of which fine upward to siltstone. Ripple cross-lamination and small-scale trough crossbeds are abundant in these sandstones. Palaeocurrent measruements indicate a uniform direction of palaeoflow throughout the sequence towards the north-west.

Interpretation

The lowermost silty claystones are interpreted as low-energy deposits in a shallow lake and the overlying erosively-based sandstones as a series of north-westward-prograding crevasse splay deposits.

7.9.3 The High Main Coal

The High Main seam (E000) is the uppermost widely worked coal in the Durham coalfield. The seam varies unpredictably in thickness but may be as thick as 3.30 m in the area around Jarrow and South Shields.

Commonly, the High Main coal is banded, and may be split locally into Bottom (E100) and Top (E200) High Main seams. The High Main is noted for its "shaly" character, and the commonly-occurring "stringers" beneath the seam are usually composed of inferior coal. Generally speaking, high ash values for the High Main coal occur where it is thickest.

The High Main coal shows a regional trend of impoverishment in the area where the underlying Fivequarter and Metal coals are in close proximity to each other, but this may be due to erosive removal by post-High Main channels (Figs. 14 and 15 of Smith and Francis, 1967). In the area north of Blackhall colliery, the Metal and High Main coals are close together or merged into a single seam

(Figs. 14 and 15 of Smith and Francis, 1967).

Sulphur values for the High Main coal are characteristically variable, ranging from less than 0.88 to over 3.11%, but are most commonly in the 1.5-2.0% range.

Three exposures of the High Main coal were examined; at Moss Close O.C.C.S. (Fig. 7.25), Edmondsley O.C.C.S. (Fig. 7.26) and Ibbetsons O.C.C.S. (Fig. 7.20, Plate 7.21),(Fig. 7.2).

7.9.4 Discussion

Sedimentary environments of the Fivequarter-High Main interval appear to have been similar to those of previous intervals, from the interpretations of examined exposures. These are placed in their regional setting on Fig. 7.24, which also shows the distribution of active major channels. The interval is, however, characterized by complex coal seam splits involving the Metal seam, and it is apparent that several "generations" of channels may be represented. Unfortunately, it is virtually impossible to separate individual "generations", since records of the Metal seam are scarce in some areas, a problem compounded by the common occurrence of several thin coals in the FOOO-EOOO interval.

Channels/channel belts appear to have been 2-2.5 kms in width, display some sinuousity and virtually no preferred direction of flow (Fig. 7.24). Comparison of Figs. 7.19 and 7.24 indicates that there was some tendency towards reoccupation of earlier channel courses, while at the same time, other channels avoided earlier pathways.

As with previously-discussed intervals, considerable evidence for long-term channel stability and decreased sediment supply exists in the Fivequarter-High Main interval, in the form of thick channel overbank sequences, and sediments of comparatively deep, and in some cases sediment-starved, lakes.

Again similarly to underlying intervals, the pattern of subsidence appears to have been very localized and not regionally controlled, leading to the frequent changes in the character of the interval. Local differential subsidence is amply demonstrated by the variation in coal and parting thicknesses at Ibbetsons O.C.C.S. (Fig. 7.27), where a cummulative "balancing effect" appears to have operated (similar to the relationships inferred for the Busty and Tilley seams at Deborah O.C.C.S. :- Chs. 6.6, 6.7). From the relationships displayed at Ibbetsons, and on a more regional scale (Fig. 7.24), this differential subsidence was controlled partly by compaction of peat, and probably also by local structural influences.

Areas of moderate subsidence up to a few kms wide, indicated by the presence of thick amalgamated coals, often developed at the edges of local sedimentary basins, and themselves often led to subsequent compaction-induced, accelerated subsidence, and shallow basin formation (Fig. 7.27).

It seems likely from the above discussion that the thickness of the laterally variable High Main coal was controlled by this irregular pattern of subsidence.

7.10 HIGH MAIN COAL TO RYHOPE MARINE BAND

7.10.1 Introduction

The succession between the High Main coal, the highest widely-worked seam, and the base of the Ryhope (=*AEGIRANUM*) Marine Band, marking the top of the Westphalian B, totals some 150 m in thickness. However, in the Durham coalfield, these uppermost Westphalian B sediments are only preserved in small fault blocks and in the area around Sunderland, and are very poorly-exposed. For this reason, the entire sequence is considered here as one unit, though it is worth remembering that the High Main coal-Ryhope Marine Band interval constitutes approximately half of the thickness of the Westphalian B (Fig. 7.1).

The sequence contains several workable coals in the lower part, notably the Shield Row (3DOO), Seventy Fathom (2DOO), Charlaw (1DOO), Ryhope Little (DOOO) and Ryhope Fivequarter (COOO) seams, and rich non-marine faunas are commonly found in intervening shales (Fig. 7.1).

In the upper part of the sequence, thinner coals and a number of Marine Band horizons occur. These are characterized predominantly by the presence of *Lingula* and Foraminifera.

Four exposures of the strata immediately above the High Main coal were examined, and a further two higher in the sequence. Following a consideration of these exposures, a general description of the entire interval is given, to complete the documentation of the Westphalian B sequence in the Durham coalfield.

7.10.2 Examined localities in sediments between the High Main coal and Ryhope Marine Band

7.10.2.1 The "High Main Post"

Description

At Edmondsley O.C.C.S. a sequence of predominantly fine-grained lithologies, known from nearby boreholes to be at least 10 m in thickness, overlies the High Main coal.

At Ibbetsons O.C.C.S., up to 3.5 m of siderite nodule-bearing claystones above the High Main are overlain by up to 10 m of fine-to-coarse-grained trough cross-bedded sandstone (the "High Main Post"; Plate 7.21), which displays abundant internal erosion surfaces and occasional sandstone-filled channel-like scours (Fig. 7.20). Locally, a thin coal (High Main Rider) occurs about 1 m above the High Main roof, "sandwiched" within the sandstone. Palaeocurrent measurements from trough cross-bedding indicate a palaeoflow towards the south-south-west.

At Moss Close O.C.C.S. a similar sandstone, known from borehole data to be at least 15 m thick, directly overlies the High Main coal (Fig. 7.25). At one locality within the sandstone, a series of asymptotically-based bedding surfaces 3 m high, inclined towards the south-west, are associated with ripple cross-lamination indicating a palaeoflow towards the south-east. At another exposure, however, only 50 m away, similar though lower-angle cross-bedding surfaces dipping towards the north-north-west are associated with smaller-scale structures indicating a palaeoflow towards the north-north-east.

A further exposure of "High Main Post" sandstone was examined at Forgebank Plantation Quarry (G.R. NZ 224538), (Fig. 7.2).

Interpretation

The fine-grained lithologies overlying the High Main coal are interpreted as low-energy deposits of shallow lakes formed as a result of drowning of the High Main swamp peats.

Thick cross-bedded sandstones, known collectively as the "High Main Post", are common immediately above the High Main seam, and are often associated with "washouts" in the coal (Fig. 7.28). These are interpreted as deposits of major channels, which flowed in various directions across the Coal Measure plain. No indication of channel size is available,though the scattered palaeocurrent distribution and development of low angle cross-bedding, interpreted from relationships with other flow structures as lateral accretion cross-bedding, is suggestive of a sinuous channel morphology.

7.10.2.2 Sediments above the "High Main Post"

Description

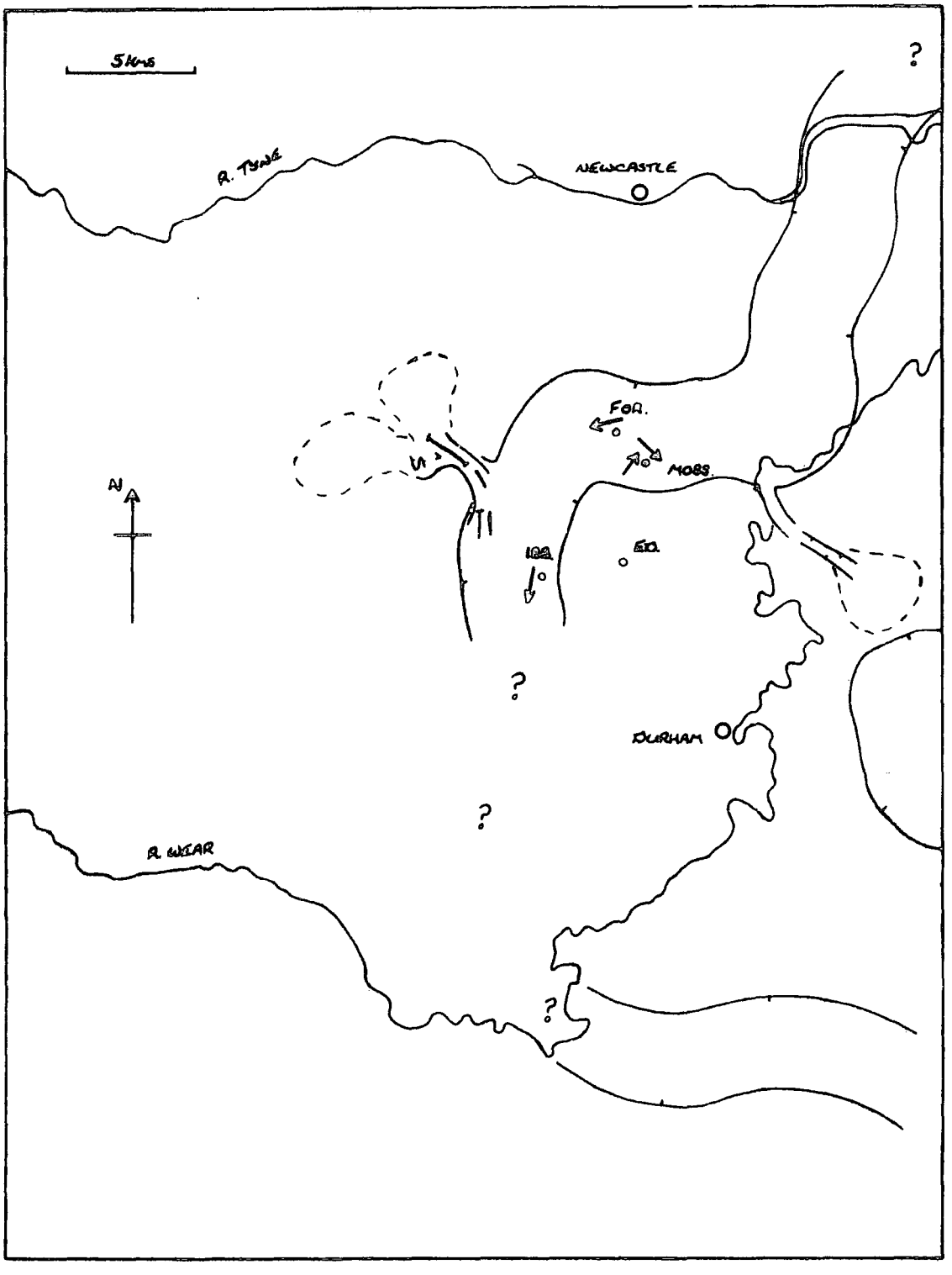
At Westerton Quarries and Park Head Bank (G.R.s NZ 237312 and 230308, respectively; Fig. 7.2), exposed sections of coarse-grained sandstone represent a stratigraphical position above the Ryhope Fivequarter coal (Figs. 7.1, 7.29). Palaeocurrent measurements from these exposures indicate considerable variance in palaeoflow direction both between and within individual localities, but with an overall palaeoflow towards the south-west.

Interpretation

The sandstones are interpreted as channel deposits, and in the case of the Westerton/Park Head Bank exposures, as major channel sediments. No information is available on the size or morphology of these channels.

Fig.7.28

THE HIGH MAIN COAL, POST-HIGH MAIN PALAEOCURRENTS AND SPECULATIVE CHANNEL/CHANNEL BELT TRENDS

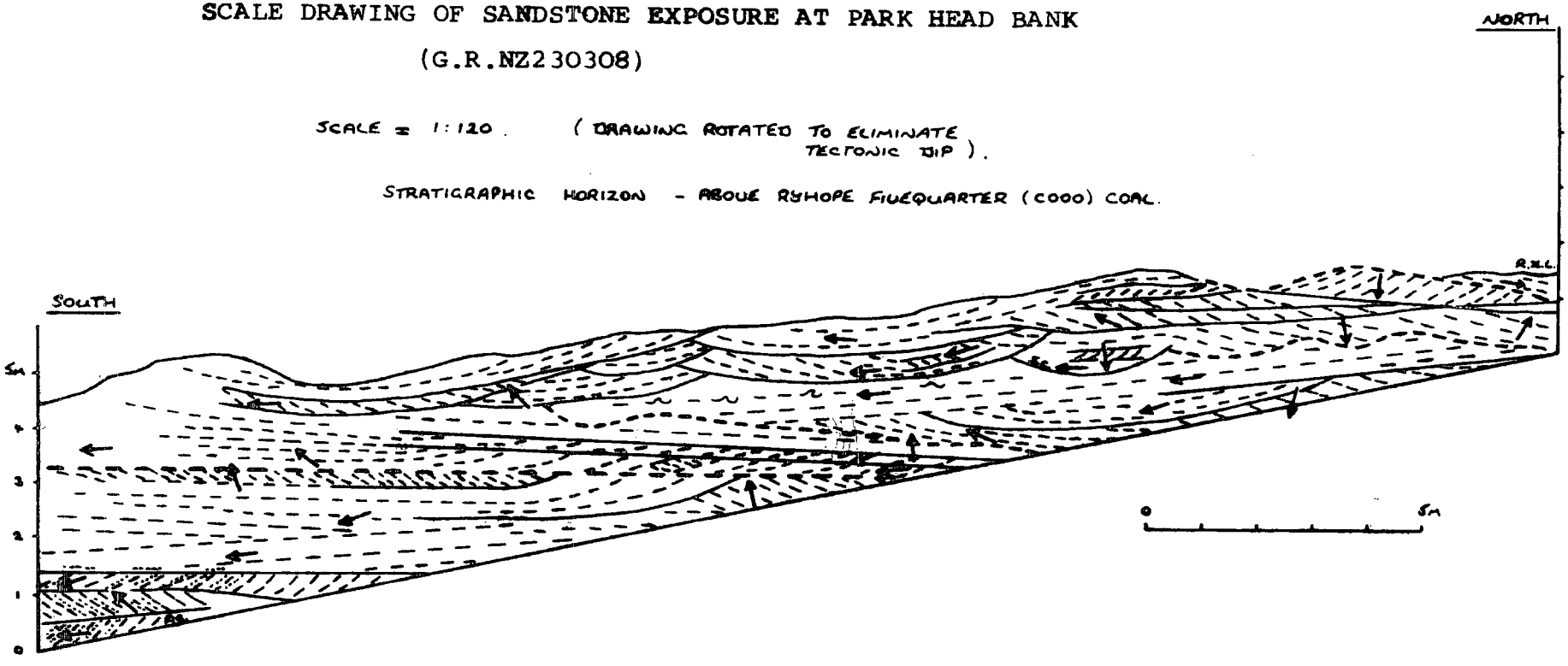


SCALE DRAWING OF SANDSTONE EXPOSURE AT PARK HEAD BANK

(G.R.NZ230308)

SCALE = 1:120. (DRAWING ROTATED TO ELIMINATE TECTONIC DIP).

STRATIGRAPHIC HORIZON - ABOVE RYHOPE FIVEQUARTER (COOO) COAL.



BOUNDING SURFACE

PROMINENT BEDDING PLANE

CROSS-BEDDING SURFACE

SYNSEDIMENTARY DEFORMATION

PALAEOCURRENT READING (CROSS-BEDDING)

R.X.L. RIPPLE CROSS-LAMINATION

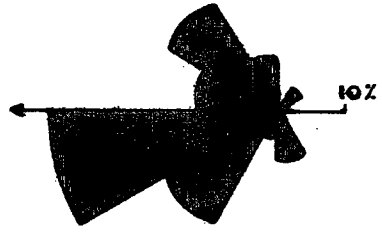
P.C. PLANT CASTS

S.C. SHALE CLASTS

N = 28

Θ = 270°

ι = 67%



7.10.3 A brief description of the Upper Westphalian B sequence

The upper part of the Westphalian B sequence, comprising the 150 m of strata between the High Main coal and Ryhope Marine Band, is basically of similar character to the underlying succession. However, it differs in containg markedly fewer workable coals, and in containing a series of marine horizons (Fig. 7.1). This sequence of Marine Bands is continued into the lower Westphalian C (Ch. 8).

Between the High Main coal and the lowermost marine horizon, the High Main Marine Band, lies a 12-30 m sequence of typical Coal Measure lithologies, displaying characteristic lateral variability. Several coals, locally of workable thickness, occur in this interval.

The High Main Marine Band, underlain by a thin coal or seat-earth, consists of Lingula-bearing shales, and where not present, its position is always recognizable by the abundant and varied non-marine fauna which is to be found immediately above.

Some 40 m above this horizon lies the Ryhope Little coal (DOOO), which may be up to 1.07 m thick and is occasionally split into two seams. The roof shales of the Ryhope Little coal occasionally contain remains of *Lingula*, and are known as the Little Marine Band (=*CLOWN*; Ramsbottom *et al.*, 1978).

10-20 m higher up the sequence lies the highest workable seam in the Westphalian B sequence, the Ryhope Fivequarter (COOO). This coal may be up to 1.40 m thick, and is occasionally split. Above the Ryhope Fivequarter coal, the remaining 80 m or so of the sequence consists of typical Coal Measure clastic lithologies interbedded with thin coals and Marine Bands. These Marine Bands are (in ascending order) the Kirkby's (=*HAUGHTON*), Hylton (=*SUTTON*) and

Ryhope (=*AEGIRANUM*) horizons. These seems to be a definite relationship between each of these and an underlying thin coal or seatearth, an association noted in the earlier Marine Bands of the Durham coalfield.

Most of the uppermost Westphalian B marine bands consist of *Lingula*-bearing shales, but the Kirkby's Marine Band differs from this pattern in commonly comprising alternating horizons rich in marine (*Lingula*, foraminifera and occasional bivalves) and non-marine (bivalves, fish, serpulids) fossils, with several intermediate phases (see, for example, Fig. 74 of Land, 1974).

The base of the Ryhope (=*AEGIRANUM*) Marine Band marks the upper boundary of the Westphalian B sequence, and of the Lower *similis-pulchra* bivalve zone.

7.10.4 Discussion

The approximate locations of major channel belts which formed the "High Main Post" are shown on Fig. 7.28, which shows that these were about 2-5 kms in width and sinuous in morphology. The interpretation of a meandering channel form is supported by the presence of large-scale lateral accretion foresets in sandstones at Moss Close O.C.C.S., and the impression of a very complex channel sand body architecture is gained from cross-cutting relationships and from the palaeocurrent distribution at this exposure. It is thus possible that these channels meandered across 2-5 km-wide channel belts and were themselves somewhat less wide, perhaps less than 1 km. The complete pattern of "High Main Post" channels is not discernible, unfortunately, due to lack of preservation in much of the coalfield.

As with the underlying interval, some channels can be seen to have operated along the same courses as earlier ones, and others to have avoided former channel courses (compare Figs. 7.24 and 7.28). Indeed, it is possible that thick, continuous channel sandstones which "cut out" the High Main coal may represent channels active during the period of accumulation of the High Main. Alternatively and more likely, two phases of channel activity might be represented, one pre- and one post-High Main accumulation. This interpretation of vertically stacked channel sand bodies implies once again that local structural controls were influencing the location of channels. However, it is worth noting that the "High Main Post" is particularly thick in the north-eastern part of the coalfield, where the High Main coal is at its' maximum development.

The thick sequence of sediments between the High Main coal and the Ryhope Marine Band may be regarded as "normal" Coal Measure facies, superimposed upon which are a series of marine incursions. The relationship between marine bands and their enclosing sediments has been discussed at length with regard to the better-exposed and more widely-known Harvey (=*VANDERBECKEI*) Marine Band (Ch. 6.9.3).

The complex faunal facies of the Kirkby's Marine Band (Calver, 1968a), whilst possibly reflecting a complex form of marine incursion, seem more likely to represent fluctuations in ion activities, suspended sediment concentration, etc., caused by variations in sediment distribution and discharge.

CHAPTER VIII - THE WESTPHALIAN C OF THE DURHAM COALFIELD

8.1 INTRODUCTION

The Westphalian C succession in the Durham coalfield, overlying the Ryhope (=*AEGIRANUM*) Marine Band, comprises about 330 m of interbedded clastic sediments and coals, of similar aspect to the underlying Westphalian A and B (Fig. 8.1).

The sequence contains a great number of coal seams, but few reach workable thickness, exceptions being the Usworth (B000), Hebburn Fell(A000) and Hylton Castle coals (Fig. 8.1). Stratigraphical subdivision of the sequence is poorly-refined, due to a shortage of laterally extensive marker horizons. Above the Ryhope Marine Band, the only two recognized marine horizons are the Wearmouth (=*EDMONDIA*) and Down Hill (=*CAMBRIENSE*) Marine Bands. In the zonal scheme of Trueman and Weir (1946), sediments representing the entire Upper *similis-pulchra* zone and the lower part of the *phillipsi* zone are present. No strata younger than Westphalian C in age are preserved.

Westphalian C sediments are preserved only in the extreme north-east of the coalfield, though they are known to continue offshore. Furthermore, there are few exposures of any quality, and only three outcrops were visited by the author:

(1) Barnwell Quarry (G.R. NZ 326540),

(2) Offerton Heugh Quarry (G.R. NZ 344562)

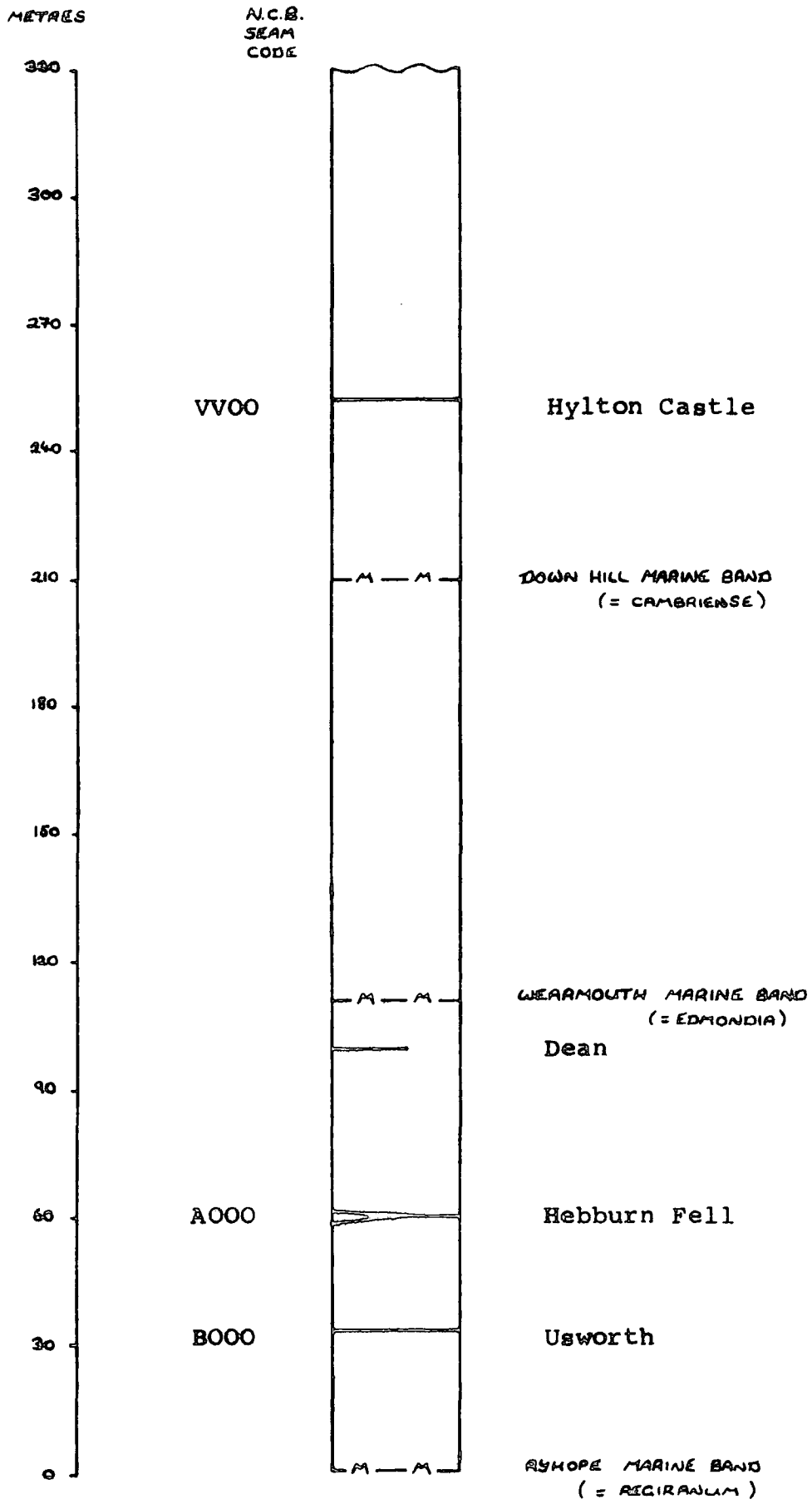
(3) Claxheugh Rock (G.R. NZ 362575)

(Fig. 7.2).

These exposures are briefly described and interpreted, and this

Fig.8.I

WESTPHALIAN C STRATIGRAPHY OF THE DURHAM COALFIELD



is followed by a general discussion of the Westphalian C sequence.

8.2 EXAMINED LOCALITIES IN WESTPHALIAN C SEDIMENTS

8.2.1 Barnwell Quarry

Description

At Barnwell Quarry, Penshaw, a 15 m sequence comprising mainly sandstones is exposed, referable to the "Grindstone Post", stratigraphically between Ryhope Marine Band and Usworth coal (Fig. 8.1), (Appendix 1:- Section 403). Two units of trough cross-bedded sandstone at least 4.0 m and 6.0 m thick respectively are separated by 4.5 m of weathered, laminated siltstones (Section 403). Trough cross-sets are common (up to 0.6 m thick, and often arranged in cosets), as are bounding surfaces ("master bedding planes"), ripple cross-lamination, small shale clasts, and in the basal part of the upper sandstone, abundant coaly laminae and "scares".

Trough cross-bedding and ripple cross-lamination indicate palaeoflow towards the south in both sandstones.

Interpretation

The lower sandstone was deposited by high-energy current activity, sustained at least periodically over a considerable time (to produce cosets of cross-strata), and is tentatively interpreted as the upper part of a channel deposit. The southward-flowing channel was rapidly abandoned, leading to deposition of silts within and eventually over the inactive channel.

The upper sandstone was probably deposited by similar processes to those responsible for the lower one, perhaps in a slightly different setting. The basal part of this sandstone is tentatively

interpreted as the proximal deposit of a crevasse splay lobe which prograded southward across underlying shallow floodbasin sediments, from a comparison with similar, better-exposed sequences (e.g., Cabin House: Ch. 6.8.2.2). The upper part is interpreted as the deposits of a channel which was diverted across this floodbasinal lake, presumably by the crevassing of an earlier channel bank.

8.2.2 Offerton Heugh Quarry

Description

This disused quarry exposes a 9 m sequence, stratigraphically a short distance above the Bottom Hebburn Fell (A100) coal (Fig. 8.1), (Appendix 1:- Section 404).

The sequence is composed almost entirely of fine-to-very-fine-grained sandstones, which in the upper part occasionally fine upward to siltstone (Section 404). Trough cross-bedding (in sets up to 1.0 m thick) and ripple cross-lamination are the most common structures in the lower part of the exposrue, while upper levels contain only ripple cross-lamination. Cross-sets are occasionally contained within cosets, and bounding surfaces are also present.

Palaeocurrent measurements from directional structures throughout the exposed vertical sequence indicate palaeoflow towards the north-west.

Interpretation

The sandstone body exposed at Offerton Heugh is interpreted as the upper part of a north-westward-flowing channel deposit.

8.2.3 Claxheugh Rock

Description

A 5 m section of sediments including the Down Hill (=*CAMBRIENSE*) Marine Band is exposed by the waterline of the River Wear below Claxheugh Rock, Sunderland (Fig. 8.1), (Appendix 1:- Section 391).

A bioturbated, ripple cross-laminated sandstone with fine-grained partings is overlain by well-laminated claystones containing small (up to 2 mm) impressions of *Lingula mytilloides*, *Planolites* burrows and fish fragments. This claystone becomes gradually more silty upward and contains nodules and lenses of ? siderite (Section 391).

Interpretation

The sediments exposed at Claxheugh are interpreted as the deposits of a ? shallow floodbasin environment which became inundated by the sea during the *CAMBRIENSE* marine incursion.

8.3 A BRIEF REVIEW AND DISCUSSION OF THE WESTPHALIAN C SEQUENCE

To complete this study of the Durham Coal Measures, salient features of the Westphalian C sequence are now summarized.

The Ryhope (=*AEGIRANUM*) Marine Band, which marks the base of the sequence and of the Upper *similis-pulchra* bivalve zone, contains a variety of diverse marine fauna, particularly in the north of the region (Land, 1974, p. 104; Armstrong and Price, 1954).

In the area around Sunderland, a prominent sandstone up to 30 m thick, which has been worked for refractory purposes and named the "Grindstone Post", occurs between the Ryhope Marine Band and the

Usworth coal (Fig. 8.1). Part of this sandstone, which is probably the deposit of a channel or a series of channels, is exposed at Barnwell Quarry (Ch. 8.2.1).

The Usworth coal (B000; see Fig. 8.1) has been worked in the area between Sunderland and the River Tyne, where it is commonly 1.5 m thick. Where close to the overlying Permian unconformity, however, it is substantially reduced in quality.

The Hebburn Fell coal (A000; see Fig. 8.1) is similar in thickness and character to the underlying Usworth seam, though is often split into Bottom (A100) and Top (A200) Hebburn Fell coals. Again, the A000 coal is commonly of reduced quality in proximity to the Permian unconformity.

Some 50 m or so higher in the sequence lies the Wearmouth (=*EDMONDIA*) Marine Band (I.G.S. Sheet 21; Sunderland), which is largely of *Lingula* "facies" (se Ch. 8.2.2), (Fig. 8.1).

The Down Hill Marine Band marks the base of the Upper Coal Measures sequence, and of the *phillipsi* bivalve zone. In the 120 m or so of preserved Upper Coal Measures strata one coal, the Hylton Castle seam (VV00; see Fig. 8.1), is quite well-known and sporadically worked.

Although many coals occur in the Westphalian C sequence, most appear to be impersistent. Much of this lateral variability might, however, be due to oxidation of coals during the Permian period, when the Coal Measure sequence was exposed to severe weathering in an arid climate. Oxidation has been inferred to explain the absence of coal seams in the Thornhill outlier of SW Scotland (Simpson and Richey, 1936), and has also been reported from Ayrshire (Mykura, 1960) and Cumbria (Taylor, 1961), amongst other areas.

Discounting the often considerable effects of post-Carboniferous oxidation, the Westphalian C sequence of the Durham coalfield is not noticeably different from the underlying Westphalian A and B. This oxidative reddening of Westphalian strata, up to 90 m below the Permian unconformity in the Durham area, is ascribed to processes operating during the Permian period (and possibly during Uppermost Carboniferous times) from the varying stratigraphical position of the reddened zone, the gradual lessening of reddening effects downward and concentration of reddening along joints (Anderson and Dunham, 1953; Smith and Francis, 1967, pp. 18-19). There is no evidence of facies associated with "primary" red beds in the Durham sequence.

The proportion of sandstone appears similar to that characteristic of the underlying Westphalian A and B, from the available records (Smith and Francis, 1967; Land, 1974; unpublished N.C.B./I.G.S. records) and allowing for the effects of Permian oxidation the only noticeable change in sedimentary style within the Westphalian C succession is the absence of marine horizons above the Down Hill Marine Band, as in other coalfields of Great Britain (Ramsbottom, *et al.*, 1978). Examined localities certainly show very similar facies to those characteristic of the Westphalian A/B.

The gradual change in sedimentary environment which marked the transition from the humid, tropical setting of the Upper Carboniferous to the arid, continental Permian setting began in upper Westphalian C times, or later, over much of Great Britain. This change, heralded by the deposition of *Spirorbis* limestones and "primary" red beds (see, for example, the Westphalian C and D of North Staffordshire), is not manifested in the Durham Coal Measures, which probably preserve only the lower half of the Westphalian C sequence.

CHAPTER IX - DEPOSITIONAL ENVIRONMENTS OF THE DURHAM COAL MEASURES

9.1 INTRODUCTION

From the detailed descriptions and interpretations of exposed sequences in this thesis, the sediments of the Durham Coal Measures may be divided into five environmental Associations, each of which contain the deposits of a number of environments. The salient features, interpretation and distinguishing characteristics of environment-related sequences within each Association are summarized in this Chapter, and brought together into a sedimentary model in Chapter 10.1.

9.2 CHANNEL ASSOCIATION

Deposits of five environments may be grouped into a Channel Association:

(1) Trunk and major distributary channels

(2) Minor distributary channels

(3) Minor crevasse channels

(4) distal feeder channels of crevasse/minor distributary channels and

(5) levees.

9.2.1 Trunk and major distributary channel deposits

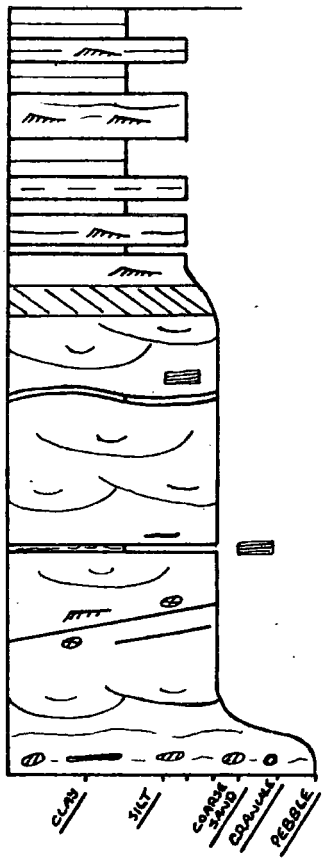
Description

Major channel deposits are composed largely of fine-to-coarse-grained sandstone, in vertical sequences usually of at least 10 m and exceptionally up to 30 m (Fig. 9.1). The sequences generally

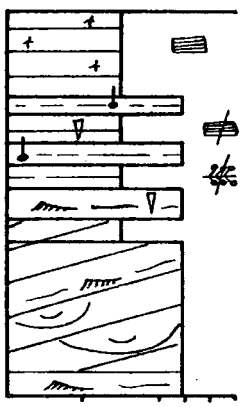
Fig.9.Ia

SEDIMENTARY ENVIRONMENTS OF THE DURHAM COAL MEASURES
I - VERTICAL SEQUENCES

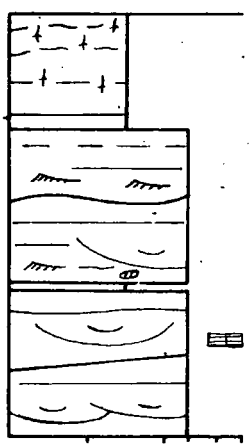
A - CHANNEL ASSOCIATION



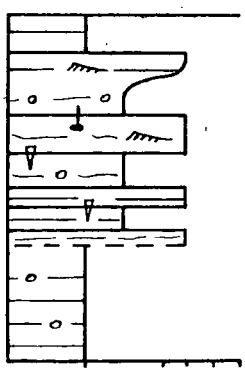
Major channel deposits.
Sequences ≤ 30m.



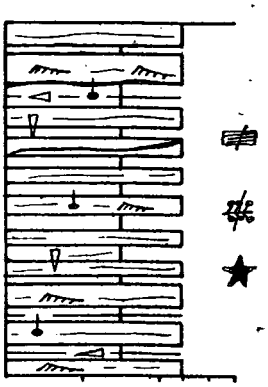
Minor channel deposits.
Sequences ≤ 6m.



Minor crevasse channel deposits.
Sequences ≤ 2m.
(COMMONLY VERTICALLY STACKED)



Distal feeder channel deposits.
Sequences ≤ 2m.

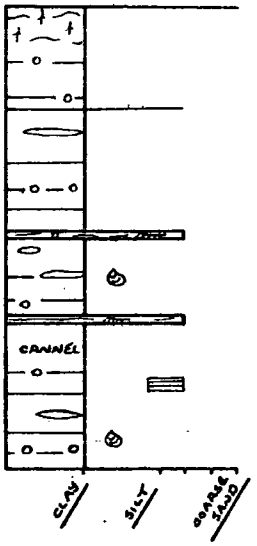


Levee deposits.
Sequences ≤ 4m.

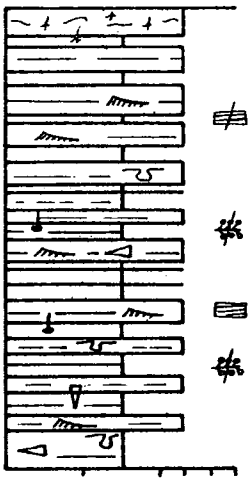
Fig.9.Ib

SEDIMENTARY ENVIRONMENTS OF THE DURHAM COAL MEASURES
I- VERTICAL SEQUENCES

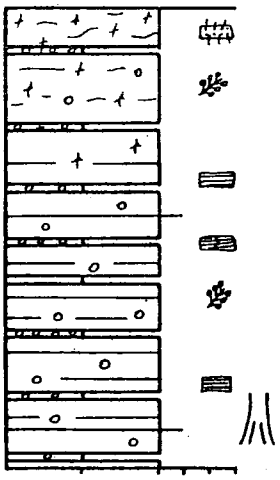
B - LAKE/BAY ASSOCIATION



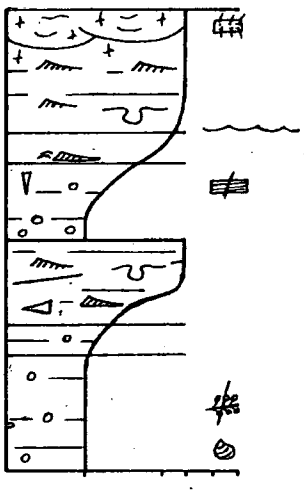
Quiet water claystones
Sequences ≤ IOm



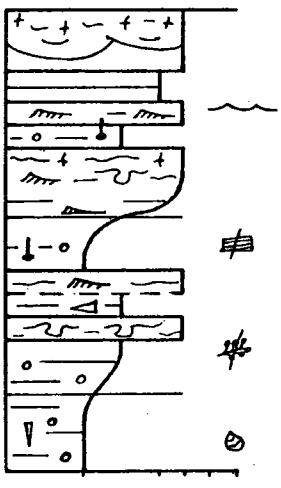
Coarse-grained overbank deposits
Sequences ≤ IOm



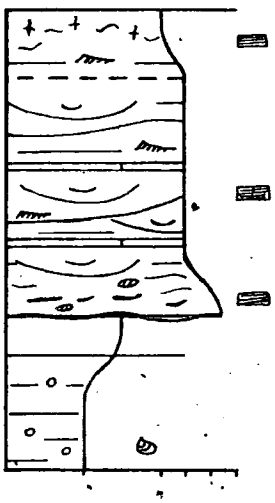
Siltstone-dominated overbank deposits
Sequences ≤ IOm



Distal

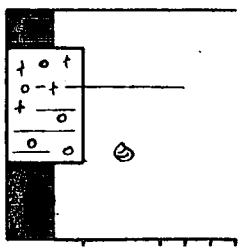


Medial



Proximal

Crevasse splay/Minor delta deposits - Sequences ≤ IOm

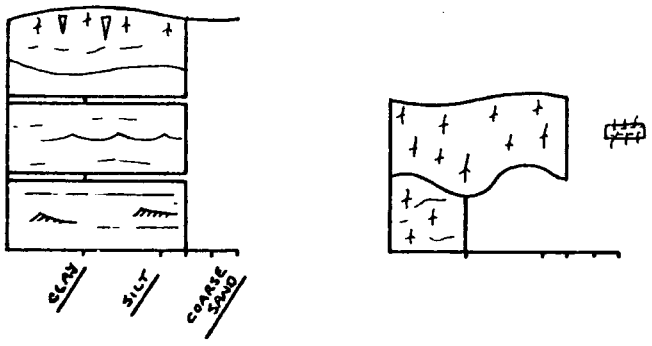


Passive lake margin deposits
Sequences ≤ 3m

Fig.9.Ic

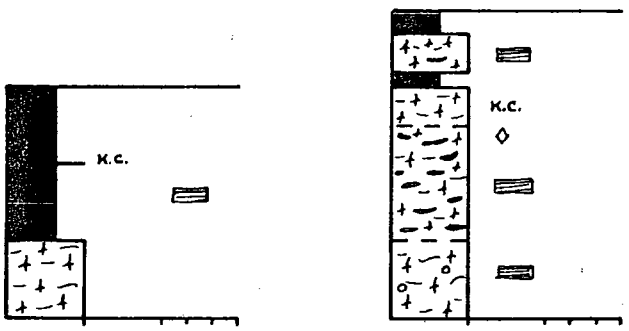
SEDIMENTARY ENVIRONMENTS OF THE DURHAM COAL MEASURES
I- VERTICAL SEQUENCES

C - SHORELINE ASSOCIATION



Quartz arenitic sandstones of shoreline and pedogenic origin. Sequences ≤ 5m and ≤ Im respectively.

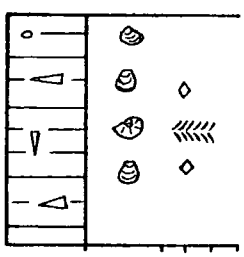
D - SWAMP ASSOCIATION



Coals
Sequences ≤ 4m

Shaly coals
Sequences ≤ 4m

E - MARINE BAND ASSOCIATION



"Marine bands"
Sequences ≤ 2m

have sharp and erosive bases, and abrupt to transitional tops, passing upward into lake and floodbasin deposits, or in the basal Westphalian A sequence into quartz arenitic shoreline deposits.

Fine-grained partings are common within the sandstones, and occasional intraformational conglomerates occur, particularly at the base of sequences.

The major channel sandstones contain abundant sets and cosets of trough cross-bedding(sets typically 0.5-1.0 m thick and with width/height ratios of 10-20/1). Erosive bounding surfaces separating units of sandstone may be laterally persistent over hundreds of m, and lateral accretion surfaces are occasionally seen in large exposures (for example, see Chs. 6.8.2.1 and 7.10.2.1). Other less common current-produced structures include tabular cross-bedding, ripple cross-lamination and primary current lineation, and other features include deformed peat and claystone rafts up to 2 m or more in length.

Detailed descriptions and drawings of major sandstone deposits are given in Fig. 7.29, Enclosure 1 and in Haszeldine (1981a, Chs. 6 and 7).

Major channel deposits are generally of sheet geometry (Friend, Slater and Williams, 1979), being several 10s of kms at least in length and usually up to 5 kms in width (see for example, Fig. 6.39) though exceptionally up to 10-20 kms (see Figs. 6.10 and 7.15). Palaeocurrent vectors from individual localities show low-to-high spread, and between localities at the same stratigraphical level display extreme spread.

Petrographically, major channel sandstones are poorly sorted and commonly contain 30% or more of clay grade material. They may be

highly porous and friable if subaerial weathering has caused leaching of carbonate cement, feldspar framework grains, etc.

Discussion

The trunk and major distributary channels probably formed the primary avenues of sediment transport across the Coal Measures delta plain (Fig. 9.2). Identification of distributary, as opposed to fluvial, channels is based on the overall context and setting of the Coal Measures, and on the high frequency of avulsion which seems to have been characteristic of these channels and predominance of subaqueous, as opposed to subaeirally-exposed, levee sediments (see Ch. 10.1).

The geometries of these major sandstones and their palaeocurrent patterns suggest these distributaries to have been generally 1-3 kms wide, meandering in form and to have been contained within low-to-high sinuosity, mobile channel belts up to 10 kms wide (Friend, 1981).

Two exceptions to this occur:

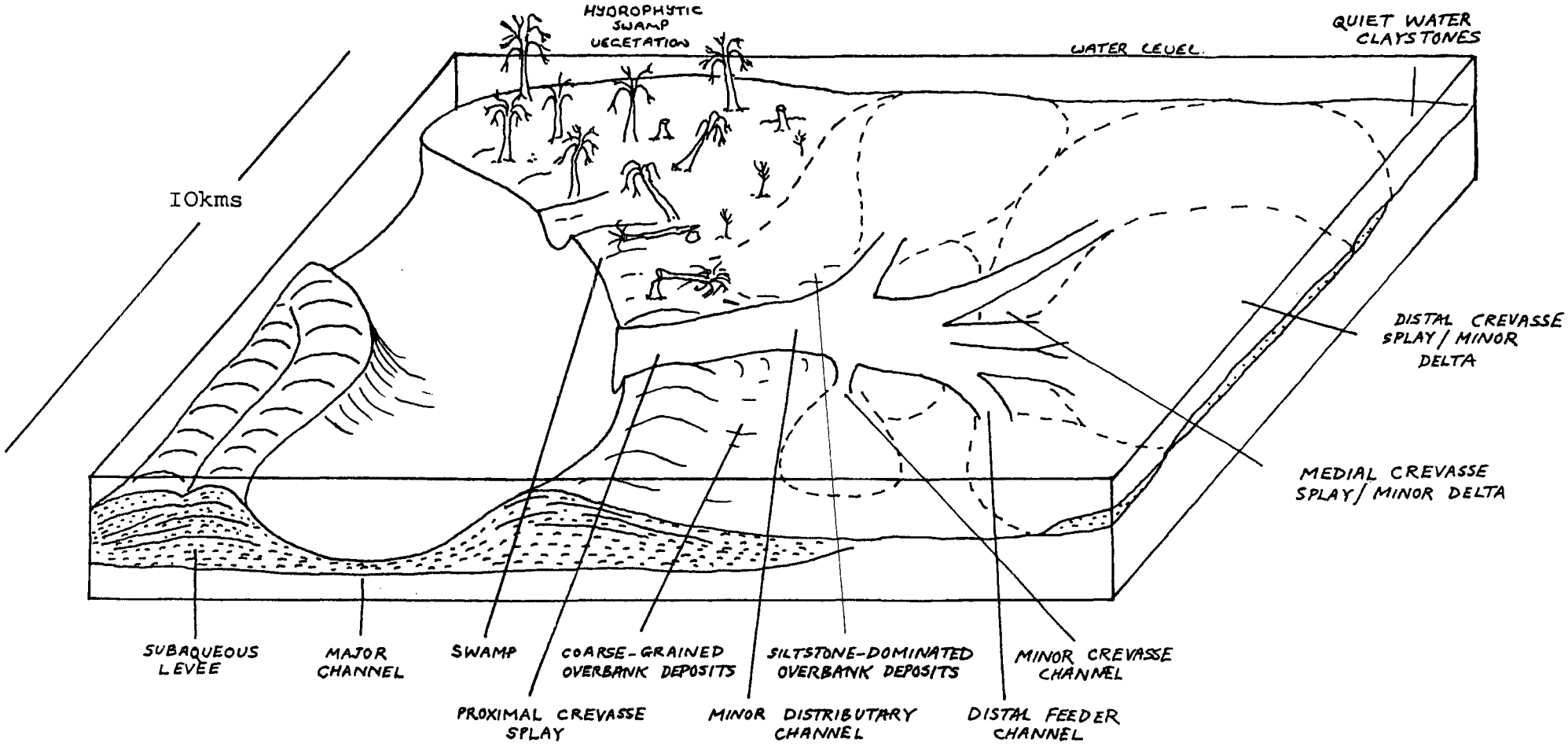
(1) in the basal Westphalian A, channel belts were possibly up to 10s of kms wide, within which individual channels were perhaps 5 kms wide and of low sinuosity (Ch. 6.2, Figs. 6.4, 6.10), and

(2) in the Low Main-Maudlin interval (lower Westphalian B; see Fig. 7.1) channels of moderate-high sinuosity and 2-5 kms width were contained within comparatively low sinuosity channel belts up to 20 kms wide.

These variations in channel and channel belt type will be discussed further in Ch. 10.3.

The major distributaries had scour depths of a few m, and exceptionally perhaps up to 20 m. Various types of channel-floor bedforms are thought to have formed in these channels, notably lateral

SEDIMENTARY ENVIRONMENTS OF THE DURHAM COAL MEASURES
2 - PALAEOGEOGRAPHICAL SETTING



(bank-attached) and medial (mid-channel) bars (Bluck, 1976; Haszeldine, 1981a).

Numerous features within the major channel deposits indicate a varying discharge regime; erosive bounding surfaces of various types (Jones and McCabe, 1980; Haszeldine, 1981a), evidence of superimposition of small-scale bedforms over large ones (Jones, 1977), chaotically bedded units and fine-grained partings, among others. It is inferred from these that the major Coal Measure distributaries were subject to frequent (? seasonal), rapid variations in discharge, and often flooded; this interpretation is supported by the common preservation of levee deposits (see Ch. 9.2.5). Abandonment of these channels was in various cases achieved either swiftly or slowly.

Distinguishing Characteristics

Major distributary channel deposits are distinguished, both in outcrop and subsurface, by their thickness of sandstone (usually 10 m+). No other U.K. Coal Measure environment is considered capable of producing such thick sandstones. These deposits are also characterized by their sheet geometry, and assemblage of high-energy sedimentary structures, particularly abundant trough cross-stratification.

9.2.2 Minor distributary channel deposits

Description

Deposits of minor distributary channels are composed of inter-bedded units of fine-grained sandstone, siltstone and claystone. Traced laterally, these deposits are lenticular or channelized and usually less than 100 m wide and 6 m thick, though it is evident that these deposits may be vertically stacked (Fig. 9.1).

Sequences generally, though not exclusively, display sharp or erosive basal contacts, and many show a general fining upward tendency (see, for example, Ch. 6.7.4.5) although others comprise a coarse member overlain by a finer deposit (see Chs. 6.7.4.1 and 7.4.2.3). They generally overlie and are overlain by lake/bay or swamp sediments (see Chs. 9.3 and 9.5).

Sandstones display abundant trough cross-bedding (sets up to 0.6 m thick), ripple cross-lamination and uneven/parallel lamination, and finer-grained sediments are commonly micaceous, carbonaceous and contain plant fragments. Low-angle cross-bedding surfaces (Epsilon cross-bedding; Allen, 1965b) up to 3-4 m in height are common and dip in directions 60-120 degrees from those of other current-formed structures. Occasionally, sandstone beds within such inclined units are seen to fine both vertically upwards and updip along individual bedding planes.

Bivalve escape traces (*Pelecypodichus*) are sometimes present, as are *Planolites* and other burrows.

Deposits of minor distributary channels are generally of ribbon or sheet geometry (Friend, Slater and Williams, 1979), and may often be complex in form (see, for example, Chs. 6.7.4.5 and 6.8.2.1). In the latter case, sediment-filled channel forms are enclosed laterally by sandstone-dominated sequences which may themselves display remnants of channelized hollows, Epsilon cross-bedding, etc. Such belts may be at least several hundred m in "width".

Palaeocurrent distributions both within and between individual localities often show a very wide spread.

Petrographically, minor distributary channel sandstones are characterized by poor sorting and a high content of recrystallized clay-grade material as with those of major distributaries, though

are generally finer-grained than the latter.

Discussion

From the scale and geometry of preserved sediments, minor distributaries were generally up to 100 m wide and sinuous in morphology (see, for example, Enclosure 6, Ch. 6.7.4.1 and Plates 6.33, 6.34), (Fig. 9.2). Epsilon cross-bedded units are interpreted as the product of lateral accretion on point bars, and at one locality (Rowley O.C.C.S.; see Ch. 6.7.4.1) channels are interpreted to have become abandoned by chute cut off (Allen, 1965b). Where channel forms are contained within a complex, sandstone-dominated deposit, this is interpreted as the result of channel migration across a meander belt.

From the interbedded nature of many laterally-accreted units and the generally fine-grained nature of channel fills, minor distributary channels are inferred to have carried a high suspended load and comparatively fine bedload (the "muddy, fine-grained streams" of Jackson, 1981).

Abandonment, partial abandonment and active channel fills are represented in these deposits (Meckel, 1972) and considerable evidence for a variable discharge is again preserved in the form of "interbedded" laterally accreted units, and in the presence of trace fossils indicating faunal colonization.

From the environmental setting and from a comparison with modern coastal plain environments (e.g., see Coleman, Gagliano and Webb, 1964; Arndorfer, 1973; Elliott, 1974, 1978), minor distributaries are believed to have originated by operation of crevasse channels (themselves formed by breaching of major channel banks) over a long period, allowing the formation of a well-developed channel profile (see Ch. 9.2.3).

The minor distributary channels have highly variable width/depth ratios, ranging from perhaps 50/1 to 3/1, lower values associated with channels which incised into highly cohesive peat deposits. Many of these channels seem to have been entirely subaqueous, from the presence of bivalve escape traces, and those channels with higher width/depth ratios seem to be associated with deeper water (? up to 4 m). Palaeochannel parameters have been calculated for a number of minor distributary channels in this study, using the method of Guion (1978), (Fig. 9.3). These subaqueous minor distributary channels are believed to pass distally into very high width/depth ratio "feeder channels" (Ch. 9.2.4.).

Distinguishing characteristics

In good outcrops, minor distributary deposts can be distinguished by their geometry, and by the presence of low-angle lateral accretion surfaces. In poor exposure or in borehole cores, however, these deposits may be difficult to identify; in such cases the association of sharp base, low angle cross-bedding, trace fossils and general vertical fining-upward over 2-6 m may be distinctive.

9.2.3 Minor crevasse channel deposits

Description

Minor crevasse channel deposits consist of fine-grained sandstone with occasional thin partings of siltstone and claystone (Fig. 9.1). These deposits have a lens-shaped or broadly channelized profile with a width usually of up to 50 m and thickness of up to 2 m. Well-defined channel margins are generally absent, as is evidence of lateral accretion. Minor crevasse channel deposits are generally incised into lake/bay sediments, may be as narrow as 1.3 m

Fig.9.3

PALAEOCHANNEL PARAMETERS OF SOME MINOR DISTRIBUTARY CHANNELS

Channel	Width (m)	Depth (m)	Width/ Depth	Sinuosity	Meander Wavelength (m)	Mean Annual Discharge (cusecs - Imperial)
Buckhead O.C.C.S. above Top Hutton	50m	4m	12.5	2.77	580m	437.5 cusecs
Rowley O.C.C.S. above Top Tilley	50m	2m	25	3.35	580m	437.5 cusecs
Rowley O.C.C.S. above Middle Tilley	100m	2m	50	4.03	1169m	2009 cusecs
Cobey Carr Quarry above Middle Tilley	15m	2m	7.5	2.42	172m	31.1 cusecs
Buckhead O.C.C.S. above Bottom Tilley	10m	2m	5	2.17	114m	12.7 cusecs

Based on the equations of Leeder (1973) and others - see discussion in Guion (1978)

and have width/depth ratios as low as 3:1 (see, for example, Ch. 6.7.2.5, Plate 6.13). They may pass downcurrent into lake/bay deposits.

Minor crevasse channel deposits are commonly multi-storey, individual units separated by erosive surfaces or fine-grained partings (see, for example, Ch. 6.6.4.1), (Fig. 9.1). Sandstones almost always display sharp, erosive, lower contacts and sharp upper contacts. Sedimentary structures include small-scale trough cross-bedding (in sets up to 0.3 m thick), ripple cross-lamination and climbing ripple cross-lamination. "Rip-up clasts" of shale, ironstone and coalified peat are occasionally present, along with silicified pith casts of plant stems as *Calamites* (see Enclosure 6 and Plate 6.20).

In three-dimensional form, these units have a ribbon, or occasionally sheet, geometry (Friend, Slater and Williams, 1979) and display low to moderate palaeocurrent spread.

Petrographically, the sandstones are very similar to minor distributary channel sandstones, though occasionally displaying better sorting.

Discussion

The minor crevasse channels are interpreted as having been active over periods of time insufficient to allow development of a full channel morphology (Fig. 9.2). In many cases, these short-lived channels were filled by a single erosional/depositional event although others seem to have been active over longer periods.

The crevasse channels were evidently formed by breaching of a

channel bank, usually a minor channel, though also from major channels, (see, for example, Chs. 6.7.4.1 and 6.7.2.3). Crevasse channel plugging was rapid, though often intermittent. The channels with a particularly low width/depth ratio are those incised deeply into host sediments.

Crevasse channels pass downcurrent into crevasse splay deposits, as the erosive flood flow(s) decelerated and deposited sheet-like, unconfined splay sediments (see Ch. 9.3: lake and bay sediments).

Distinguishing characteristics

Minor crevasse channel deposits may be distinguished from the other channel facies, in good quality exposure, by the comparatively small dimensions, low width/depth ratio and evidence for rapid, high-energy plugging. In poor exposures and borehole core, however, minor crevasse channels may be impossible to distinguish from crevasse splay deposits (see Ch. 9.3).

9.2.4 Distal feeder channels of minor distributaries and crevasse channels

Description

"Feeder channel" deposits comprise units of fine-grained sandstone, finer-grained sediments or interbedded lithologies (Fig. 9.1), generally up to 2 m thick and 200 m wide with a broad, shallow channel outline (in sections perpendicular to palaeoflow; see, for example, Enclosures 5 and 13).

These deposits most commonly contain only parallel and uneven lamination, sometimes with low-angle draping, but occasionally show ripple cross-lamination and, rarely, small-scale trough cross-bedding. Often, they are only distinguishable from a sequence of lake/bay

sediments (within which the distal feeder channels are always found) by the recognition of a low-angle channel-like outline (see Ch. 7.5.2.2).

In three dimensions, distal feeder channel deposits are interpreted to have an elongate sheet geometry, being continuous over at least several hundred m (Enclosure 13), pass upcurrent into minor distributary channel sediments, and die out downcurrent. The few palaeocurrent measurements taken from these deposits (see, for example Ch. 6.6.4.3 and Enclosure 5) indicate a moderate dispersion of current flow directions.

Petrographically, sandstones are similar to those of minor crevasse channels.

Discussion

The distal feeder channels developed as a response to increasing water depth and decreasing flow power, as shallowly-submerged minor distributary channels prograded into the deeper waters of lacustrine basins (perhaps 3-4 m?),(Fig. 9.2). Thus the feeder channels have a very high width/depth ratio (up to 100/1), generally fine-grained fill and only subtle definition. However, they probably play an important role in the infilling of Coal Measure lacustrine basins.

The recognition of such subaqueous feeder channels is not widespread in modern delta plain environments (see Elliott, 1974) although it is apparent that these channels do occur, from examination of published maps, photographs and subsurface contour maps (compare, for example, Enclosure 13 with Fig. 10 of Arndorfer, 1973).

Distal feeder channels have not been previously recognized as such from the British Coal Measures.

Distinguishing characteristics

Identification of distal feeder channels is dependent on recognition of the subtle, broad and shallow channel profile, and as such requires large exposure. These channels will be virtually impossible to distinguish from lake/bay sediments in borehole core.

9.2.5 Levee deposits

Description

Levee deposits comprise units of thinly interbedded fine-grained sandstone and carbonaceous claystone or silty claystone, in beds typically 5-15 cms and 1-3 cms thick, respectively (Fig. 9.1). In a direction parallel to palaeoflow, these deposits vary up to at least 4 m thick and 1 km "wide", and possess an arched profile, with one limb usually steeper than the other (see Enclosure 16 and Fig. 6.28). Low-angle depositional dips are prevalent, parallel to the upper surface of the unit (Plate 7.14).

While parallel and uneven lamination are the most common sedimentary structures, ripple cross-lamination and small-scale trough cross-bedding are also present, and sediments occasionally show low-angle internal discordances. Rootlets are occasionally present in the upper parts of sequences.

Trace fossils are very common, and while most abundant on the arch crest (Fig. 6.28) are usually present across the whole width of the levee.. Commonest ichnogenera are *Planolites* and *Pelecypodichnus*, while *Arenicolites*, *Skolithos* and *Monocraterion* are also represented (Plate 6.7).

Levees occur as lateral equivalents of major or minor distributary channel and overbank deposits (Ch. 9.3), and may overlie swamp (see, for example, Ch. 7.8.2.1) or overbank deposits (see Ch. 7.9.2.4).

Levee sequences may be overlain by almost any of the sequences described and may be eroded into by deposits of crevasse channels. In plan, levee deposits are situated in elongate strips paralleling major and minor distributary channels, (see Enclosure 16, for example).

Palaeocurrents tend to be directed perpendicular or oblique to the contours of the deposit, and have low-moderate dispersion (see Enclosures 5, 16).

In thin section, levee sandstones tend to be comparatively poorly sorted, though it is apparent that sediment fabrics have been modified by bioturbation.

Discussion

Channel levees in the Durham Coal Measures were up to 1 km wide and 4 m in height, and from a general lack of rootlet penetration, are inferred to have been largely subaqueous. This has considerable significance with respect to the overall setting (discussion in Ch. 10.1).

Levees developed at the margins of major and minor distributaries (Fig. 9.2), and built up by channel bank overtopping and crevasse splay deposition at flood stage (Coleman, Gagliano and Webb, 1964; Ray, 1976; Collinson, 1978). Indeed the steeper, inner limb of the levee deposit represents the channel bank. Thus palaeocurrents are directed directly or obliquely away from the channel margin and isopachs of the levee deposit tend to parallel the channel margin.

The common obliquity of palaeocurrent directions in levee deposits with respect to the contours of the levee may be explained as a result of location on the outer (erosive) bank of a channel bend (see Enclosure 16, for example).

The abundance of trace fossils in these subaqueous levee deposits is probably an indication that levees were comparatively well-oxygenated and well-suited to infaunal colonization, being elevated above normal lake bottom and subject to greater water turbulence.

Levee deposits separate channels from interdistributary lakes and bays (see, for example, Coleman, Gagliano and Webb, 1964; McEwan, 1969) and will thus pass distally into overbank dominated lake/bay sequences. Indeed, levees themselves develop by a build up of channel-derived overbank material, and are thus often also underlain by overbank sediments (see Ch. 7.9.2.4).

Levee deposits are poorly known from ancient fluvial and delta plain sequences, perhaps due to their low preservation potential and to relative difficulty of recognition. That the remnants of several channel levees have been observed in this study implies that these features were commonly developed on the Coal Measures plain.

Distinguishing characteristics

Levee deposits are distinguished, in good exposures, by their association with adjacent channels, arched geometry and thinly bedded alternation of lithologies. In poor quality exposure and in borehole cores they may be more difficult to recognize, though the regular interbedding of fine-grained sandstone and caronaceous claystone, and the assembalge of trace fossils, should be distinctive (see also discussion of possible levee sediments in Gjelberg, 1977, p. 83).

9.3 LAKE/BAY ASSOCIATION

Sedimentary sequences indicative of seven environments may be grouped into a lake/bay association:

(1) quiet water claystones,

(2) coarse-grained overbank deposits,

(3) overbank siltstones,

(4) distal,

(5) medial,

(6) proximal crevasse splay/minor delta sequences, and

(7) passive lake/bay margin deposits

9.3.1 Quiet water claystones

Description

Quiet-water deposits comprise dark-to-light grey-coloured, fissile-to-unlaminated claystones, occurring in sequences up to 10 m thick, and persistent laterally for distances of up to several kms (Fig. 9.1).

These sediments are most commonly parallel laminated, occasionally with a silty or sandy streak ("linsen bedding"). Nodules, lenses and thin layers (up to 5 cms thick) of siderite and other carbonate minerals (see Haszeldine, 1981a, Ch. 4) are abundant, as are flattened impressions of plant fragments. Occasionally, the darker and least-laminated claystones may pass laterally or vertically into canneloid claystone or cannel coal. Thin (up to 10 cms) units of kaolinitic claystone are also rarely present (Plate 6.8), as are thin (up to 10 cm) bands of ripple cross-laminated sandstone.

Impressions of non-marine bivalves are common in the basal parts of these claystone units, with ostracods, branchiopods, and fish fragments occasionally being found.

Quiet water claystones usually overlie coal seams (swamp deposits), and occasionally occupy the entire interval between two coals, the uppermost part of the sequence being rootlet-penetrated. More commonly, however, they pass vertically upward (and also laterally) into overbank deposits.

Quiet water claystones may occupy large areas, and volumes, of rock within given sequences, and are of sheet geometry. Sedimentary structures allowing palaeocurrent measurement are largely absent, but measurements of the long axes of plant fragments suggest a wide spread of palaeoflow directions, even on the scale of a single outcrop.

Discussion

The claystones were deposited in lakes and bays largely by slow fallout from suspension, following overbank flooding and crevasse splay activity, at rates of sedimentation sufficiently low that thriving bivalve communities or even ostracods and branchiopods could colonize the sediment surface (Fig. 9.2).

Such sediments are inferred to have been deposited beyond the influence of minor delta systems, from lateral relationships and lithology. The presence of cannel coal/claystone, previously interpreted as the deposits of stagnant, sediment-starved lakes, also supports this interpretation, though it must be noted that these lithologies are only present in non-marine-influenced sequences (see Ch. 7.9.2.6).

Since entire inter-seam sequences are occasionally composed of claystones (see, for example, Ch. 7.5.2.3) it is evident that water

turbulence was sometimes increased, perhaps as a response to nearby crevasse splay deposition, to such an extent that sufficient clay-grade sediment could be mobilized as to infill shallow basins (1-2 m) deep. Similarly, disarticulated and transported bivalve shells, the presence of silty or sandy streak, or discrete beds, and the occasional presence of feeder channel deposits within these sediments (Ch. 9.2.4) imply the operation of low-energy tractional currents, and these may have been important in depositing units of claystone.

It is worth noting that the presence of a 10 m thick lake fill sequence probably does not imply that the lake concerned was 10 m deep (discussed further in Ch. 9.3.8).

Interdistributary lake and bay fills in modern delta plain settings are often composed largely of overbank flood-derived clays, beyond the influence of regular tractional current activity (Coleman, Gagliano and Webb, 1964; Coleman, 1966; Donaldson, Martin and Kanes, 1970). Such deposits are also known to contain abundant bivalve and other faunal and floral remains.

Distinguishing characteristics

The quiet water claystones are readily recognizable in outcrop and core by their lithology, which may be confused only with marine band claystones. The presence or absence of marine fossils is distinctive.

9.3.2 Coarse-grained overbank deposits

Description

Coarse-grained overbank deposits comprise rhythmically inter-bedded dark, carbonaceous claystone or silty claystone and siltstone,

or occasionally, very fine-grained sandstone (Fig. 9.1, Plate 6.11). Vertical sequences may be up to 10 m, and this facies is flat-lying and laterally persistent over at least several hundred m in a direction parallel to palaeoflow.

The claystones are dark-coloured and contain abundant, comminuted plant debris, and usually occur in beds 1-5 cms thick. The siltstones or sandstones are generally parallel-laminated or unlaminated, may contain abundant, well-preserved plant fragments and commonly occur in units 5-20 cms thick. Occasional load casts and ripple cross-lamination are present, as is evidence of bioturbation in the form of rare *Pelecypodichnus* and *Planolites* traces. Rarely, non-marine bivalves are found *in situ*, as are rootlets.

Coarse-grained overbank deposits pass laterally into either levee sediments or quiet-water claystones, generally overlie swamp or quiet-water deposits and in turn may be overlain by a variety of sequences, most commonly those of levees. Minor crevasse channels are often incised into coarse-grained overbank sediments (Plate 6.13).

In plan, these sediments are thought to occur in wide areas broadly parallel to channel deposits, often separated from them by levee deposits. Palaeocurrent measurements indicate a low-to-moderate spread of palaeoflow directions away from the channel source within individual localities, and a somewhat higher spread between exposures.

In thin section, the very fine-grained overbank sandstones are similar to those occurring in channel levees.

Discussion

The coarse-grained overbank sediments are interpreted to have been deposited by overtopping of channel banks at flood stage (Fig. 9.2). These sequences are thus situated between channel levees, where present, and passive lake/bay fill sequences, and may be regarded as representing a lateral setting on a major channel or prograding minor distributary system (Fig. 9.2). In time, build-up of overbank material may lead to the progressive advance of a levee (in a direction away from the channel source of sediment) over the overbank sequence, as has been invoked to explain the Fivequarter-2EOO interval at Edmondsley O.C.C.S. (Ch. 7.9.2.4).

Considerable similarities exist between the coarse-grained overbank sediments and those of levees, the main difference lying in the generally finer grain-size of the former. Both are thought to have been deposited by essentially the same processes, i.e., sheet floods of coarse-grained material from channel bank overtopping, alternating with quiet periods of low-energy sedimentation. Plant fragments were preserved by rapid entombment during flood events, and finely broken plant debris settled out of suspension during quiet periods. Little or no evidence of wave reworking has been observed in these deposits.

The regularity of interbedding in the coarse-grained overbank and levee sediments suggests a periodic, possibly seasonal, pattern of flood events (see Ch. 7.9.2.4), and the preservation of thick sequences of overbank sediments in the Durham Coal Measures implies that many channels were positionally stable over long periods of time. That entire intervals between coal seams may be occupied by such deposits (e.g., at Woodland O.C.C.S.,

see Ch. 6.5.2.2), implies that overbank processes were capable of completely infilling shallow lakes and bays.

Overbank sedimentation has been recognized from modern delta plain and fluvial plain environments (Coleman, Gagliano and Webb, 1964; Coleman, 1969), but in the former case, deposition of all but clay grade sediment is considered to terminate at the distal margin of a channel levee (see also Elliott, 1974). It is here proposed that silts and even very fine sands may be deposited in rhythmic alternation with clays by overbank processes, on an interdistributary lake or bay floor at distances of up to 2-3 kms from the source channel margin, as a precursor to levee construction, *sensu stricto*.

Overbank sediments have been identified in the British Coal Measures, for example by Guion (1978), as have rhythmically interbedded sediments (Broadhurst, Simpson and Hardy, 1980; Haszeldine, 1981a). However, in the latter two works, crevasse-initiated minor delta sedimentation has been invoked to explain the regular interbedding of sediment. It is here proposed that these occurrences, and the similar cases outlined in this thesis, are the result of overbank, and not crevasse-derived sedimentation, since :

(1) such sequences can occupy entire inter-seam partings, a situation unlikely were sediments deposited by a prograding minor delta, and

(2) sedimentation in a crevasse-initiated, minor delta system is likely to be rather more erratic, even in a seasonal climate, leading to a rather less regularly-organized vertical sequence (see Chs. 9.3.4 and 9.3.5).

Distinguishing characteristics

Coarse-grained overbank deposits may be recognized fairly easily, both in outcrop and core, by the rhythmic alternation of lithologies, and distinguished from the more "proximal overbank" levee deposits by their finer grain-size (commonly interlaminated siltstone and claystone), entirely flat-lying aspect and by lateral relationships with other facies.

9.3.3 Siltstone-dominated overbank deposits

Description

Siltstone-dominated overbank deposits comprise massive or poorly-laminated, light grey-coloured siltstones, occasionally with either a sandy streak or with very thin (up to 5mm) regularly-spaced, claystone bands (Fig. 9.1). Such sequences, which may be at least 10 m thick, are laterally persistent over several hundred m, if not more. Sediments are largely level-bedded, though are occasionally inclined at a low angle (see Ch. 6.6.4.3, for example).

Siltstones contain abundant, well-preserved fronds and stems of pteridosperms and other plants (Plate 7.18), often inclined at all angles to bedding. Upright, *in situ* tree trunks are commonly preserved in these sediments (Plate 7.19), standing up to at least 2 m in height, and smaller plants (especially *Calamites*) and Stigmarian rootlets are often found *in situ*. Nodules of siderite (generally up to 10 cms in diameter) are common, and often concentrated on the fine-grained claystone partings, where present.

Sedimentary structures in the siltstones are rare, but occasional sharply-, erosively- or load-based sandstones up to

0.8 m thick may be present, containing small-scale trough cross-bedding and ripple cross-lamination (see, for example, Fig. 7.6).

The siltstones occur as elongate bands parallel to and within a few hundred m of minor distributary channel deposits (and occasionally those of major channels) in an upcurrent direction, and downcurrent grade into quiet-water claystones. They may also overlie such sediments, or those of swamps, and may be overlain by almost any other sequence recognized, though most commonly by swamp deposits.

The "fine-grained" and coarse-grained overbank deposits are closely related lithologically, and a spectrum of variation exists between the two. In this respect, the overbank deposit at Woodland O.C.C.S. (Ch. 6.5.2.2) is intermediate in character between the two. Limited palaeocurrent measurements from flattened plant fragments and inclined, *in situ* tree trunks indicate a moderate local dispersion around a strong vector mean, usually directed away from a nearby channel.

Discussion

These siltstones are interpreted in a similar way to the coarse-grained overbank deposits.

However, the important lithological distinctions between the two are considered to stem from the nature of the supplying channel, and its' discharge regime.

The massive siltstones are interpreted as having been derived largely from minor distributary channels and deposited from suspension, whereas the more regularly interbedded overbank deposits are thought to have been mostly deposited from major channels and deposited both from suspension and bedload traction

(Fig. 9.2, and compare Enclosures 5, 16, 18). Minor distributary channels have been shown to carry a comparatively fine-grained bedload and abundant suspended load (see Ch. 9.2.2) and inferred to have had a rather more erratic discharge pattern than that of the major channels by virtue of their mode of formation and operation. Thus, overbank material is likely to be finer-grained and more irregularly bedded, with a lesser and more variable "seasonal" signature (see Phoenix Quarry; Ch. 7.4.2.1). Upright trees, rooted into subsiding peat swamps, and drifting plant fragments,evidently stood a greater chance of survival in this setting than in any other, presumably as a result of rapid burial by silt-settling,mostly from suspension. Similarly the abundant presence of well-preserved plant remains probably reflects a limited period of entrainment and deposition from suspension. Plant material was probably derived from nearby, near-emergent, vegetated surfaces which were eroded into by the minor distributaries.

The presence of *in situ* vegetation within the overbank siltstones implies that the receiving basins were generally only 2-3 m deep, and received sediments at a rate roughly equal to that of subsidence. In this way, thick (10 m) sequences of siltstone-dominated overbank sediments could accumulate adjacent to long-lived minor distributary channels.

Sharply-based sandstones are probably the result of crevasse splay deposition, and with a more prominent contribution from crevasse splay sediments overbank sequences may pass transitionally into crevasse splay/minor delta-dominated deposits.

Siltstone-dominated sequences are not described as such from modern delta plain or alluvial plain environments, although it is possible that such sediments have been grouped with distal overbank clays. As far as the author is aware, no lithological distinction has been made between overbank sediments of major and minor distributary channels.

"Massive siltstones" were recognized in the East Midlands Coal Measures by Elliott (1968) and Guion (1978), and attributed to overbank deposition, but the possible association with minor distributary channels has not previously been considered.

Distinguishing characteristics

Overbank siltstones are distinguished both in oucrop and borehole core by their lithology, their occurrence in vertical sequences of up to 10 m, and by the abundance of well-preserved plant remains.

9.3.4 Distal crevasse splay/minor delta deposits

Distal crevasse splay/minor delta deposits comprise a coarsening-upward sequence or stacked series of sequences, varying up to 10 m thick. Deposits are laterally persistent over several hundred m, although variations in thickness may occur (see, for example Ch. 6.7.4.2 and Enclosure 8).

Sediments coarsen upward from claystones to siltstones or fine-grained sandstones (Plate 6.23) though commonly with a complex interlamination and interbedding of lithologies (Ch. 7.5.2.2), (Fig. 9.1). Siltstones often contain a sandy streak with ripple form sets, ripple cross-lamination, backflow and wave ripples, and may display abundant, small siderite nodules. Sandstones,

which usually contain muddy laminae, show similar ripple structures, loading features and occasional small-scale trough cross-bedding. Low-angle depositional dips are occasionally visible.

The uppermost parts of such sequences are often penetrated by *Stigmarian* roots and rootlets, and broken drifted plant remains are common throughout sequences. Evidence of bioturbation is contained in occasional *Planolites* and other burrows, particularly in lower levels.

The distal crevasse splay/minor delta deposits almost invariably overlie quiet water claystones and are in turn overlain medial/proximal sediments, swamp peats or channel deposits. In the basal Coal Measures, they may be overlain by quartz arenitic shoreline sandstones. The distal deposits pass down-palaeocurrent into quiet water claystones, and upcurrent into medial minor delta/crevasse splay sediments. Occasionally, deposits of distal feeder channels are contained within these sequences.

In three dimensions, the distal deposits often define a lobe-shaped outline, up to several hundred m in width and ? 1-2 kms in length (see, for example, Enclosures 7 and 8). Within these lobes, the maximum sequence thickness is found in the centre, tapering outwards.

Palaeocurrent measurements from current-generated structures indicate a moderate spread of directions, and wave ripples indicate largely north-south-directed wave motion.

In thin section, the sandstones are generally very fine-grained and poorly sorted.

Discussion

The "distal sediments" are interpreted as the deposits of minor mouth bars on a crevasse-initiated lake delta system. The upward-coarsening profile is characteristic of this distal setting, and produced by the progradation of minor mouth bars at the delta front, fed by crevasse and minor distributary channels which flowed across previously deposited medial and proximal deposits (see Chs. 9.3.5 and 9.3.6, and Fig. 9.2). Alternatively, a coarsening-upward sequence might represent the distal portion of a single crevasse splay deposit.

Minor delta lobes prograded over lake bottom fines and often coalesced to form platforms across which channels could flow towards a yet more distal locus of sedimentation (see Elliott, 1974, for a model of interdistributary lake/bay sedimentation). In this way, medial and proximal minor delta sediments may overlie distal deposits, but often do not in the non marine-influenced Coal Measures; in this setting, minor mouth bars were frequently capable of completely infilling shallow lacustrine basins. Subaqueous feeder channels were apparently operative in this setting.

Synsedimentary deformation features are suggestive of rapid deposition on the minor mouth bars, and an upward change in preserved sedimentary structures often reflects a gradual increase in current strength with shallower water. Backflow ripples were produced by eddies on the minor mouth bar front.

Wave ripples are interpreted as indicating northward, i.e., onshore-directed winds. Curiously, other than in the Basal Westphalian A succession, wave ripples are less common than might be expected in such environments (see, for example, Coleman and

Gagliano, 1964). This phenomenon has been explained by Haszeldine (1981a) as a result of generally low fetches in Coal Measure lakes. The lacustrine environment will be considered as a whole in Ch. 9.3.8.

Another feature somewhat at variance with models of minor delta progradation is the absence of a very high spread in palaeocurrent directions; this may simply be due to only limited palaeocurrent data. Minor mouth bars are well-represented in modern coastal plain settings, though proximal-distal relationships are poorly resolved (Coleman, Gagliano and Webb, 1964; McEwan, 1969; Donaldson, Martin and Kanes, 1970, among others).

Such environments have been recognized by several workers in the Coal Measures, for instance Elliott (1968), Heward (1976) and Guion (1978).

Distinguishing characteristics

The minor mouth bar deposits may be distinguished by their coarsening-upward nature, particularly superimposed upon quiet water claystones, and by the assemblage of contained structures and features; comparative abundance of nodules and wave ripples and comparative absence of large-scale cross-bedding, sharply-based beds and erosion surfaces.

9.3.5 Medial crevasse splay/minor delta deposits

Description

Medial crevasse splay/minor delta deposits display a similar character to the distal sequences, but rather than possessing an overall upward-coarsening trend, are composed of more interbedded silty claystones, siltstones and fine-grained sandstones (Fig. 9.1).

Vertical sequences are of similar thickness, i.e., up to 10 m, and deposits are laterally persistent over a few kms (see Enclosure 13). Individual beds, generally up to 2 m thick, are often of considerable lateral extent, but difficult to trace confidently between outcrops (Ch. 6.6.4.1).

The "coarsely" and irregularly interbedded sediments of the medial minor delta setting (Plate 7.2) contain a variety of bed contacts; coarsening-upward, fining-upward, sharply transitional, sharp and even erosive boundaries are present. Finer-grained sediments contain occasional non-marine bivalves, *Pelecypodichnus* traces and burrows, nodules and often a sandy streak. Sandstones contain abundant ripple cross-lamination, small-scale trough cross-bedding (in sets up to 0.5m thick) and synsedimentary deformation, and rarer internal erosion surfaces. Wave ripples rarely occur as do miniripples which were only observed at one locality in this study (Tanners Hall O.C.C.S.,; see Ch. 7.4.2.2). Deposits of feeder channels are contained within the medial minor delta sequences (see Chs. 6.6.4.3 and 7.4.2.2 for detailed examples).

Occasional *in situ* plants and rootlets occur, and the uppermost parts of sequences are commonly root- and rootlet-penetrated. Medial minor delta deposits usually overlie quiet water claystones, swamp peats or more rarely distal feeder channel deposits, and are overlain by proximal deposits, swamp peats or channel sediments. In the lowermost Westphalian A, quartz arenitic shoreline sandstones may overlie the medial minor delta sediments. Medial sediments pass down palaeocurrent into distal deposits, and upcurrent into proximal deposits. In three dimensions, they may occupy large

(several sq. kms; see Enclosure 13) areas and volumes, of uncertain but probably irregular shape.

Palaeocurrent measurements from current-produced structures indicate a moderate spread over areas of several hundred sq. m (see Enclosure 5, for example).

In thin section, sandstones are similar to those of distal deposits.

Discussion

The medial minor delta deposits are interpreted as the deposits of crevasse splays (sharply-based sandstones) and minor mouth bar lobes (coarsening-upward units) in interdistributary lakes or bays. The exact setting is considered up-palaeocurrent from the minor mouth bar-dominated distal environment described previously, but downcurrent from a highly erosive proximal/axial setting (Ch. 9.3.6). Thus, preserved sequences show a mixture of sharply-based and coarsening-upward units, reflecting comparative proximity to the crevasse source (compare Figs. 6.25, 6.30, Enclosures 5, 13).

Crevasse splays are considered to have been deposited predominantly by tractional currents, rather than by turbiditic underflows, as suggested by some workers (for example, Haszeldine, 1981a), since no sedimentary features diagnostic of turbidites have been found in these deposits. While turbidity currents are known to operate in lacustrine basins (see, for example, Sturm and Matter, 1978), they seem to be largely associated with stratified lakes possessing steep depositional slopes, a setting

not thought to be represented in the Coal Measures.

Subaqueous feeder channels occur within these medial deposits and minor distributary and crevasse channels are common within or overlying them (Plates 6.10, 6.31). These are considered to represent the principal modes of sediment transport to and across the area, augmented by unconfined or partly confined crevasse splays. Thus sediment, prograding out from an initial channel bank crevasse, is deposited by a combination of shallow channels, unconfined crevasse splays and minor mouth bars. Minor mouth bars are probably most important in the inital stages of progradation, and of only minor significance subsequently.

As mentioned previously, medial minor delta deposits often, but not always, overlie distal sediments, representing outward progradation of the crevasse delta system. Medial deposits are rarely if ever, overlain by sediments other than those of channel or swamp environments and may be considered as being positionally and temporally quite stable.

The medial deposits fit well into Elliott's (1974) model of interdistributary bay/lake infilling, though from his study it is evident that the medial setting is poorly understood. The detailed mode of infilling of modern interdistributary bays and lakes, between the distal, mouth-bar-dominated and proximal, erosive crevasse splay-dominated settings, is not well-known, and this is largely due to the present lack of detailed, *long term* studies of deltaic environments, and deep borehole data (to 10s m depth).

Crevasse splays are relatively well-known and documented (for example by Kruit, 1955; Coleman, Gagliano and Webb, 1964; Coleman, 1969; Arndorfer, 1973) and deposit lobe-shaped or elongate

bodies of sand up to 1-2 m thick and a few sq. kms in area. It is thus evident that such deposits could partially, or even completely fill the shallow floodbasins of the Coal Measures (see, for example, Fig. 6.36 and Chs. 6.7.4.3 and 7.5.2.3).

Crevasse splays and crevasse-filled shallow basins have been recognized from the British Coal Measures, for example by Guion (1978, Ch. 7) and Fatona (1980), but have never been placed in a satisfactory regional context.

Distinguishing characteristics

Medial minor delta deposits may be distinguished by their coarsely interbedded nature, the presence of both sharply- and gradationally-based beds of up to 2 m thickness and geometrical relationships. However, the more thinly-bedded sequences may be difficult to distinguish from overbank or levee deposits.

9.3.6 Proximal crevasse splay/minor delta deposits

Description

Proximal crevasse splay/minor delta deposits comprise units of fine-to-coarse-grained sandstone up to 7 m thick, with occasional thin (up to 0.10 m) partings of dark, carbonaceous claystone (Fig. 9.1). Sequences possess markedly erosive bases, and are laterally persistent over at least several hundred m. A fine-grained unit up to 2 m thick usually caps sequences of proximal minor delta deposits.

The sandstone contains trough cross-bedding and large trough-like scour surfaces up to 2.0 m in amplitude (Plate 7.21), internal erosion surfaces and ripple cross-lamination. Some troughs are partly or completely filled by siltstone, ripple cross-laminated sandstone or massive,unorganized sandstone containing abundant coaly plant remains.

Coaly "scares", large plant casts and sediment rafts and clasts are common throughout units, but most abundant near the base.

Proximal minor delta deposits overlie other lake/bay sediments, most commonly quiet water claystones, and/or those of swamps and levees. They are most commonly succeeded by swamp deposits. Up-palaeocurrent, the proximal deposits pass into channel sediments, and downcurrent into medial minor delta sediments. In a direction perpendicular to palaeoflow, the proximal deposits occupy a channelized hollow up to 3-400 m in width and 5-6 m deep. Parallel to the direction of palaeoflow, they downcut progressively in a downcurrent direction, from their upcurrent limit, and may occupy a spoon-shaped hollow in some cases (see Fig. 6.43, Enclosure 18). These deposits may extend in an up/downcurrent direction for up to 2 kms.

Palaeocurrent measurements from current-produced structures indicate unimodal palaeoflows with low dispersion.

Petrographically, sandstones are similar to those of channel sediments.

Discussion

These sequences are interpreted as the highly erosive, channelized or partly confined, proximal deposits of crevasse splays (Fig. 9.1). Such crevasses, caused by breaching of channel banks at high flow stage, caused erosion of channel bank and levee material as well as adjacent shallow basin deposits. The presence of fine-grained partings suggests that channelized scours were filled by sand and other sediment, probably during several depositional events.

The preserved structures indicate that disequilibrium conditions often existed between the sediment surface and depositing currents, in turn suggestive of an irregular discharge regime.

It is evident that the major crevasse splay channels may have been plugged quite rapidly in some cases, or may have operated as more persistent, long-lived avenues of sediment transport, supplying lacustrine delta systems. In this way, some exposures may show a character transitional between proximal minor delta sediments and the deposits of minor distributary channels.

Proximal crevasse splay deposits show considerable evidence of waning flow in the down-palaeocurrent direction; widening of the overall deposit (Fig. 6.43), subdued erosiveness and sedimentary structures, and the spoon-shaped scour profile (Enclosure 18). Thus, they pass downcurrent, perhaps over a distance of 1-2 kms from the supplying channel, into a less confined, lower-energy, medial environment characterized by thinner and less frequent sandstone beds, less evidence of erosion, the occurrence of gradationally based units and more widely-dispersed palaeocurrents.

The fine-grained uppermost part of proximal sequences is interpreted as abandonment deposits, laid down after cessation of coarse-grained sediment supply to the area. Commonly, abandonment seems to have occurred following complete infilling of a shallow basin, from the frequent occurrence of roots and rootlets in abandonment deposits and the presence of overlying coal seams.

Crevasse splays are known from modern environments to be channelized in their proximal parts, depositing narrow, erosively-based bodies of sand which generally become thinner, less erosive and wider as they splay out downcurrent (Coleman, Gagliano and Webb, 1964; Arndorfer, 1973). Proximal crevasse channels are known to pass downcurrent into subaqueous feeder channels and/or

complexes of crevasse splays, but as has been noted previously, the exact nature of this transition is poorly-known.

As stated in Ch. 9.3.5, crevasse splays are quite well-described from the British Coal Measures, and Guion (1978) in particular has noted the existence of channelized, erosive-based proximal crevasse splay deposits passing downcurrent into thinner, less erosive sheet deposits (see his Ch. 7, p. 335).

It is apparent that proximal crevasse deposits, being partly channelized, could have been included in the Channel Association; they have been retained in the Lake/Bay Association since they form part of the crevasse delta depositional sub-system. Similarly they are distinguished from the relatively minor crevasse channel deposits, which are probably the result of similar processes.

Distinguishing characteristics

Proximal crevasse deposits may be recognized by their sandstone-dominated nature, erosive and channelized base, downcurrent pattern of erosive downcutting and proximity to channel deposits. In good quality outcrop, they should therefore be easily identified, but in borehole core may be confused with distributary channel sandstones.

9.3.7 Passive lake margin deposits

Description

Passive lake margin deposits comrpise sequences of mainly claystones and siltstones, with occasional, thin fine-grained sandstones (up to 5 cms), overlain and underlain by coal seams (swamp deposits), (Fig. 9.1). In one direction the thickness of the clastic unit decreases to zero, passing laterally into swamp deposits. Thus the sediments of passive lake margins form a coal seam split, and increase in thickness from zero to several m away from the line of

split (Fig. 7.21).

The sediments themselves display few structures, other than parallel lamination; the entire sequence is commonly penetrated by rootlets and siderite nodules, and where not rootlet-penetrated often contains shells of non-marine bivalves.

As mentioned above, passive lake margin deposits are enclosed by and pass laterally into swamp sediments, and in the opposite direction into quiet water claystones. In the latter respect, an arbitrary limit of 3 m vertical thickness has been chosen to seaprate sequences of the two, since lithologies are identical. Passive lake margin deposits thus occur as elongate wedges of clastic sediment between the leaves of a split coal seam and parallel to the line of split.

Discussion

The lake or bay margins at which these sequences developed evidently received virtually no clastic sediment other than from suspension. Lakes formed as a result of accelerated subsidence of peat swamp areas (see Ch. 10), causing splits in seams of peat. The passive lake margin arose away from the influence of all channels and minor delta systems. An example of such a seam split was encountered at Ibbetsons O.C.C.S. Extension (Ch. 7.8.2.3).

Curiously, the author has encountered no accounts of peat seam splits in modern coastal plain environments, although it is clear that such features must occur.

Coal seam splits are well known from the British Coal Measures, and have been ascribed both in previous works, (e.g., Broadhurst, Simpson and Williamson, 1968; Elliott, 1969; Guion, 1978) and in this thesis to patterns of differential subsidence.

Distinguishing characteristics

Passive Lake margin deposits are distinguished from quiet water claystones by being enclosed between two seams of coal and comprising mainly rootlet-penetrated claystones, up to 3 m thick.

9.3.8 General considerations

A number of points regarding Coal Measure interdistributary lakes and bays are worthy of a further general discussion.

Regarding the depth of the Coal Measure basins, it is immediately apparent from the thickness of sequences separating root-penetrated horizons that these lakes and bays were quite shallow. Klein (1974) suggested a simple method of calculating the depth of water into which shorelines or delta prograded, which assumed that the infilling of most shallow basins is achieved "instantaneously" in the geological sense, thereby minimizing the possible effects of synsedimentary, compaction-induced subsidence. This method merely takes the thickness of a deltaic sequence or cycle, measured between recognizable deltaic abandonment deposits, as being equivalent to the depth of water into which the delta prograded. This method has been commonly applied in the literature, and Haszeldine (1981a), for example used it to calculate basin depths for the Coal Measures in north-east England.

It is here proposed that the method of Klein (1974) is often open to error as it stands, when applied to the Coal Measures and to similar sequences, for the following reason; in this study of Coal Measure sediments it has become apparent that great thicknesses of clays may accumulate at very slow rates over long periods of time in shallow lakes and bays. These bear no relationship to the depth of the basin immediately before its' final (and relatively

rapid) infilling, as represented by a coarsening-upward or similar sequence. Thus, for example, at Ibbetsons O.C.C.S. Extension (see Fig. 7.20) a 6 m claystone succession is overlain by a coarsening-upward sequence of only 2 m; clearly this does not imply that the basin of deposition was 8 m deep before infilling commenced.

On the other hand, it has been demonstrated that clay grade sediment may be mobilized under certain conditions, perhaps by crevasse splays (see, for example, Ch. 7.5.2.3), and it is also evident that a rootlet-penetrated or coal horizon need not quite require complete lake infilling.

It is therefore proposed that the depth of an interdistributary lake or bay such as existed in Coal Measure times may be estimated more accurately by measuring the sequence thickness between the first indication of traction current-derived sediment and a capping coal or seatearth, bearing in mind the provisos stated above.

In this way, the depths of interdistributary bays and shallow marine environments of the basal Westphalian A deposits, represented in the Marine Bands, were probably 5-15 m, and in the non-marine-influenced Coal Measure basins were generally up to 5 m, and exceptionally, 8 m. These water depths are supported by calculations involving wave ripple parameters (J. Allen, 1979; P. Allen, 1981).

The wave ripples in both the basal and productive Coal Measure sediments indicate wave fetches of perhaps 10-20 kms, and this is seen as the average width range of open stretches of water. However, it is apparent that the total width of lakes/bays, discounting the barriers formed by channels, swamps and other near-surface deposits, may often have been substantially greater.

The ironstone nodules common in Coal Measure lacustrine deposits are considered to result from precipitation of siderite and other carbonate minerals, in highly reducing geochemical environments associated with high sediment organic content. They are thus most commonly associated with slowly-accumulated organic-rich clays.

9.4 SHORELINE ASSOCIATION

Deposits of several environments may be grouped into this Association, mainly those of beach ridges, chenier ridges and washovers. Certain of these sandstones may have been affected by pedogenic processes.

9.4.1 Quartz arenitic sandstones of Shoreline and Pedogenic origin

Description

The shoreline deposits comprise bodies of quartz arenite sandstone up to 5 m thick, occasionally with thin shale partings.

These quartz arenite sandstones are laterally persistent over hundreds of m to a few kms, and exceptionally several kms (for example, in the case of the Tow Law Ganister; see Ch. 6.2.2.6).

The sandstones often appear structureless in outcrop, but may contain cross-bedding, ripple cross-lamination, wave ripples and undulating bedding planes. Commonly, the uppermost few cms of the quartz arenites are bioturbated and rootlet-penetrated and occasionally the entire unit may be penetrated by rootlets, (see Percival, 1981, for a fuller description of these lithologies).

The quartz arenites possess either gradational or abrupt lower

boundaries (in some cases irregularly noded), and sharp upper surfaces which may be flat, curved or undulating. They occur only in the basal Westphalian A, marine-influenced Coal Measures, overlie bay or channel sediments and are overlain by quiet water claystones, or rarely by swamp deposits. The quartz arenites pass laterally into bay deposits.

In three dimensions, quartz arenite bodies have sheet geometries and are commonly lenticular (see, for example, Fig. 6.7, regarding the West Butsfield Ganister, which is elongated approximately east-north-east-to-west-south-west). A limited number of palaeocurrent measurements indicate a general north-south palaeoflow orientation, a direction also shown by wave ripples.

In thin section, the quartz arenites are composed of 95-100% quartz (detrital grains and overgrowths), with minor amounts of heavy minerals, clays and carbonaceous material, and are commonly also very well-sorted (see Appendix 2, and Percival, 1981).

Discussion

The quartz arenitic sandstones are considered to have formed by shoreline reworking of previously-deposited channel and delta sediments, in very shallow or possibly emergent conditions, following abandonment of channel or minor delta systems. This reworking was probably achieved largely by waves, but from the interpretation of some of the quartz arenites as chenier ridges (Percival, 1981, Ch. 7), longshore currents also redistributed sediment.

From the sharp tops of the quartz arenite bodies and presence of overlying bay clays, it is evident that reworking occurred under conditions of low sediment supply and gradual subsidence, thus preserving the quartz arenites by ? permanent burial. The thin (< 1 m), entirely rootlet-penetrated "ganisters which often possess noded bases are interpreted as the result of pedogenic processes (see Chs. 4.3,

6.2.2.6, 10, 11 and Percival, 1981), but from their sorting characteristics may have been subject to wave reworking subsequent to their initial deposition as petrographically immature, ? crevasse splay sands.

The recognition of shoreline environments (after the work of Percival, 1981) forms the only direct evidence of the influence of basinal processes, other than the scant record of marine faunal remains in marine bands; waves such as may have developed in the closed lacustrine environments of the Productive Coal Measures are considered unlikely to have been capable of causing any significant reworking. Other than the work of Percival (1981) and a largely petrographic study by Hawkins (1978), no studies of Coal Measure environments have identified shoreline facies. Curiously, shoreline deposits in the Coal Measures seem confined to the lowermost Westphalian A, and have not been found in association with marine bands higher in the sequence, (discussed further in Ch. 10.3).

Mature, quartz arenite sandstones are commonly formed by current and wave reworking of sediments on modern shorelines (see Davis, 1979, and Heward, 1981), for reviews of clastic shoreline environments), particularly in association with deltaic deposits (Elliott, 1978). The tentative identification of chenier ridges is suggestive of longshore currents which caused redistribution and reworking of the basal Westphalian lower delta plain deposits.

Distinguishing characteristics

The quartz arenites may be distinguished both in outcrop and in core by their pronounced petrographic maturity, hard, well-indurated character and sedimentary structures/contacts.

9.5 SWAMP ASSOCIATION

This association comprises coals and shaly coals which accumulated in swamps under clastic sediment-starved and sediment-influenced conditions respectively.

9.5.1 Coals

Description

Seams of coal are generally up to 2.5 m thick, but exceptionally up to 4 m. The coal seams are mostly persistent over several 10s of kms, except in the basal Coal Measures where somewhat thinner coals (up to 0.8 m) are mostly persistent over distances of up to ? 10 kms.

The coal seams are mostly composed of bright coal, with minor amounts of dull coal and fusain, and occasional clastic "bands". A certain amount of mineral matter is also disseminated through the coal, and is represented by the seam's "ash content" (typically 5-15%). "Bands" within the coal (generally up to 5 cms thick) are most commonly composed of claystone or kaolinitic claystones, but similar thicknesses of sandstone, siltstone, or plastic, illitic clay also occur (see Ch. 6.7.4.1 for a case study involving most of these "band" lithologies). Coals are invariably underlain by root- and rootlet-penetrated sediments (with the exception of cannels; see Ch. 9.3.1).

The detailed nature and origin of coal seams has been reviewed in Ch. 4.1, and the Durham coals will be discussed again in Ch. 10.

Coals generally overlie lake/bay sediments, and more rarely channel or shoreline deposits. They are in turn overlain most commonly by quiet water claystones, though may be succeeded and/or eroded into by deposits of minor deltas or channels. Coals may pass laterally into shaly coals, quiet water claystones, passive lake margin deposits or shoreline sandstones.

In three dimensions coal seams are of sheet geometry and cover up to 100s (or even 1000s) of sq. kms.

Discussion

The Durham coals are interpreted as the largely autochthonous deposits of peat swamps, from their lithological character. These swamps developed through the prolific growth of hydrophytic vegetation on the shallowly-submerged (?<1 m) abandoned surfaces of minor delta lake infills, channels and shoreline deposits. The swamp vegetation acted as an efficient sediment filter, and only occasional thin layers of clastic material were allowed to settle on the surface, as decaying plant material accumulated with some clay grade material, deposited from suspension, and slowly subsided under its' own weight. Plant material accumulated largely *in situ*, but with a minor allochthonous component, from the occasional preservation of aligned plant stems on bedding planes.

From the frequent occurrence of quiet water claystones above coals, it seems likely that peat accumulation was generally terminated by subsidence overtaking the rate at which peat was accruing (see Ch.9.5.2), leading to deposition of lake/bay sediments.

Peat swamps are common in modern coastal settings, particularly on tropical coastlines where mangrove swamps may develop (Scholl, 1964; Anderson, 1964; Spackman *et al.*, 1976), and also on delta plains such as those of the Mississippi (Frazier and Osanik, 1969) and Niger rivers (Allen, 1965a).

Coals seams are of course, well-known from the British Coal Measures (see Chs. 2 and 4.1).

Distinguishing characteristics

Coals are instantly indentifiable both in outcrop and core by their lithological character.

9.5.2 Shaly Coals

Description

Shaly coal and dark-coloured, coaly shale up to a limit of 50% ash (the author's own arbitrary boundary) occur in units up to 4 m thick.

These sediments are composed of interlaminations of coal and claystone, preserve abundant flattened plant casts (which occasionally show preferred orientation) and are frequently seen to have been penetrated by rootlets. The shaly coals are transitional between coals and lake/bay claystones, and may often be found as discrete units within coal seams. Shaly coals are commonly, though not invariably, underlain by rootlet-penetrated sediments, and are generally overlain by lake/bay sediments.

In three dimensions, shaly coals are usually restricted in extent, occurring often as elongate wedges or lens-shaped masses of coaly shale, up to a few kms in length, particularly beneath, within or above coal seams, or more rarely as thin, widespread (over several 10s sq. kms) sheets.

Discussion

Shaly coals are interpreted as the sediments of rapidly subsiding peat swamps, whereby the rate of peat accumulation was unable to keep pace with that of subsidence and fine clastic sediment was mixed with whatever plant debris were accumulating (both drifted and *in situ*).

The occurrence of shaly coals in association with true coals reflects differing subsidence patterns. Where a coal seam is underlain by an inferior, shaly coal, as with the Main coal at Langley O.C.C.S. (Ch. 7.7.3), this implies gradual deceleration

of subsidence to a point where peat could accumulate relatively. Where a unit of shaly coal occurs within a coal seam, this is thought to reflect a temporary increase in subsidence (or alternatively, a failure of the swamp vegetation due perhaps to a forest fire), and where a coal is overlain by shaly coal passing transitionally up into claystones (the most common situation) this implies an acceleration of subsidence rate, due in many cases to autocompaction of the peat deposits themselves (see, for example, Fig. 7.23).

Modern swamp environments commonly preserve thicknesses of organic-rich clays or "peat and muck" layers (Coleman, 1966; Frazier and Osanik, 1969; Staub and Cohen, 1979, for example).

Inferior coals are well-known from the British Coal Measures, and even more so from the more allochthonous Permian "Gondwana" coalfields (for instance, in the Ecca Group of South Africa).

Distinguishing characteristics

Shaly coals are distinguished from other Coal Measure sediments, including true coals, by their lithological character.

9.6 MARINE BAND ASSOCIATION

9.6.1 Marine Bands

Description

Marine bands comprise dark-coloured, carbonaceous, well-laminated claystones (shales) with marine fossils (Fig. 9.1). Occasionally, beds of fine-grained sandstone or other lithologies are found containing marine fossils for example, at West Butsfield; Ch. 6.2.2.3.

These beds are generally less than 1 m thick, and thought to be laterally persistent, though not continuous, over several 10s or even 100s of kms.

The shales and their associated sediments are often highly sulphurous, and their most common contained fossils include *Lingula*, productid brachiopods, with occasional bivalves, nautiloids and goniatites. Trace fossils such as *Zoophycos* and *Planolites* are often present.

Many marine bands are thought to be traceable across much of central and southern Britain, and even across N.W. Europe. They most commonly succeed, and are in turn overlain by, non-marine quiet water claystones. Often a seatearth or coal horizon occurs a few metres below such marine bands.

Discussion

The marine bands are interpreted as the deposits of low-energy shallow (10-15 m water depth) marine incursions, possibly controlled by fluctuations in sediment supply (see Ch. 10.2). During such incursions, a part of the Coal Measure plain was inundated by the sea, and sedimentation was restricted to slow accumulation of clays.

Sandstones and other lithologies containing marine fossils may be explained as the deposits of other environments which were inundated by a marine incursion and colonized by marine fauna.

Marine bands are well-described from the British and N.W. European coalfields (Calver, 1968a) though there is little agreement on the origin of the marine incursions. This topic will be raised again in Ch. 10.2.

Distinguishing characteristics

Marine bands may be distinguished from all other facies by their lithology and by the presence of proven marine fossils. They are in many cases, however, still difficult to identify, since many such marine horizons contain only scattered, small (1-2 mm) *Lingula* shells as evidence of their marine (or near-marine) nature.

CHAPTER X - A SEDIMENTARY MODEL FOR THE DURHAM COAL MEASURES

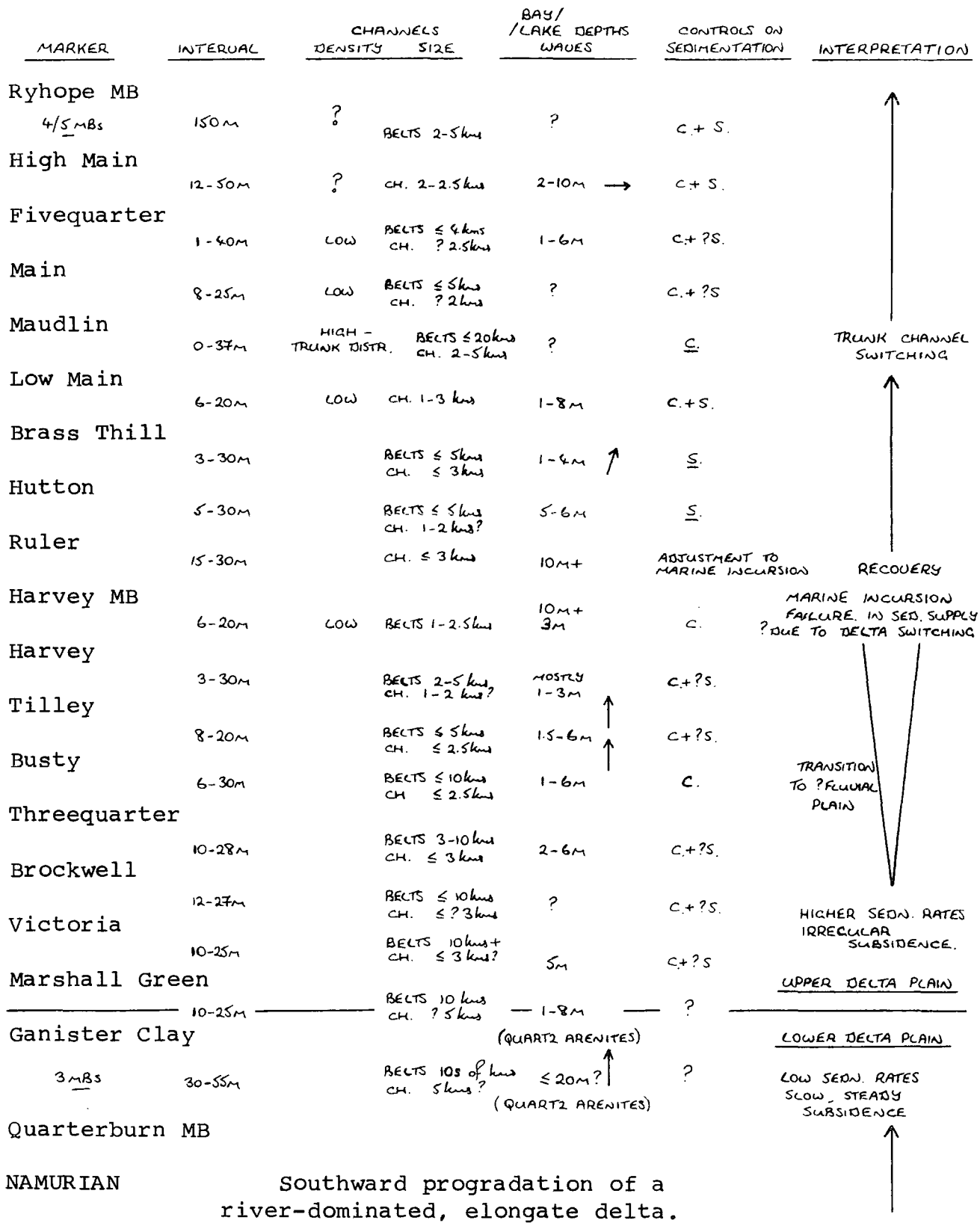
10.1 THE ENVIRONMENTAL SETTING

The Durham Coal Measures were deposited on a broad, flat, coastal, deltaic plain characterized by having virtually no palaeoslope or relief (Fig. 9.2). Indeed, there is only occasional evidence to suggest that the sediment surface was ever emergent. This delta plain environment was crossed by a trunk distributary channel system in which individual ? sinuous channels, perhaps 5 kms wide, wandered across 20 km wide channel belts and fed a system of sinuous, major distributaries up to 3 kms wide which were contained within 5-8 kms-wide belts (Fig. 10.1). Major distributaries in turn fed a network of minor distributaries which were often sinuous, generally up to 100 m wide and only occasionally developed meander belts.

Minor distributaries supplied lacustrine deltas which built out into shallow, unstratified, eutrophic lakes (2-8 m deep) with wave fetches of perhaps 20 kms, although the total width of these lakes was probably considerably more (Fig. 10.1). Lakes were filled by minor delta progradation and/or by overbank sedimentation, and peat swamps were able to develop on near-emergent sediment surfaces. In the lowermost Westphalian A, these swamps were comparatively restricted in extent (up to 10s of sq. kms), but in the productive Coal Measures became much more widespread (up to 1000s of sq. kms) and longer-lived, although were undoubtedly diachronous in their development. Peat accumulated largely *in situ*, but with some introduction of drifted plant and clastic debris.

Fig.IO.I

EVOLUTION OF THE COAL MEASURE ENVIRONMENT IN THE DURHAM AREA



ABBREVIATIONS - MB - MARINE BAND
CH. - CHANNEL
C. - COMPACTION-INDUCED SUBSIDENCE
S. - STRUCTURALLY-INDUCED SUBSIDENCE

In lowermost Westphalian A times, the delta plain was open to marine influence, and abandoned channel and interdistributary bay fill sediments were often reworked by storm waves and longshore currents to form quartz arenitic shoreline sand bodies (Fig. 10.1).

Several times during the Westphalian, the Coal Measure plain was inundated by low-energy marine incursions, which led often to the development of widespread, anoxic, shallow marine conditions (10-15 m water depth).

The environment is considered to be a deltaic, as opposed to fluvial, plain, for the following reasons:

(1) there is little evidence of subaerial exposure, and so the plain was probably rarely above water level,

(2) channels were similarly submerged, from the strong predominance of subaqueous, as opposed to subaerial, levees,

(3) palaeocurrent patterns are more dispersed than would be expected on a river floodplain, where overbank flows might travel approximately parallel to source channels,

(4) the proportion of the sedimentary succession penetrated by roots and rootlets (about 10%), is rather less than would be expected in a fluvial plain environment,

(5) the association of widespread (10s of kms wide) lakes separated by relatively narrow (up to a few kms wide) channels which show considerable indication of being distributaries (downstream bifurcation, frequent avulsion, relatively low width/depth ratios) is not considered indicative of a fluvial plain environment, and

(6) the occurrence of marine bands is not considered reconcilable with a fluvial plain model.

In the coastal environmental models of Horne *et al.* (1978), fluvial plains are characterized by sedimentary sequences containing a high proportion of channel sandstone; this is not considered a valid distinguishing criterion, since the proportion of channel sands in a fluvial or delta plain sequence will depend to a large extent on the rate of subsidence, relative to sedimentation (Allen, 1978).

In a recent paper regarding some Westphalian coal-bearing rocks from Nova Scotia, Gersib and McCabe (1981) interpreted the environmental setting of these rocks as a fluvial plain, rather than a deltaic plain, on the basis of a lack of deltaic deposits or marine fauna, and on the overall stratigraphical context of the sequence. Gersib and McCabe (*op. cit.*) concluded that "alluvial plains with extensive lakes may be difficult to discriminate from the deposits of an upper delta plain unless the regional sedimentary sequence is examined". The present author would contend that such environments may be quite confidently separated on the basis of field observations, by using the six criteria mentioned above.

The climate of N.W. Europe in Westphalian times is considered to have been humid tropical or subtropical, as contended by Schopf (1973), and to have possessed a marked seasonality, as suggested by Haszeldine (1981a).

10.2 CONTROLS ON SEDIMENTATION AND PEAT ACCUMULATION

Sedimentation in the Durham Coal Measures is considered to have been governed by the balance between two factors; sediment supply and subsidence.

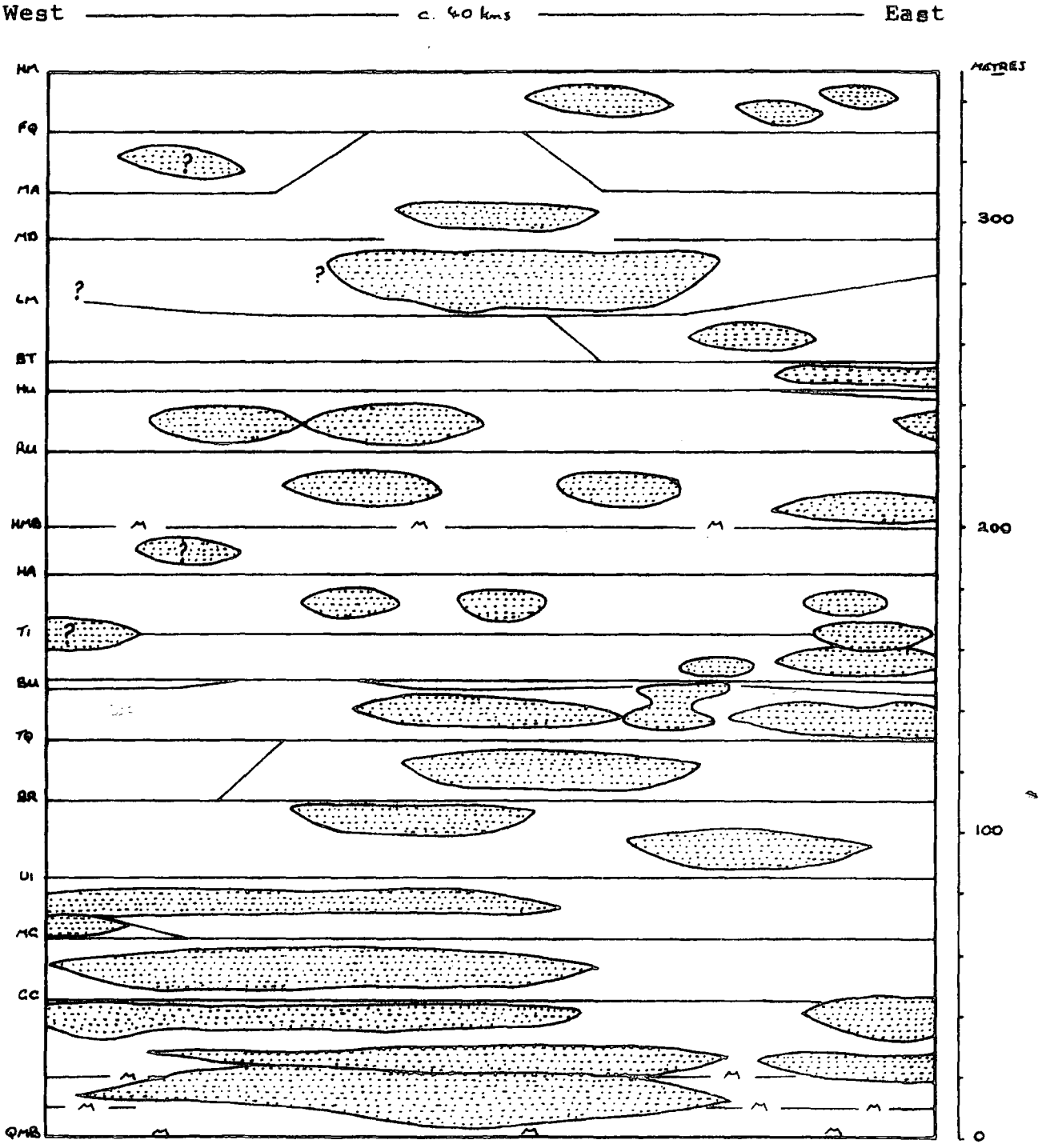
Epeirogenic subsidence is considered to have been very slow (an *average* of 7-10 cm/1000 years, estimated by Haszeldine, 1981a, probably greatly overestimates actual rates), but was accelerated locally by structural and palaeotopographical controls during the deposition of the productive Coal Measures.

Relative compaction rates of peat and sand, and their consequent palaeotopographical expression, were often the dominant controls on subsidence. Channel sand bodies, which were comparatively uncompactable, subsided slowly and formed relative topographical highs, which were avoided by subsequent channels, and thick peat (and to some extent, clay) sequences compacted rapidly, thereby forming topographic hollows into which channels later avulsed. This pattern of subsidence led to the development of a vertically offset pattern of channel positions (Fig. 10.2), and to the operation of a "see-saw" effect of alternate rapid and slow subsidence across a given area through a number of successive intervals (see Fig. 6.23, for example).

Superimposed upon the palaeotopographical control was a structural influence, caused by activation or reactivation of lines of crustal weakness across parts of the coalfield, in certain cases at several times during the Westphalian A and B (*cf.* Fisk, 1944, on the Mississippi delta plain), perhaps particularly those relating to the system of Lower Carboniferous structural "hinge lines" (Fig. 2.7). This led to the development of elongate, graben-like

Fig.IO.2

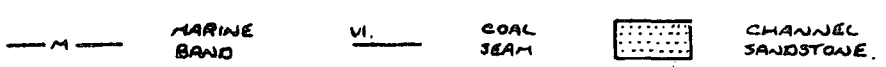
CHANNEL SANDSTONE ARCHITECTURE OF THE DURHAM COALFIELD



N.B.I. The horizontal axis of the section represents an east--west line across the coalfield at latitude NZ50.

2. Positions of some channel sandstones in the extreme west are speculative, due to lack of information.

3. For Key to stratigraphical abbreviations, see Figs. 6.I and 7.I.



depressions down which channel courses were funnelled, leading in some cases to a vertical stacking pattern of channels (Fig. 10.2). Vertical stacking of channels is not thought to result from reoccupation of relict channels, or the relative ease of erosion of channel sands, since these channel deposits are commonly separated by coal seams and other sediments.

On a more local scale, minor synsedimentary faulting was probably quite common, induced by overpressured/under-compacted conditions in lake/bay sediments.

Excluding palaeotopographical and structural controls, the architecture of sedimentary sequences was governed by sedimentary processes. Major distributaries were probably formed by crevassing of trunk distributary banks, and occasionally these crevasses led to complete channel avulsion (see, for example, the "Low Main Post"; Ch. 7.6). Crevassing of major distributary banks led either to channel avulsion or to the development of minor distributary or major crevasse channels which prograded out into shallow lakes and bays. At the same time, overbank flooding of trunk, major and minor distributaries during periods of flood stage led to deposition of abundant levees and more distal overbank sediments in interdistributary areas.

From the author's studies of Coal Measure interdistributary environments *in three dimensions* (see, for example, Ch. 7.4.2.2), it is thus apparent that two processes were responsible for lake/bay infilling, crevasse-initiated minor delta progradation and overbank sedimentation, a conclusion also reached by Elliott (1974) regarding the infilling of modern interdistributary lakes and bays. Of these, minor deltas were probably most important, but overbank processes are thought to have also made a significant contribution. Minor

delta progradation was probably quite rapid (? 100s of years for the active life of a single lobe), whereas the thick overbank sequences described in this thesis accumulated rather more slowly through long-term channel stability (1000s of years). As has been mentioned previously, details of interdistributary lake/bay infilling, and their resultant sedimentary sequences, are poorly known, and the data in this thesis may to some extent help refine the model of Elliott (1974).

Infilling of lakes (which is considered to have taken 1000s of years from the time of their initial formation) led to abandonment of minor distributary, and hence minor delta, systems, and on abandoned, near-surface substratas hydrophytic swamp vegetation became quickly established. *Calamites* was often the pioneer vegetation which colonized new areas, and was swiftly followed by lycopod-dominated communities.

Thus established, peat swamps were often very long-lived, existing for up to 10,000s of years at any one locality. The development of peat swamps was, however, strongly diachronous, as a result of the locally variable subsidence pattern. Swamp peat accumulation was generally terminated through drowning of the swamp, leading to the development of shallow lake/bay environments and the commencement of another sedimentary cycle.

The accumulation of peat in Coal Measure swamps is considered to have been largely a function of the rate of subsidence. Coals above sandstone-dominated channel sequences are generally thin and low in ash content, whereas those overlying finer-grained sequences tend to be thicker and to contain more ash and clastic partings. From this, it is evident that the thickest peats developed over rapidly-compacting and - subsiding clay/peat sequences (see, for

example, Ch. 6.7.4.1).

However, this relationship is complicated by the effects of very rapid subsidence, which was often greater than the rate at which peat could accumulate. In both the detailed case studies of coal seam and inter-seam thickness variation undertaken in this thesis (Deborah O.C.C.S. and Ibbetsons O.C.C.S. Extension; see Chs. 6.6.4.3/ 6.7.2.6/6.7.4.2 and 7.8.2.3/7.9.2.3 respectively), the thicknesses of coals have been shown to vary both directly and indirectly with the rate of subsidence during deposition of the underlying interval, as implied by sequence thicknesses. Similarly in areas of inferred, structurally-induced accelerated subsidence, seam thickness and quality has been shown to deteriorate.

Thickest accumulations of peat, and hence of coal, are associated with moderately rapid subsidence. Thus, the thickened, united coals at the margins of seam splits are best considered as ? belts of moderate subsidence bounding areas of rapid subsidence where peat swamps were drowned. From this deduction, it is evident that patterns of subsidence within subsiding shallow basins were very irregular, and are difficult to predict.

This study has shown that the density of channels operative in any stratigraphical interval of the Coal Measures varied considerably through time. Discounting the basal Westphalian A deposits, on which little information is available, no fundamental changes in channel type occur throughout the preserved sequence; the channels of the "Low Main Post" are considered to be only slightly larger than the norm, and probably little different in morphology.

According to the "geomorphic threshold" and "episodic behaviour" concepts of Schumm (1977, 1981) sedimentary sequences

of most fluvial systems may be expected to show changes in channel style as a result of changes in source area behaviour and also as a natural response to geomorphological processes. Changes in basinal subsidence rates may also be important, but in the case of the Durham Coal Measures are not considered to have produced the changes in channel density (Ch. 10.3). There are no significant changes in sandstone petrography through time.

It is possible that the "Low Main Post" reflects the response to a "geomorphic threshold" in the source area. However, it is considered more likely that the distributions of this and other channels were controlled by the process of distributary channel switching across the wide Coal Measures plain (Ch. 10.3). Thus, the "Low Main Post" may be regarded as the deposit of perhaps the largest "trunk" distributary crossing the plain, which probably changed both position and size frequently through time.

The origin of the Westphalian marine incursions is poorly understood. One favoured contention is that the marine bands of the British Carboniferous, or some of them, were produced by eustatic rises in sea-level (Ramsbottom, 1979, 1981). Ramsbottom, indeed invokes 50 m+ of overall sea-level rise through Westphalian A times, to explain the lack of evidence for any sea-level falls between marine incursions.

This hypothesis has recently been challenged by Haszeldine (1981a), who presented an alternative model where marine bands resulted from the failure of sediment supply to part of the Coal Measure

plain on a regional scale, allowing shallow, low-energy marine incursions to take place. Haszeldine, however contended that fluctuations in sediment supply were controlled by source area effects, and not by deltaic switching.

The almost ubiquitous presence in the Durham coalfield of a thin coal or seatearth a few metres (or less) below marine bands, succeeded by a thick sequence of claystones, suggests that marine or near-marine conditions were only established following failure of sediment supply, i.e., on subsiding swamp areas. The marine bands are better-developed in the central Pennine coalfields, and this is probably a simple function of more rapid subsidence in those areas (see Haszeldine, 1981a).

Furthermore, there is substantial evidence that global sea-levels through Upper Carboniferous times were dropping, rather than rising, in response to the development of extensive Gondwanaland ice-sheets (Frakes, 1979; Vail, Mitchum and Thompson, 1977). This is hardly compatible with the Ramsbottom (1981) model of eustatically rising sea level.

It is thus considered that the rate of sediment supply relative to that of basinal subsidence, superimposed upon long-term sea-level lowering, was largely responsible for the development of Westphalian marine bands, as suggested by Haszeldine (1981a). However, this study has found no conclusive evidence of source area controls on sediment supply, and it is thought that fluctuation in sediment supply may be adequately explained by processes of deltaic sedimentation (i.e. delta switching, see Ch. 10.3). Additionally, tectonic or eustatic factors may have influenced the development of certain marine bands.

Marine faunas contained with a given marine band on a national scale need not represent a single marine incursion or a single delta switching event, since it is apparent that any marine incursions occurring over the same broad period of time are likely to be represented by similar fossils.

Excluding the basal Westphalian A marine bands, which show evidence of wave and longshore current reworking (in the form of quartz arenites and "ganisters"), the Westphalian marine incursions did not cause basinal processes to have any pronounced effect on the Coal Measure environment, and the "marine band setting" may simply be regarded as a drowned upper deltaic plain. Lack of sedimentation probably meant that trends of accelerated subsidence did not develop, and so the submerged, quiescent sediment surface subsided very slowly until sedimentary progradation began to reconstruct the delta plain "platform". Such a model explains the apparent paradox created by the time involved in the formation of marine bands (10^4-10^5 years, according to Haszeldine, 1981a), and yet the very shallow depth of marine incursions (5-15 m).

In summary, sedimentation of the Durham Coal Measures was controlled on the regional scale (100s of sq. kms) by patterns of deltaic sediment distribution, on the medium scale (10s of sq. kms) by a combination of structurally- and compaction-induced subsidence and on the small scale (kms) by local sedimentary processes.

10.3 EVOLUTION OF THE COAL MEASURE ENVIRONMENT

It is evident from this study that the Coal Measures depositional setting in the Durham area underwent substantial change at various times during the Westphalian. The most fundamental change occurred in early Westphalian A times, and involved a transition from a marine-influenced, lower delta plain environment to a more terrestrial, upper delta plain setting (see Chs. 6.2 and 6.3, Fig. 6.11).

This environmental transition, which was effectively complete by the time of accumulation of the Marshall Green coal, was reflected in the sedimentary sequence by the following features:

(1) a change in interdistributary character from moderate depth (up to 15 m), marine-influenced bays around which sediment was reworked by waves and longshore currents to form shoreline sand bodies, to shallow (mostly up to 6 m, but occasionally, 8 m), largely enclosed, freshwater lakes, entirely unaffected by basinal processes,

(2) a change in the extensiveness of peat swamp environments from ? elongate areas several kms long to vast areas of up to 1000s of sq. kms,

(3) a complete lack of marine bands throughout much of the Westphalian A sequence, in comparison to their relative abundance towards the base of the sequence, reflecting an overall increase in sedimentation rate.

(4) a possible change in character of major distributary channels from low to moderate/high sinuosity,

(5) the advent of non-marine bivalves, in the Durham area, at about the time of accumulation of the Ganister Clay coal, and

(6) A transition from very slow, epeirogenically-controlled subsidence, which gave rise to the markedly condensed Namurian and basal Westphalian A sequences, to a more irregular and often much more rapid pattern of subsidence, brought about largely by the increase in overall sedimentation rate and the development and compaction of thick seams of peat.

The change in environmental setting during lower Westphalian A times is considered to be a result of gradual southward progradation of an Upper Carboniferous "Pennine delta" system, which had been active since perhaps the time of the Dinantian/Namurian boundary, but which prograded quite slowly across its' very shallow, marine receiving basin (see Ch. 6.2.4, Fig. 6.11). Following the establishment of upper delta plain conditions in the Durham area, the area remained much the same for several million years, affected by only occasional, low-energy marine incursions which were possibly caused by failure of sediment supply.

In the uppermost part of the Westphalian A sequence and through much of Westphalian B, the density of major channels active over any one interval is noticeably reduced in comparison to the greater part of Westphalian A. As far as it is possible to tell, channels are of similar size and morphology throughout the succession. The reduction in channel density might be due to

(1) an increase in subsidence rates, or

(2) a decrease in the sediment supply to the area.

Regarding the first alternative, there is little general increase in the depths to which interdistributary lakes were allowed to subside, and no evidence that channels were vertically stacked to any greater degree than before. Furthermore, it is apparent from the inferred depths of the Westphalian marine incursions that any substantial increase in subsidence rates would have led to permanent flooding by the sea (although it seems that *local*, structurally-induced, accelerated subsidence was an important factor, particularly in Westphalian B times).

It is thus considered that the decrease in channel density towards the end of Westphalian A times was the result of a decrease in sediment supply to the area, caused by either source area effects or by delta switching processes. Of these two alternatives, the latter is favoured, since there are several lines of evidence to suggest that conditions in Upper Westphalian A times were becoming progressively more terrestrial, perhaps a precursory stage to large-scale delta switching;

(1) occurrences of kaolinitic claystones, interpreted in many cases to be the result of pedogenesis in partly-drained conditions, are restricted to Upper Westphalian A,

(2) the only two recorded occurrences of subaerial de siccation cracks in the Durham Coal Measures are from the sediments enclosing the Tilley coals (Deborah O.C.C.S., and Buckhead O.C.C.S., Chs. 6.8.2.1 and 6.7.4.4),

(3) swamp paleosol profiles in the Upper Westphalian A display vertically elongated siderite nodules, a feature indicative of partial drainage (see Ch. 4.3),

(4) Upper Westphalian A lakes were often only allowed to develop 2-3 m water depth before being infilled,

(5) the proportion of the sedimentary sequence which is root- and rootlet-penetrated is noticeably higher in the Upper Westphalian A than elsewhere in the sequence, and

(6) considerable evidence exists for the development of minor distributary meander belts at this time, a feature which would require persistent conditions of near-emergence.

It is thus proposed that the Harvey (=*VANDERBECKEI*) Marine Band was formed in the area of N.E. England as a result of large-scale delta switching, following build-up of the sediment surface to almost fluvial plain elevation, and it is possible that other Marine Bands were formed by similar processes, though the evidence for emergence is these latter cases is not obvious. Such a cycle of evolution could perhaps be represented in terms of sequence and megasequence models (*cf.* Heward, 1976, 1978).

There is a general increase in the thickness of coal seams in the Westphalian B Coal Measures of the Durham area, and this is seen as a reflection firstly of increasing environmental stability, and secondly of the above-mentioned lower level in channel density (and by inference, lower level of deltaic sedimentation). The upper delta plain of Westphalian B times is considered to have operated well into Westphalian C times, (excluding the records of a few marine incursions), since there is no evidence in the Durham area of the transition towards more arid, terrestrial conditions thought to have occurred in Upper Westphalian C times across Britain.

10.4 EXPLORATION/PRODUCTION MODELS

As mentioned previously in Ch. 3, depositional models for coal exploration and production have been produced by Horne and co-workers for Upper Carboniferous coal-bearing sequences of the U.S.A. (Ferm, 1974; Horne *et al.*, 1978; Howell and Ferm, 1980).

It has become apparent from some recent publications, however, that these models are not as widely applicable as was first thought (see review by Flores and Ethridge, 1981).

In the models of Ferm *et al.*, lower delta plain sequences are characterized by a low proportion of sandstone and thin, widespread coals with irregular patterns of sulphur distribution, and those of upper delta plains/fluvial plains by a higher proportion of sandstone, and thick, laterally discontinuous coals with low sulphur contents.

In the Durham coalfield, lower delta plain coals are thin and laterally discontinuous, reflecting relatively low general rates of sedimentation with respect to subsidence, and upper delta plain coals are thick and display great lateral persistence, reflecting establishment of long-lived diachronously-developed peat swamps. In the latter case, variations in seam thickness were caused by the variable rate of subsidence (itself a result of the development of upper delta plain conditions), rather than by the influence of channels, as in the models of Horne *et al.* (1978). Sulphur contents of coals are highly variable, and do not seem to bear any relationship to depositional setting. Furthermore, the upper delta plain coals of the Durham coalfield were controlled by structural

influences as much as by depositional processes. Clearly, the environmental models of Ferm *et al.*, do not apply to the Durham Coal Measures.

An alternative exploration/production model is presented in Fig. 10.3, and may be applicable to other coalfields of northern Britain. In it, thickest coals are associated with:

(1) an upper delta plain, rather than lower delta plain, environment,

(2) moderately high subsidence induced by rapid compaction of thick clay/peat sequences, and

(3) lack of, or reduced, structural control on subsidence.

Sulphur contents of coals are considered to be a result of early diagenesis, and are not of environmental significance in this case.

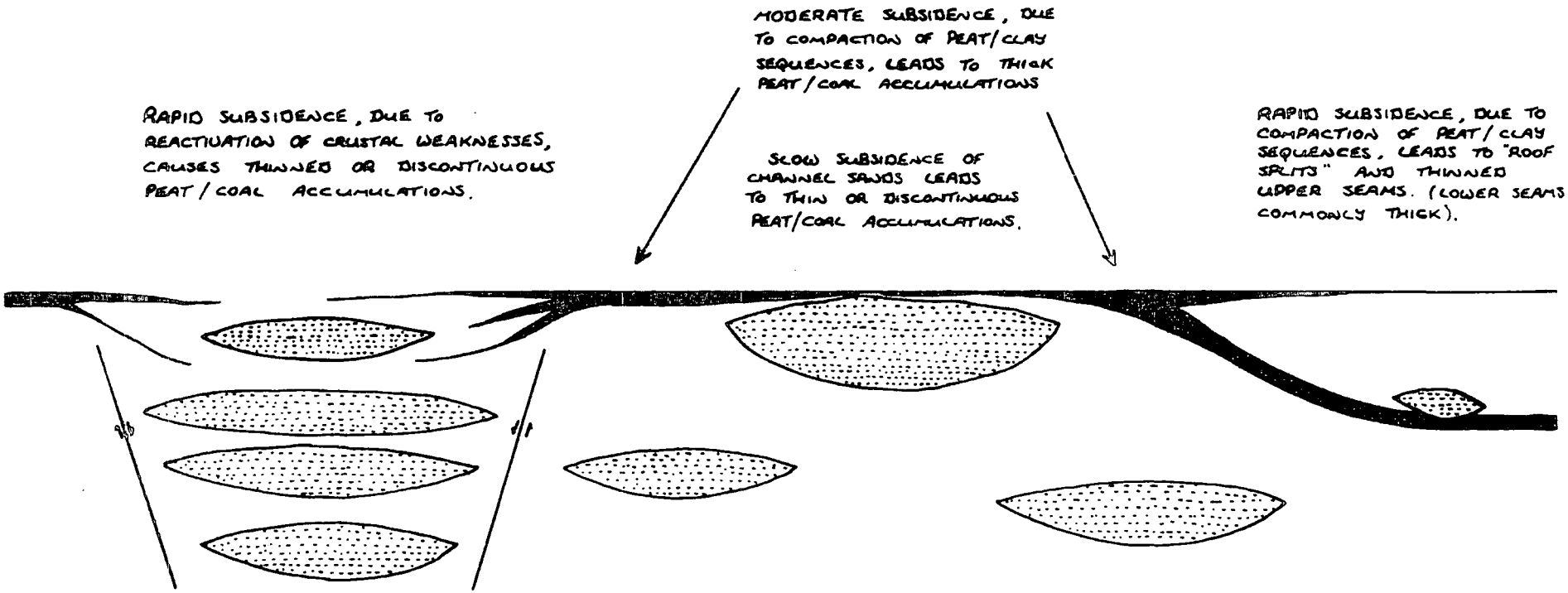
10.5 STRATIGRAPHY

Stratigraphical subdivision of the Durham Westphalian sequence is based on a number of horizons which have very little chrono-stratigraphical significance (see Ch. 5). Coal seams represent diachronous development of peat over 10,000s of years, marine bands took perhaps 100,000 years or more to accumulate and non-marine marker bands might be inferred to represent similar periods of time. Nevertheless, these are the only available stratigraphical markers, with one possible exception; some of the extensive upper delta plain channel sandstones, particularly the "Low Main Post", may represent the most rapidly formed deposits and consequently the most valid datum planes in the Durham Coal Measures. The life of

AN EXPLORATION/PRODUCTION MODEL FOR THE DURHAM COAL MEASURES

Structurally-controlled subsidence

Compaction-induced subsidence



CHANNEL SAND BODIES VERTICALLY STACKED

CHANNEL SAND BODIES VERTICALLY OFFSET.

CHANNELS ATTRACTED INTO AREAS OF RAPID SUBSIDENCE MAY CAUSE PARTIAL OR TOTAL

the "Low Main Post" channel system *in one area* was estimated as 15,000 years (see Fig. 7.18), and thus even allowing for a certain amount of diachroneity in the deposition of the "Low Main Post", this is clearly a geologically instantaneous event. Unfortunately, there are few if any, other laterally extensive, upper delta plain channel sandstones in the Durham sequence.

10.6 SANDSTONE PETROGRAPHY AND DIAGENESIS

The petrography of the Durham Coal Measure sandstones has been severely affected by post-depositional modification. Despite this, and the relative petrographic uniformity of these sandstones, it has been possible to make some conclusions from petrographic studies.

Sorting is considered to reflect depositional environment to some extent; highest sorting coefficients are associated with mineralogically mature, shoreline sandstones, moderate sorting characterizes sandstones of crevasse channels, levees and some crevasse splay environments and those of most crevasse splays and channels are poorly sorted.

Diagenesis of the Coal Measure sandstones is also environmentally-realted to some extent; while the presence of early quartz and kaolinte/illite cements is almost ubiquitous, finely crystalline siderite has been found to be associated with an initial high organic content, a tentative identification of chamosite has been made from a marine-influenced sandstone, and the presence of coarsely crystalline kaolinite and dolomite/calcite cements may also be environmentally specific. There is much potential for further work in this respect.

The petrography of the sandstones implies a distant mixed source area, containing granitic, low grade metamorphic and sedimentary lithologies. A limited amount of recycling is indicated by occasional rounded, recycled grains with hematite dust rims underlying multiple and abraded overgrowths (Heward and Fielding, 1980).

Petrographic differences between samples of individual sandstones can be attributed to grain size, diagenetic dissolution and replacement, problems of identifying untwinned feldspar from quartz and the presence of intraformational rock fragments (Odom, Doe and Dott, 1976; Blatt, Middleton and Murray, 1980; Wilson and Pittman, 1977; Heward and Fielding, 1980).

It is thus considered that the main source area for the Pennine Westphalian Coal Measures was the Caledonian mountain chain to the north and north-east, with perhaps a certain amount of recycling of Devonian and early Carboniferous sediments causing minor contributions from slightly less distant sources.

10.7 KAOLINITIC CLAYSTONES

Kaolinitic claystones, recognized extensively from the Upper Westphalian A of the Durham coalfield in this study, are interpreted as the products of subsurface pedogenic and very early diagenetic crystallization of kaolinite, perhaps in connection with fluctuating water-table levels. In the same part of the sequence, considerable evidence exists for the gradual development of more terrestrial, perhaps occasionally emergent, conditions than was typical during Westphalian times in this area (see. Chs. 6.7-6.9 and Ch. 10.3).

It is thus interpreted that the extensive development of kaolinitic claystones in the upper part of the Westphalian A sequence of the Durham coalfield was due to the progressive, but only temporary, development of partially-drained ground conditions. This interpretation is supported by observations of the inter-Tilley kaolinitic claystones at Mown Meadows and Cabin House O.C.C.S.'s where this lithology has been shown to pass laterally into normal clastic lithologies in association with an increase in local subsidence rates (Ch. 6.7.4.3 and Fig. 6.36). It is perhaps also significant that some seatearths encountered during this study, both in Westphalian A and B sequences, display characteristics transitional between those of "normal" Coal Measure palaeosols and kaolinitic claystones (see also Ch. 10.8).

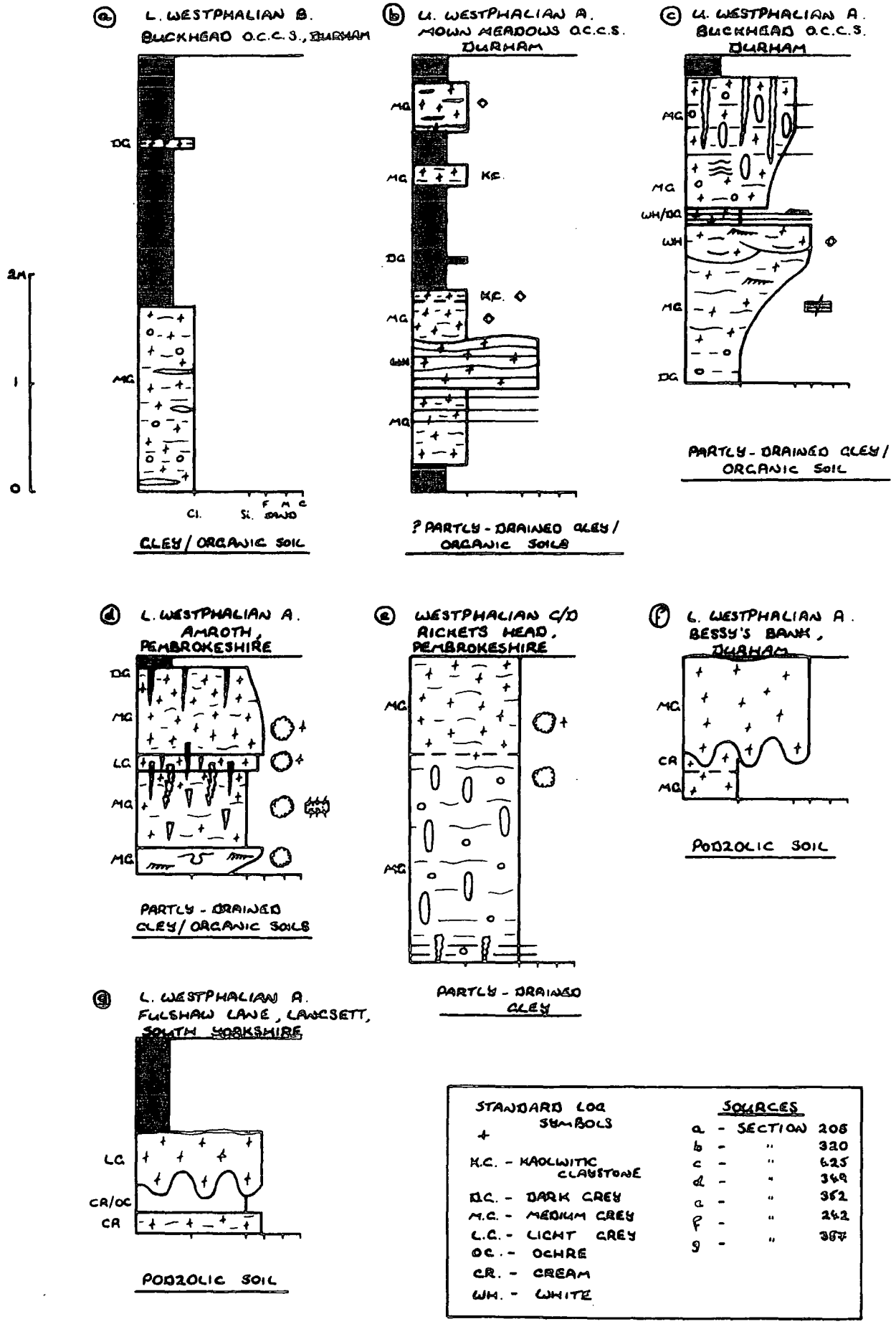
10.8 PALAEOSOLS

The vast majority of Coal Measures palaeosols, as might be expected, display great similarity with modern groundwater gleys, and generally show few signs of vertical drainage. These are medium-dark grey-coloured, rootlet and siderite nodule-bearing units with little or no vertical profile (Fig. 10.4a).

Occasionally, notably in the Upper Westphalian A sequence, palaeosol profiles display evidence of partial drainage or emergence, development of kaolinitic claystones, vertically elongated nodules, colour and other vertcial profile changes and de siccation cracks (Fig. 10.4 b-c). These palaeosols are associated with the progressive development of better-drained ? fluvial plain conditions, inferred from other sediment features, and may be compared with similar paleosols from other coalfields (Fig. 10.4 d-e).

Fig. IO.4

COAL MEASURE PALAEOSOLS



In the basal Westphalian A deposits of Durham and other Pennine coalfields, associated perhaps with wave reworking of previously-deposited sediment and local fluctuations in water-table, a number of podzolic soil profiles occur ("ganisters"), characterized by bleached, eluvial, quartz-enriched A horizons and clay-enriched, illuvial B horizons (Fig. 10.4 f-g). These occur only in the lowermost part of the Westphalian sequence, where it is inferred that shoreline reworking of sediment was possible.

Histosols, or organic soils, are of course abundantly represented in the Coal Measures as coals; these have been dealt with previously. Inceptisols, or incipient/partial soil profiles, are also common, as might be expected (see Ch. 4.3).

Fluvisols are not thought to be represented in the Durham Coal Measures, since channel banks, levees and surrounding areas were almost all subaqueous, largely preventing plant colonization. Some of the Westphalian C sequences examined in Pembrokeshire, however, may represent Fluvisol palaeosols (see Ch. 11.3.4).

Vertisols are similarly considered to be absent from the British Coal Measures, since virtually no expandable clays have been detected from Coal Measure sequences (see Ch. 4.3). Thus the vertical cracks encountered in palaeosol profiles of South Wales and Durham may be attributable to subaerial exposure and dessiccation, but not to vertisol development (Fig. 10.4 c-e).

It is evident from this study that a certain amount of variety occurs in the palaeosol profiles of the Coal Measures, and that these variations are related to changes in environmental setting. Palaeosols may therefore be of considerable use in detecting changes in the Coal Measure environment in the various coalfields of Great Britain.

PART C

OTHER AREAS

CHAPTER XI - COMPARISONS WITH OTHER BRITISH COALFIELDS

11.1 INTRODUCTION

This Chapter is intended to compare and contrast the preserved succession and interpreted depositional environments of the Durham Coal Measures with those of other Westphalian sequences exposed in Britain. In Ch. 11.2, sequences in areas adjacent to the Durham coalfield are considered, and in Ch. 11.3 a selection of Westphalian sequences elsewhere in Britain are discussed, together with published information on British Westphalian sediments. Conclusions on the Pennine Westphalian environmental setting are then summarized in Ch. 11.4.

11.2 AREAS ADJACENT TO DURHAM: NORTHUMBERLAND, MIDGEHOLME STAINMORE, CUMBRIA

11.2.1 Northumberland

The Northumberland coalfield, which is an extension of that in the Durham area, preserves similar thicknesses of Westphalian A and B sediments (Ch. 2.2, Fig. 2.5, Ramsbottom *et al.*, 1978), and is of broadly similar character.

Field observations from two opencast sites (Butterwell O.C.C.S. G.R. NZ 210900; and Acklington O.C.C.S. Extension, G.R. NU 230010) have shown close similarity between Westphalian rocks of Northumberland and of Durham; sediments of major and minor channels, crevasse splays and lacustrine delta infills were recognized. In particular, the following points are worthy of mention;

(1) inter-seam partings are generally 3-20 m indicating similar sedimentation/subsidence relationships and

probably similar lake depths to Durham,

(2) in a 140 m vertical section exposed at Butterwell O.C.C.S. only three sandstones greater than 10 m thick occur, widely separated,

(3) kaolinitic claystone bands occur as intra-seam bands in coals of Upper Westphalian A age (S000-N000; Fig. 2.6),

(4) at Acklington O.C.C.S. Extension, laterally-accreted, claystone-filled, minor distributary channels 50 m in width and with width/depth ratios of 17-25/1 were exposed,

(5) at the same locality crevasse splay sandstones were seen in one rock face, perpendicular to the direction of palaeoflow, to be arranged in a vertically offset pattern, and

(6) the major coal seams of the coalfield appear to thin generally northward.

Coastal exposures of major and minor distributary channel, subaqueous levee, overbank, crevasse splay, lake delta infill and quiet-water sediments of Lower Westphalian B age in Northumberland (Tynemouth to Seaton Sluice: G.R.s NZ 375695 to 338770) are described by Haszeldine (1981a, b, in press).

11.2.2 Midgeholme

The Midgeholme coalfield preserves a similar thickness of Westphalian A strata to that of Durham and Northumberland, and appears to be broadly similar from the limited amount of available information.

A series of exposures on Black Burn, near Midgeholme (G.R. NY 641590-650592) display sediments of ? major distributary channel, shallow lake delta infill and swamp environments (Sections 444 and 445:- Appendix 1). A lake depth of about 6 m was indicated by one sequence.

A predominance of palaeocurrent directions towards the east, parallel to the trend of the nearby Stublick-90 Fathom Fault system, may or may not be significant.

11.2.3 Stainmore

A thickness of Westphalian A strata slightly greater than that preserved in Durham is preserved in the Stainmore coalfield (about 240 m:- see Fig. 2.5, Ramsbottom *et al.*, 1978). Observations on outcrops in Argill Beck (G.R. NY 838135), Mousegill Beck (G.R. NY 832127) and Augill Beck (G.R. NY 819152) indicate that similar environments to those described from Durham are represented. At least two major sandstone bodies up to 15 m thick occur (see Fig. 40 of Burgess and Holliday, 1979) and lake depths of up to 10 m are indicated. Palaeocurrent measurements indicate a wide dispersion of directions, but with a predominance in trough cross-sets of the thicker sandstones of a southward palaeoflow.

11.2.4 Cumbria

Sequences of Westphalian A and B sediments, somewhat condensed with respect to those of the Durham area, are preserved in the Cumbrian coalfield, together with up to 300 m of Westphalian C (Fig. 2.5, 2.6; Ramsbottom *et al.*, 1978).

In the basal Westphalian A, represented in exposures at

Harrington South Shore (G.R. NX 986243), (Section 382; Appendix 1), and in the underlying, markedly condensed and fragmentary, Namurian Hensingham Group, quartz arenite sandstones and ganisters occur (see also Eastwood *et al.*, 1931; Taylor, 1961). In the same part of the sequence, as many as five marine bands are present, and several locally workable coals (notably the Harrington Four Foot and Albrighton seams; see Fig. 2.5) occur. These display considerable local variation however, as do their counterparts in Durham.

The upper limit of the basal, marine-influenced unit lies at about the junction between the *lenisulcata* and *communis* bivalve zones (as with Durham) and between this level and the Solway (=*VANDERBECKEI*) Marine Band, typical Coal Measure lithologies and fossil assemblages occur, including several coals of workable thickness, represented by exposures at Cat Gill (G.C. NX 982237), Andrews Gill (G.R. NX 980227) and Barngill Quarry (G.R. NX 998218), (Sections 380, 381 and 378; Appendix 1).

Environments of deposition of these rocks were shallow lakes (2-6 m deep) filled by overbank and crevasse splay-derived sediments, minor and major ? distributary channels and peat swamps. These sediments bear considerable similarity to those of Durham, in lithology and sedimentary structures, inter-seam and unit thicknesses and interpreted environments of deposition. Palaeocurrent measurements indicate that palaeoslope was virtually non-existent, as in Durham, and there is evidence of vertical stacking of channels in some areas (see Taylor, 1978, p. 185).

The Solway Marine Band, which is of slightly more fully marine "facies" than in the Durham area (containing *Lingula*, *Dunbarella*, *Hindeodella* and foraminifera), is usually underlain, either immediately or a few m below, by a thin coal or seatearth. The overlying Westphalian B sequence is again markedly similar to that in Durham, represented for example by exposures at Benhow Beck, Whitehaven (G.R. NX 978149), in coastal cliffs south of Parton (G.R. NX 975197) and in the disused Howgill clay pits at Whitehaven (G.R. NX 972166), (Sections 181, 377, 183 and 184; Appendix 1). As with Durham, major coal seams are consistently thicker than their counterparts in the Westphalian A, palaeocurrent measurements "box the compass" and once again, vertically stacked sandstones are known to occur in certain areas. The uppermost part of the Westphalian B sequence contains the Black Metal (=*HAUGHTON*) Marine Band, and the boundary between Westphalian B and C is marked by the Bolton (=*AEGIRANUM*) Marine Band.

Westphalian C strata are well-exposed in coastal cliffs to the north and south of Whitehaven. At Bransty, to the north of Whitehaven Harbour (G.R. NX 974191) a reddened, trough cross-bedded sandstone at least 18 m thick, which is thought to underlie the Senhouse High Band coal (Fig. 2.5), contains low-angle bedding surfaces of up to 10 m height inclined at 30-40 degrees from the vector mean direction of palaeoflow (Plate 11.1). These are interpreted as lateral accretion surfaces within a major ? distributary channel which flowed towards the south-west, had a sinuous morphology and was up to 10 m deep and perhaps 600 m wide. This sandstone forms part of the so-called "Whitehaven Sandstone Series"



Plate II.I - Large-scale lateral accretion surfaces in a Westphalian C major channel sandstone exposed at Bransty, Whitehaven. Cliff is about I8m high.



Plate II.2 - The Sheffield Blue Ganister, exposed at Fulshaw Lane, near Langsett. Hammer is 35cms long.

which was once thought to lie unconformably above the Coal Measures (Ch. 2.2).

On Whitehaven South Shore (G.R. NX 967183-959160), a sequence of typical Coal Measure lithologies including a composite, proximal crevasse splay unit with a channelized axis underlies a reddened, trough cross-bedded sandstone which is at least 20 m thick, erosively-based and laterally continuous over at least 2 kms perpendicular to palaeoflow (see Sections 185-187 and 376; Appendix 1). This sandstone is interpreted as the deposit of a westward-flowing major channel system, which was evidently active over a considerable time.

In conlusion, the Coal Measures of the Cumbrian coalfield bear considerable similarity to those of Durham, and were probably deposited in similar environments, under similar controls. Evidence exists for a lower-to-upper delta plain transition in lower Westphalian A times, though the underlying truncated Namurian sequence cannot be regarded as deltaic, and was probably affected to considerable extent by proximity to the Cumbrian massif, which seems to have acted as a palaeotopographical "high" at this time.

During Westphalian times, the Cumbrian massif is not believed to have acted as an exposed palaeotopographical high. While interval thicknesses undoubtedly increase north-westwards away from the massif (Taylor, 1961), sedimentary facies do not change significantly and there is no substantial evidence from this preliminary study that the Lake District acted as a sediment source, from either palaeocurrents or sandstone petrography. Thus, the Lake District is considered to have been of similar

relief to the rest of the Coal Measures plain, but to have subsided somewhat more slowly as a result, perhaps, of the presence of isostatically buoyant granite in the subsurface (Bott, 1974).

11.3 OTHER COALFIELDS OF GREAT BRITAIN

11.3.1 South Yorkshire

The Yorkshire coalfield contains a sequence of Westphalian A sediments greatly expanded with respect to that of Durham (up to 600 m as opposed to 200 m), a slightly expanded Westphalian B succession (400 m as opposed to 300) and at least 500 m of Westphalian C rocks. A limited amount of previous work has suggested that similar sedimentary environments are preserved (Davies, 1966; Guion, 1971; Pearson, 1973; Scott, 1978; Percival, 1981).

Outcrop observations were made by the present author in the area around Penistone (Fig. 1.2), concentrated on two stratigraphical levels :

(1) The rocks immediately above and below the Hard Bed Marine Band (=*LISTERI;* Lower Westphalian A) were examined at Fulshaw Lane (G.R. SE212012), and Middlecliffe Quarry (G.R. SE 202041), (Sections 357, 189; Appendix 1), and

(2) a major sandstone of middle Westphalian A age, the Greenmoor Rock (Elland Flags) was examined at several small quarries near Lane Head (G.R. 192088), (Sections 358-361; Appendix 1), (Fig. 2.9).

The Hard Bed coal and overlying Marine Band represent an equivalent stratigraphical horizon to the Kays Lea Marine Band in Durham. Underlying the Hard Bed coal is the Sheffield Blue Ganister (Plate 11.2), a quartz arenite of pedogenic origin (see Pearson, 1973 and Percival, 1981), which thus occurs at approximately the same stratigraphical position as the West Butsfield Ganister. Several other quartz arenites and ganisters are known from the basal Westphalian A sequence of the area.

In South Yorkshire, the basal Westphalian A series of marine bands ends a short distance above the *lenisulcata/communis* zonal boundary, perhaps as expected, and is considered to reflect the southward progradation of the Upper Carboniferous Pennine delta system. The ganisters such as the Sheffield Blue, which occur within this basal marine-influenced sequence, may thus be interpreted similarly to the Durham ganisters, i.e., as the result of pedogenic porocesses acting on relatively thin bodies of sand which had been reworked to some extent by marine processes to form mature, porous, quartz arenite units.

It is also worthy of note that the Hard Bed Marine Band directly overlies the Hard Bed coal, an association commonly seen in Durham (see discussions in Ch. 10),(Section 357; Appendix 1).

At Middlecliffe quarry, the Hard Bed Marine Band is of fully marine facies (Plate 11.3) and is overlain by 8 m of shales and another Marine Band,the *PARKHOUSE* horizon, which is only of Lingula facies (Section 189; Appendix 1). The sequence overlying this Marine Band is claystone-dominated, but the upper coarse-grained part suggests a basin depth of at least 15 m.

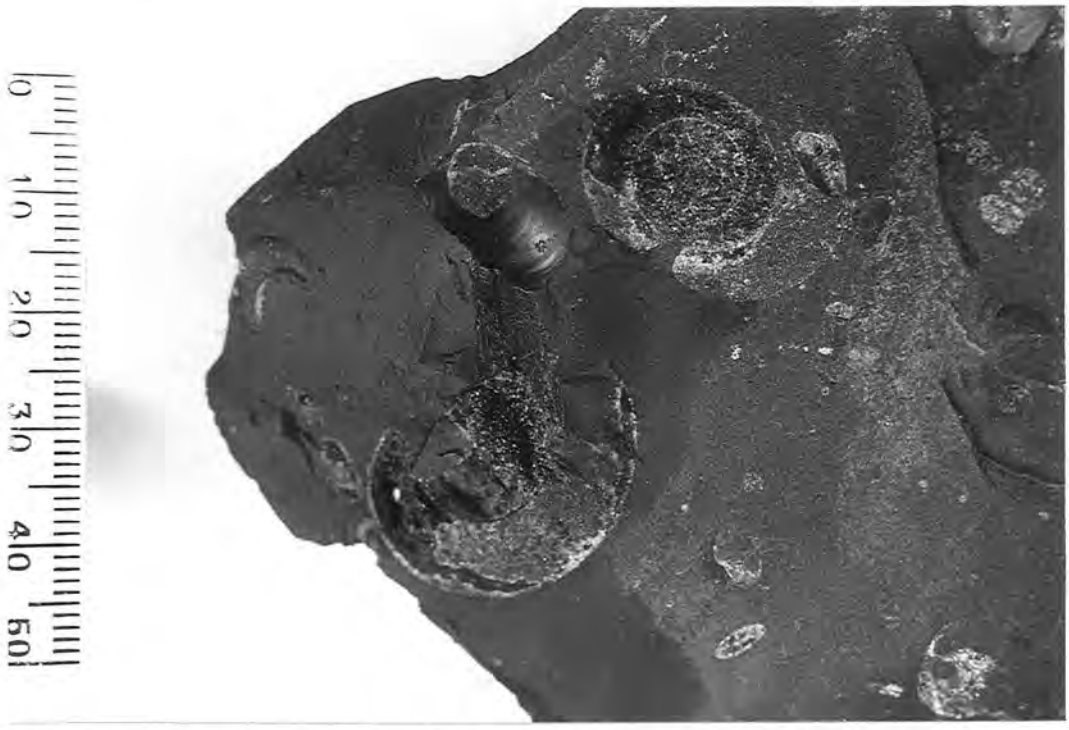


Plate II.3 - Uncompacted impressions of Gastrioceras listeri, containing bituminous infills, from the Hard Bed Marine Band at Middlecliffe Quarry, Penistone. Scale divisions in mm.



Plate II.4 -
The Greenmoor Rock, exposed at Lane Head, near Holmfirth. The upper part of the exposed sequence comprises a laterally-accreted, minor channel deposit (L). Geologist is I.75m high.

The Greenmoor rock, also known as the Elland Flags, is a laterally extensive sandstone across parts of South Yorkshire, known to vary up to 20 m in thickness. This sandstone was interpreted by Davies (1967) as the stacked deposits of fluvial channels.

Examination of quarry exposures mentioned above certainly suggests a similar conclusion, although the channels may be distributaries, rather than fluvial in nature.

The upper part of the Greenmoor Rock seems to be composed of laterally-accreted minor channel deposits (10s of m wide, 3-4 m deep), (Plate 11.4), which are composed of interbedded fine-grained sandstone and siltstones/claystones, and which pass upward into rootlet penetrated fines, in turn overlain by a thin coal (the Better Bed; Fig. 2.9). A general eastward-directed palaeoflow is indicated from directional structures, though considerable variation occurs both between and within individual localities. This "style" of channel deposit is very reminiscent of the Top Tilley Post (see Enclosure 6, Plates 6.33, 6.34), and might possibly be interpreted as a meander belt of sinuous ? distributary channels.

From the work of Scott (1976, 1978), environments of deposition and sedimentary processes in the Westphalin B of Yorkshire were entirely similar to those of Durham. In particular, meandering minor distributary channels were of comparable size and lakes up to perhaps 8 m deep.

From the limited available data, it is considered that sedimentary environments in the Yorkshire Coal Measures were broadly similar to those of Durham.

11.3.2 Lancashire

In the Lancashire coalfield, the thickest Westphalian A sequences preserved in Britain are found (up to 700 m, 3.5 times the thickness of the Durham Westphalian A), though similar to South Yorkshire, the Westphalian B succession is only 50% expanded with respect to Durham (450 m as opposed to 300 m),(Fig. 2.8). A substantial thickness of Westphalian C and D is also preserved.

Westphalain A sequences exposed in a number of quarries in the St. Helens area were examined, notably at Appley Bridge (G.R. SD 523097), Up Holland (G.R. SD 512048), Billinge Hill (G.R. SD 526014) and Chester Lane (G.R. SJ 517921 and 513919), (Sections 226-228, 354-356; Appendix 1).

At Billinge Hill and Up Holland, superbly-exposed sections occur through basal Westphalian A sequences, which again show evidence of having been affected by marine incursions (marine bands occur throughout the *lenisulcata* zone and into the basal *communis* zone in Lancashire, as in South Yorkshire, Fig. 2.8). At Billinge Hill quarry a single rock face exposed a complete section through a laterally accreted channel, which was about 250 m wide and 4 m deep, (Plate 11.5) and appeared to be part of a larger meander belt.

At Ravenhead Quarry, Up Holland, sediments representing the fills of shallow marine and non-marine bodies of water, which were about 5-10 m and 5 m in depth, respectively, were exposed. Marine Bands at this locality (including the Bullion Mine =*LISTERI* horizon) are of fully marine facies, containing goniatites and pectinid bivalves, and as with the other areas examined, invariably overlie a seatearth or coal (see Section 226; Appendix 1,and Eagar, Grayson and Williamson, 1977, p. 20). Other features worthy



Plate II.5 - Laterally-accreted channel deposit in the Crutchman Sandstone (Lower Westphalian A), exposed at Billinge Hill Quarry, near Up Holland. Height of exposed section about IOm.

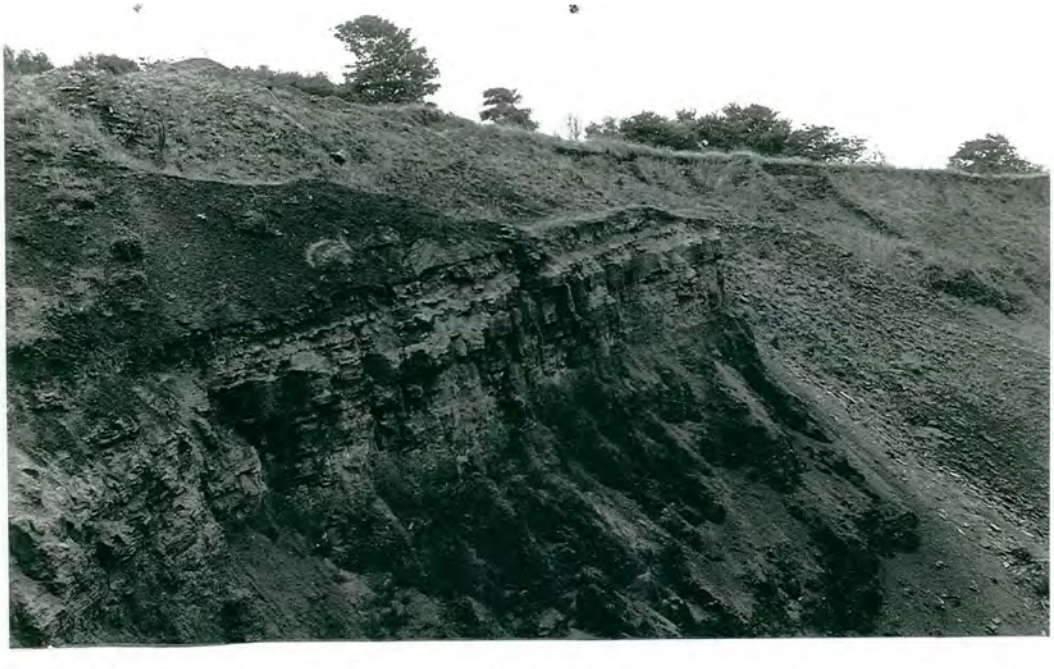


Plate II.6 - Lower Westphalian A coarsening-upward sequence exposed at Ravenhead Quarry, Up Holland. The top of the sequence contains an impure ganister, and is overlain by the Rambler Mine coal (obscured by rubble). Height of exposed section about I2m.

of note at this locality are the ganister-like sandstone forming the uppermost part of the bay fill sequence underlying the Rambler Mine coal (Plate 11.6), and a regularly interbedded series of fine-grained sandstones and siltstones above the lower Mountain Mine coal (described in some detail by Broadhurst, Simpson and Hardy, 1980).

At Appley Bridge, a Mid-Westphalian A major sandstone body known as the Old Lawrence Rock, which is known to toal up to 50 m in thickness and is laterally extensive over much of West Lancashire, is exposed. Contained sedimentary structures, the lateral extent and thickness of this sandstone suggest that it is the deposit of a major distributary channel or channel belt, and as with other major channel deposits described in this thesis contains evidence of minor channels incised into its' upper part. The highest levels of the Old Lawrence Rock at this exposure contain superbly-preserved sedimentary structures, notably wave ripples and "ladder ripples" (Plate 11.7).

Somewhat reddened sequences of Westphalian C sediments were exposed in two quarries at Chester Lane, St. Helens (Sections 227 and 228; Appendix 1).

These were of similar facies to other Westphalian sediments described in this thesis, but differed in containing a substantially higher proportion of rootlet-penetrated sediments, and a number of thin and impure coal seams. Furthermore, thicknesses of lake fill sequences suggest that lakes were only of the order of 2-5 m deep.

In conclusion, a marine-influenced basal Westphalian A sequence in Lancashire displays many features common to Durham and the other areas described, is overlain by productive Westphalian



Plate II.7 - Ladder ripples from the upper part of the Old Lawrence Rock sandstone (Lower Westphalian A), at Appley Bridge near Up Holland. Tape measure is 5cms wide.



Plate II.8 - Palaeosol profile from the basal Westphalian A east of Amroth, Pembs. The profile contains abundant sphaerosiderite, and goethite- and sandstone-filled cracks ((above hammer, 30cms long), and is overlain by a thin coal.

(A and B) sequences of similar character and capped by a secondarily reddened Westphalian C and D succession which seems to contain some evidence of a fluvial plain setting (see discussion in Ch. 10.1).

11.3.3 Other Pennine Coalfields

Detailed studies of Westphalian A-C Coal Measures in the East Midlands were made by Elliott (1968, 1969, 1970), Guion, (1971, 1978) and Fatona (1980). These studies have demonstrated, once again, that the basal Westphalian A (*lenislucata* zone) sequence was deposited under pronounced marine influence, which was relinquished by lower *communis* zone times. Much of the Westphalian A and B sequence was then laid down on an upper delta plain environment (Guion, 1978), characterized by major (kms wide) and minor (up to a few 100 m wide) distributary channel belts which were widely separated by shallow (< 10 m deep) interdistributary lakes. Slightly enhanced rates of subsidence with respect to the Durham area are indicated by thicker coals, slightly deeper lakes and thicker overall sequence thicknesses.

11.3.4 Pembrokeshire

The Pembrokeshire coalfields preserve some 350 m of Westphalian A strata, together with ? 280 m of Westphalian B and a huge thickness (1800 m+) of Westphalian C/D "Pennant Measures". The sequence was treated to detailed sedimentological analysis by Williams (1966, 1968) and more recently by Elliott (1981).

In the present study, two coastal sections of lower Westphalian A rocks were examined; Amroth-Telpyn Point (G.R. SN 174072-186072) and Amroth-Wisemans Bridge (G.R.SN 162069-148062), together with two adjacent and stratigraphically equivalent sections in the Pennant Measure, Rickets Head North and South

(G.R. SM 855188-855192), (Sections 349-353; Appendix 1).

Between Amroth and Telpyn Point, a sequence representing the infilling of the *SUBCRENATUM* marine basin culminates in a stacked series of palaeosol profiles (Plate 11.8) and is overlain by a major (10 m+) channel sandstone. This sequence includes the "Amroth Slump Sheet" (Kuenen, 1949), interpreted as a result of synsedimentary gravitational sliding or thixotropic behaviour of sediment, and indicates that the marine basin occupied by the *SUBCRENATUM* incursion was of the order of 12-14 m deep.

The Amroth-Wiseman's Bridge section exposes a generally finer-grained and stratigraphically slightly higher sequence. A numer of shallow lake fills (up to 7 m deep), palaeosols and anthracite grade coals are exposed, displaying a great variety of palaeocurrent directions. This sequence lies stratigraphically above the basal, marine-influenced section which terminates in the upper part of the *lenisulcata* zone in Pembrokeshire (Fig. 2.10).

At Rickets Head, a thick sequence of Westphalian C or D sediments is exposed, which comprises interbedded fine-grained sandstones and finer sediments is largely rootlet-penetrated and contains evidence of very shallow depths of subaqueous deposition (1-2 m). Profiles of several minor (100 m wide) channels are preserved (Plate 11.9) and intervening sediments are interpreted as overbank and minor crevasse splay deposits which emanated from these and similar channels. Interestingly, palaeocurrent vectors from a number of horizons in this interbedded sequence display uncharacteristic uniformity (directed towards the west).

The lower, interbedded sequence is overlain by a major coarse-grained sandstone (the Rickets Head Sandstone) which is at least 20 m thick and displays numerous internal erosion surfaces and intraformational conglomerate horizons (Plate 11.9).



Plate II.9 - Panorama of Rickets Head, Pembrokeshire, showing a lower sequence of interbedded sandstones and fine-grained sediments (including the stacked deposits of 2/3 minor channels - M), overlain by the major Rickets Head Sandstone. Total thickness of exposed section about 60m.

The Rickets Head sections is interpeted as the deposits of a shallow submerged floodplain which was frequently filled by overbank and crevasse splay deposits, and crossed by crevasse-initiated minor channels. Abandoned channels and infilled floodplain environments developed palaeosol profiles indicative of partial drainage (sphaerosiderite-bearing, vertically elongated nodules, colour changes, vertical profiles; see Ch. 10.8), and submerged surfaces were probably rarely allowed to subside to greater than 2 m below the surface. The floodplain sequence was overlain by a major channel belt which deposited a thick body of sand.Channel dimensions and morphology are not identifiable.

From the thickness of the major sandstone and vertical stacking pattern of minor channels discernible from outcrops (Plate 11.9), sedimentation is considered to have been controlled by a combination of rapid subsidence and relatively rapid rates of sedimentation. Conditions of sedimentation and basin evolution in the Pennant Measures are considered at length by Kelling (1968, 1974).

A marked contrast is thus exhibited between the Westphalian A sequences of Pembrokeshire, deposited in lower and upper delta plain environments, and the fluvial-dominated Pennant Measures. As was demonstrated with the Upper Westphalian A sequences in the Durham coalfield, and discussed in Ch. 10.1, the separation of Lower and Upper Delta Plain and Fluvial Plain environments, is possible with good exposure but without the need for detailed studies of regional context. Patterns of coal seam thicknesses are similar to those of Durham, i.e., thick, laterally extensive coals are associated with an upper delta plain setting, and more variable, generally thinner coals with fluvial plains and

lower delta plains.

11.4 SUMMARY: ENVIRONMENTS OF THE PENNINE COAL MEASURES

It seems likely from the interpretations of British Coal Measures environments made in the preceding pages that general conditions of sedimentation were similar, and evolved similarly, across the entire Pennine Basin (South Wales is considered to have acted as a separate sedimentary basin, and evolved quite independently of the Pennine province).

A Namurian phase of deltaic infilling was followed by lower Westphalian lower delta plain establishment over much of northern England, which by the lower part of the *communis* zone had evolved into an upper delta plain. This upper delta plain remained stable over the rest of Westphalian A, all of Westphalian B and the early part of Westphalian C, perhaps developing transitional fluvial plain conditions locally (or perhaps regionally) or drowned upper delta plain conditions as a result of a temporary failure of sediment supply.

During mid-Westphalian C times, the overall environment began to develop more permanent fluvial plain characteristics, as the Coal Measures environment began the transition towards the more arid continental environment of the Permian.

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Endispiece

"Big Geordie" at work in Butterwell O.C.C.S.

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SEDIMENTOLOGY AND STRATIGRAPHY OF THE DURHAM COAL MEASURES, AND COMPARISONS WITH OTHER BRITISH COALFIELDS

by

CHRISTOPHER ROWLAND FIELDING, B.Sc.

VOL. 2.

A thesis submitted to the University of Durham for the degree of Doctor of Philosophy

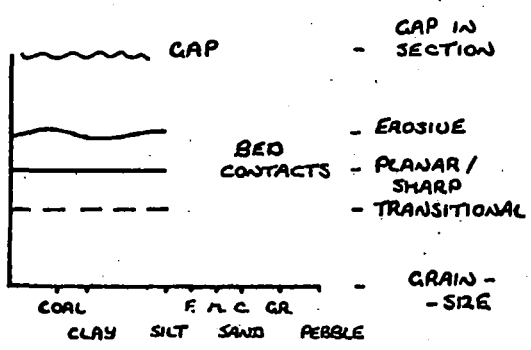
Department of Geological Sciences October 1982

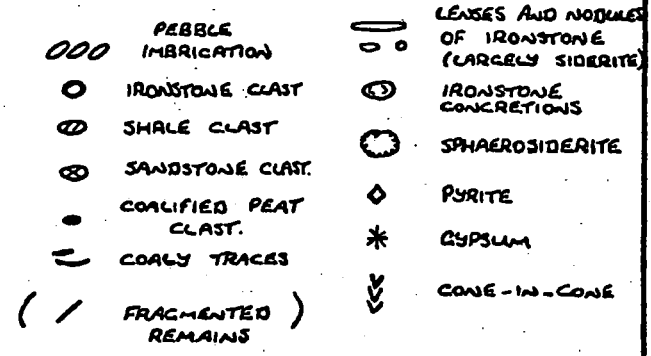
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APPENDIX I

- comprising a series of graphic sedimentary logs and other field notes, and forming the basic field information used in this thesis.

KEY TO SYMBOLS USED IN GRAPHIC SEDIMENTARY LOGS






MASSIVE / UNLAMINATED


POORLY LAMINATED


LAMINATED


WELL - LAMINATED


IRREGULARLY LAMINATED


DISTURBED LAMINATION


"CRUMBLY" LAMINATION



FAULT



TECTONIC DISTURBANCE



DRIFT DISTURBANCE

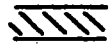

MINERAL VEIN

CANNEL - CANNEL COAL

FUS. - FUSAIN

K.C. F.C.R. } - KAOLINITIC CLAYSTONES


TROUGH CROSS - BEDDING


TABULAR CROSS - BEDDING

EROSION SURFACE

RIPPLE CROSS - LAMINATION

CLIMBING RIPPLES.

BACKFLOW RIPPLES

RIPPLE FORM SETS

SILT FORM SETS

WAVE RIPPLES


"RIB - AND - FURROW"


INTERFERENCE RIPPLES


LADDER RIPPLES

P.C.L. PRIMARY CURRENT LINEATION

P.L. PARTING LINEATION


SINUSOIDAL RIPPLES


LOAD - CASTING


DRAG FOLDING


CONVOLUTE LAMINATION


DEWATERING STRUCTURES



SYNAERESIS CRACKS



DESICCATION CRACKS

NON-MARINE BIVALVES


" - IN LIFE POSITION


FISH REMAINS

LINGULA

MARINE FOSSILS


SPIRORBIS

OSTRACODS


ALGAE

TRACE FOSSILS


VERTICAL BURROWS


HORIZONTAL BURROWS


TRACKS AND TRAILS


PELECYPODICHALUS


STIGMARIA ROOTS


ROOTLETS


IN SITU CALAMITES


IN SITU LYCOPOD


DRIFTED FOLIAGE

DRIFTED PLANT STEMS


DRIFTED CALAMITES STEMS


VERTICAL CRACKS

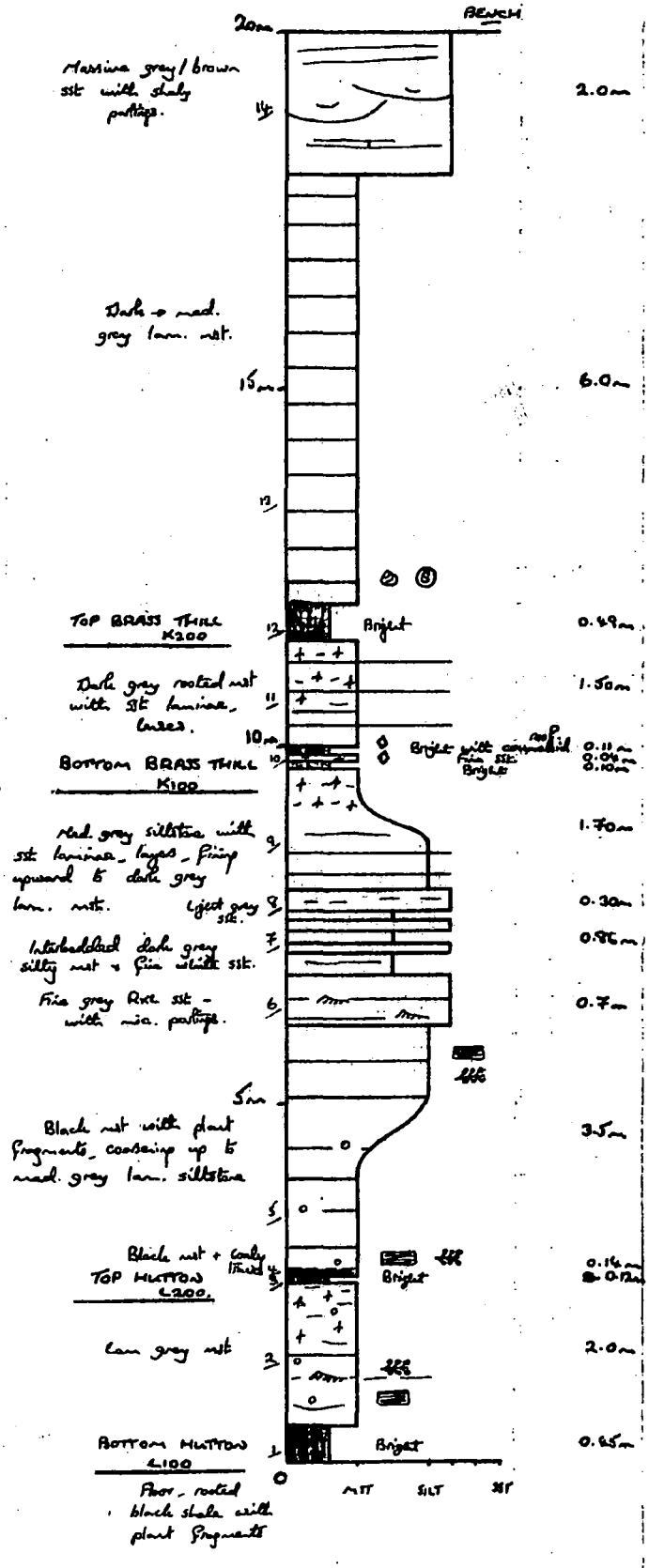

MICROFAULT

CRF 24.10.79.

INCLINE On excavated floor of Bottom Hutton coal, plentiful flattened plant stems, almost all Sigillaria, up to 6m long × 0.6m wide, on bedding planes.

SECTION 001

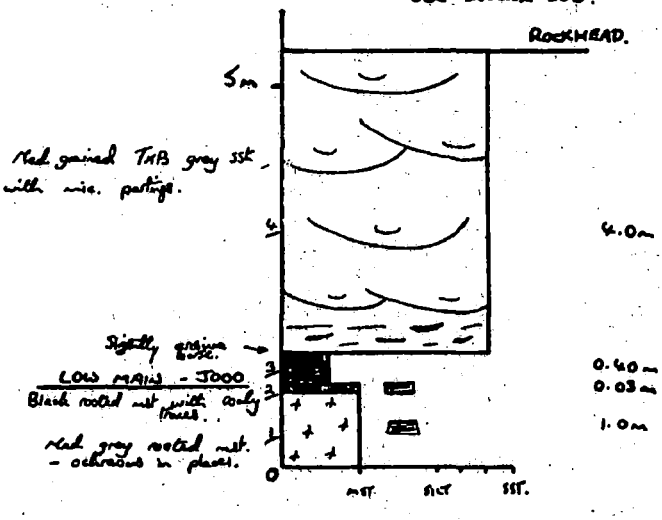
INCLINE O.C.C.S. Cut 95 - Final Cut of Site.



SECTION 002

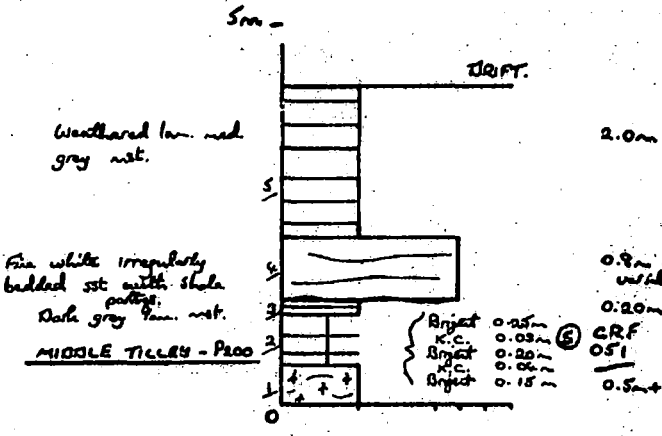
INCLINE - CUT 11.

Virtually no tectonic dip. Final cut to low Main. See Section 006.



SECTION 003

ROWLEY AS(N)



Section taken near eastern corner of mid-width. Unit 4 descends to east along wall. Virtually no tectonic dip.

C.R. FIELDING - 29/10/79

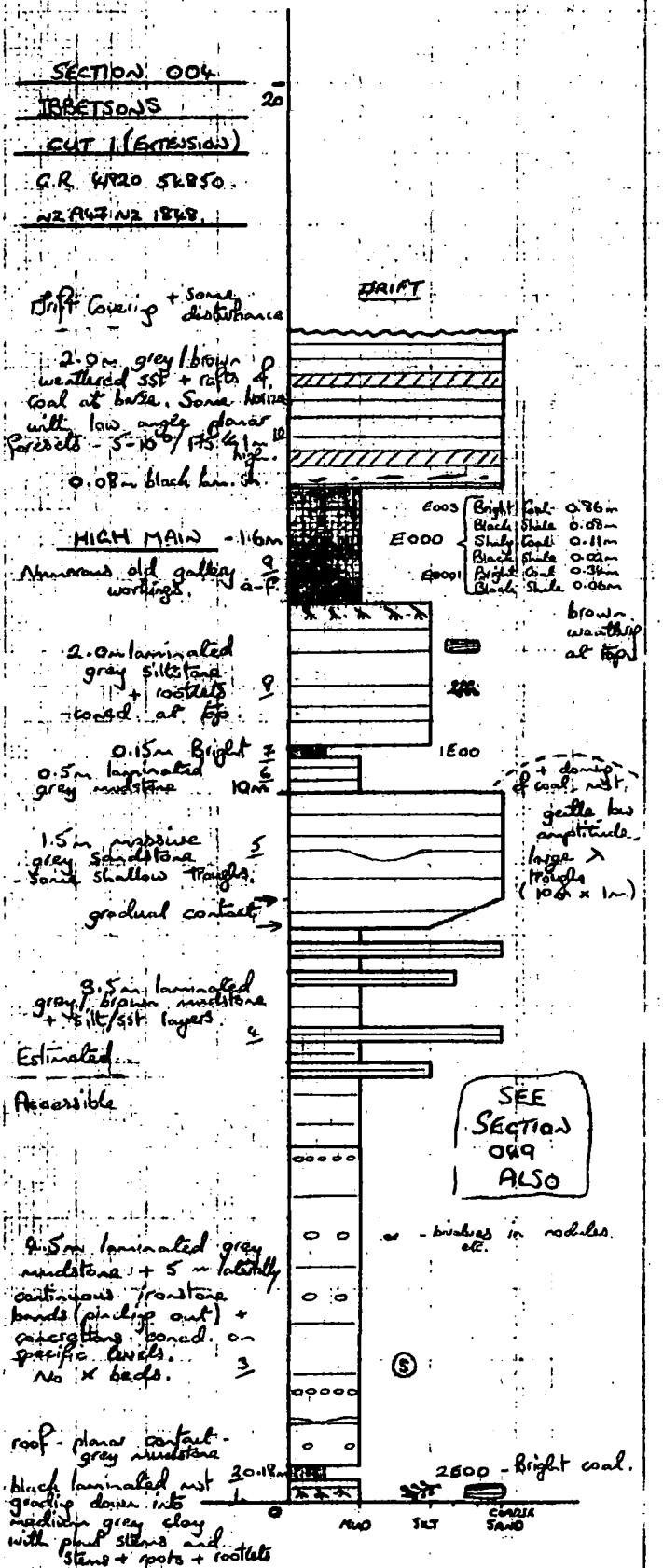
SECTION 004

IBBETSONS

CUT 1 (EXTENSION)

G.R. 4920 5850.

NZ 947 NZ 1848.



Comments - Shear backwall.

Bedding - horizontal.

NB Dip-ing in 1:00 effects

Cooling 29/10/79

8 frames b/w ASA 125 shot.

Some slight lateral variation - sst troughs & coal warping.

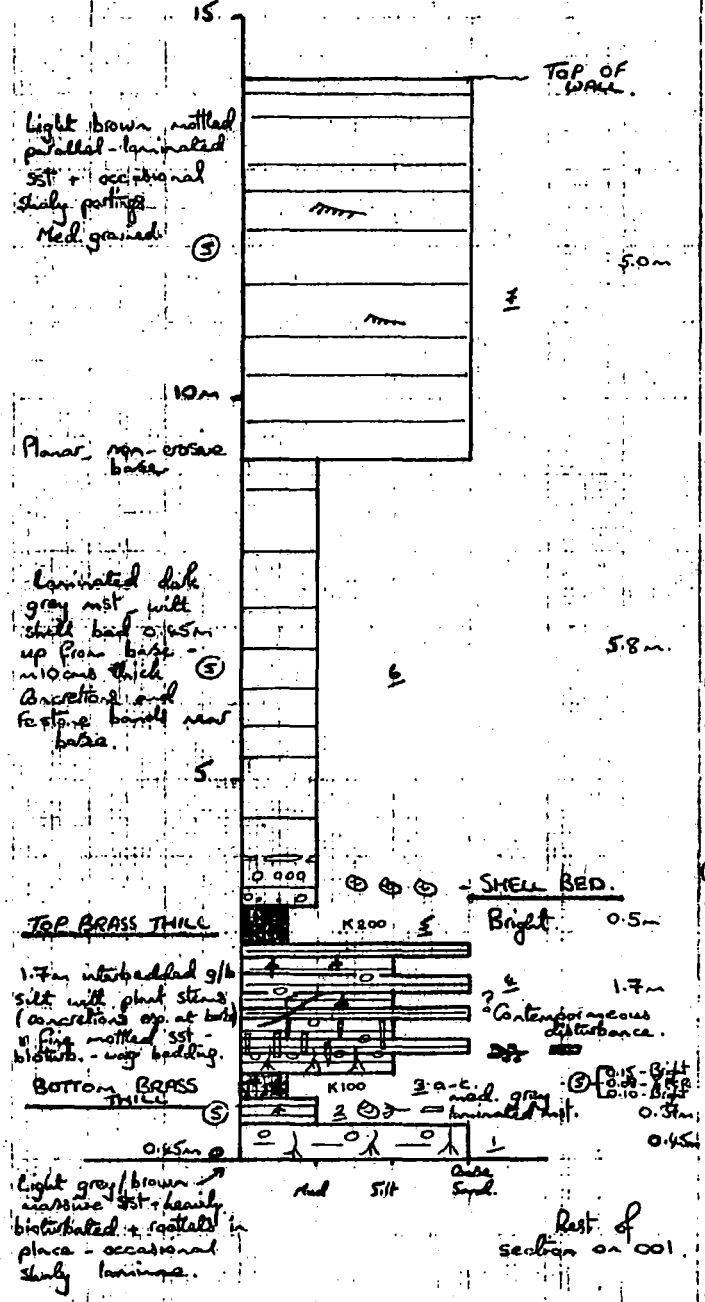
NB Seams split → NE.

SAMPLE - Ironstone Concretion.

C.R. FIELDING - 31/10/79

SECTION 005 - INCLINE.

CUT 95 - 9520 3100 G.R.



Rest of section on 001.

Comments

Shear-batter wall - backfilling 31/10/79.
Site finished coaling.
3 frames b/w ASA 125 film shot.
4 SAMPLES :- 1. BBT floor mst CRF 053
2. BBT Band CRF 054
3. BBT Mussel Band CRF 055
4. BT Post. CRF 056

All measured. Bedding = horizontal.

This section forms the upper half of Log 001 which could previously only be estimated.

C.R. FIELDING - 31/10/79

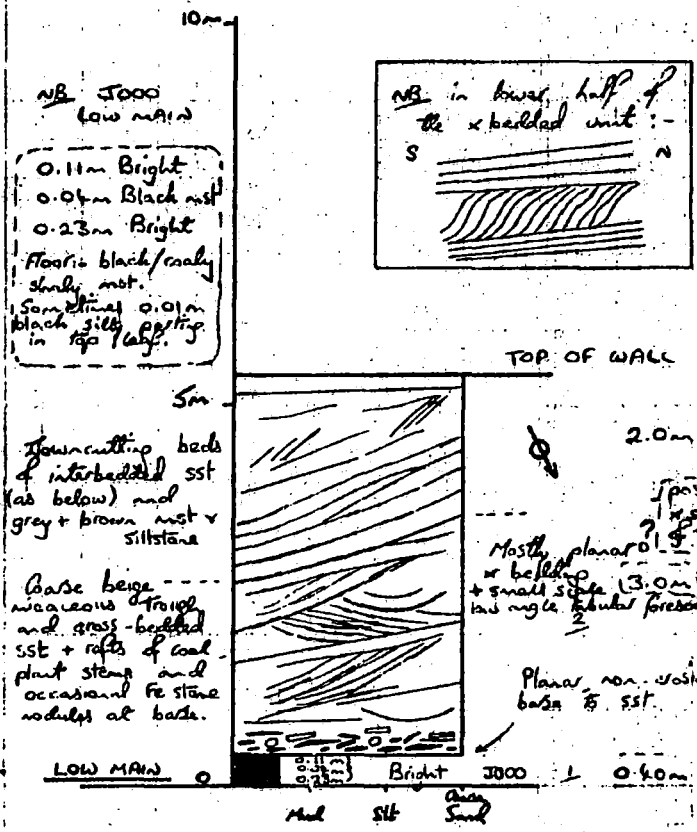
SECTION 006 - INCLINE.

CUT 11 - G.R. 9800 2600

CROSS-BEDS :- ≤2.0m ↑ - 0-15°/155°-148°-011°-159°-154°-113°-334°-135°-352°-351°-333°-206°-358°-153°-159°-157°-161°-156°-163°-357°-193°.

n = 21. - See Rose Diagram

Spurious measurements of oblique sections through troughs. * 125° Estimated



Same cut as 002 - logged slightly further south along the same face.

Slight roll in seam in 2m high.

Comments

Low cut wall - backfilling 31/10/79
Site finished coaling.
4 frames b/w ASA 125 film shot.

1 Sample - Low Main Post - CRF 057

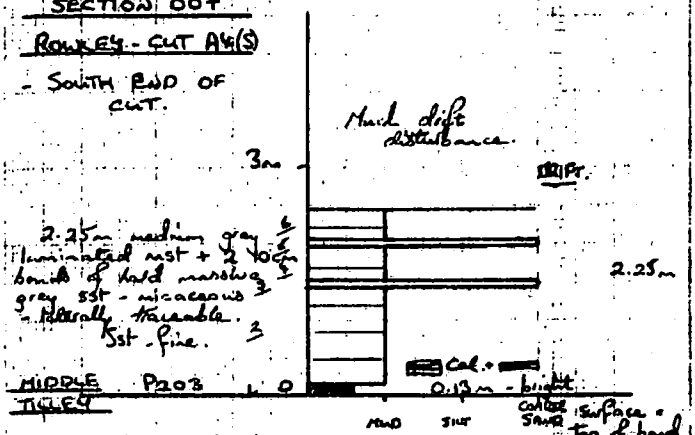
All measured.
Bedding = horizontal.

C.R. FIELDING - 5/11/79

SECTION 007

ROWLEY - CUT A4(S)

- SOUTH END OF CUT.

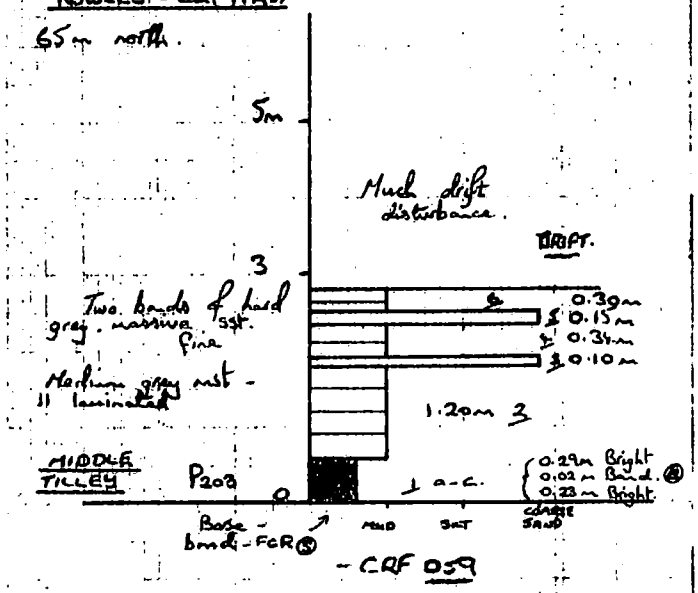


- CRF 058.

SECTION 008.

ROWLEY - CUT A4(S)

65m north.

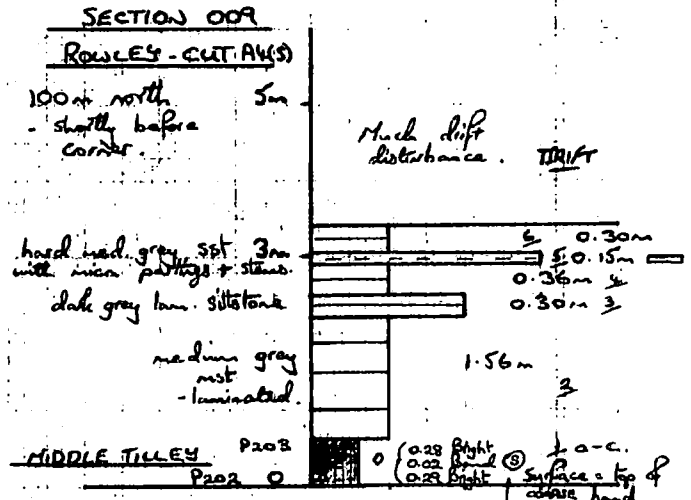


- CRF 059

SECTION 009

ROWLEY - CUT A4(S)

100m north - shortly before corner.



CRF 060

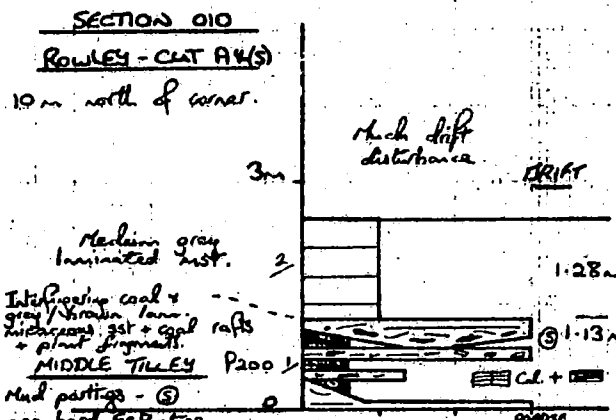
P201 - Bottom Leaf - average - 0.20m

Whole Series - South part - A4(S) - of a 1km long back wall - separated from northern half by a small fault - 3m shear walls + drift. Possibly glacial thickening of seam by raft movement - close to outcrop. Coaling 5/11/79. Not continuous exposure.

SECTION 010

ROWLEY - CUT A4(S)

10m north of corner.



- CRF 061

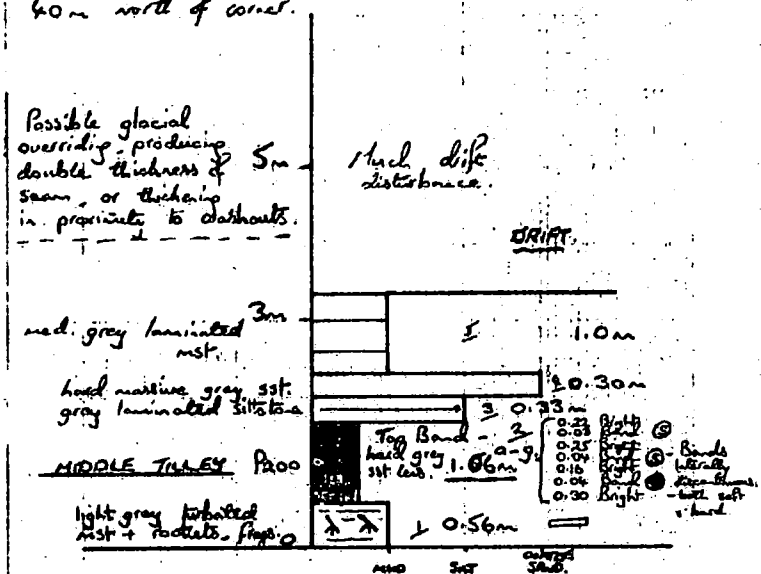
⑤ Sst - CRF 062

All seams leaves coalesce after a further 10m.

SECTION 011

ROWLEY - CUT A4(S)

40m north of corner.

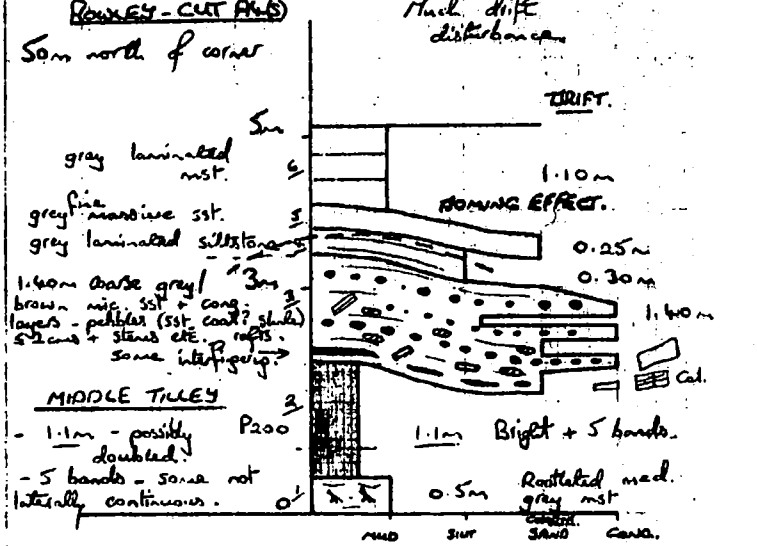


Band - CRF 063

SECTION 012

ROWLEY - CUT A4(S)

50m north of corner



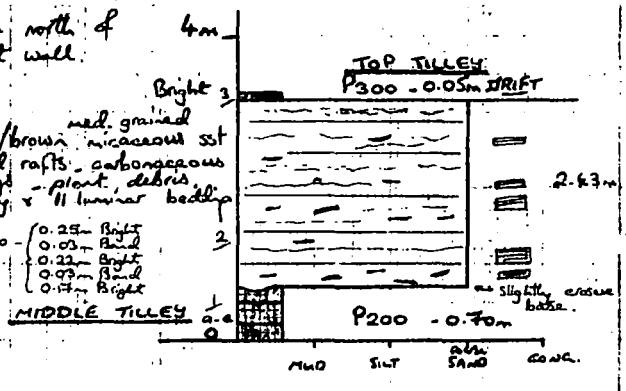
Channel orientated towards 265°. - SBE

C.R. FIELDING - 8/11/79

SECTION 013

ROWLEY - CUT AS(N)

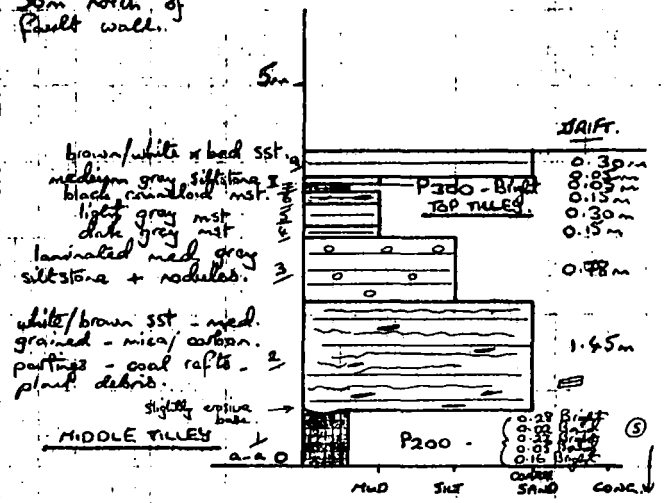
25m north of fault wall.



SECTION 014

ROWLEY - CUT AS(N)

50m north of fault wall.

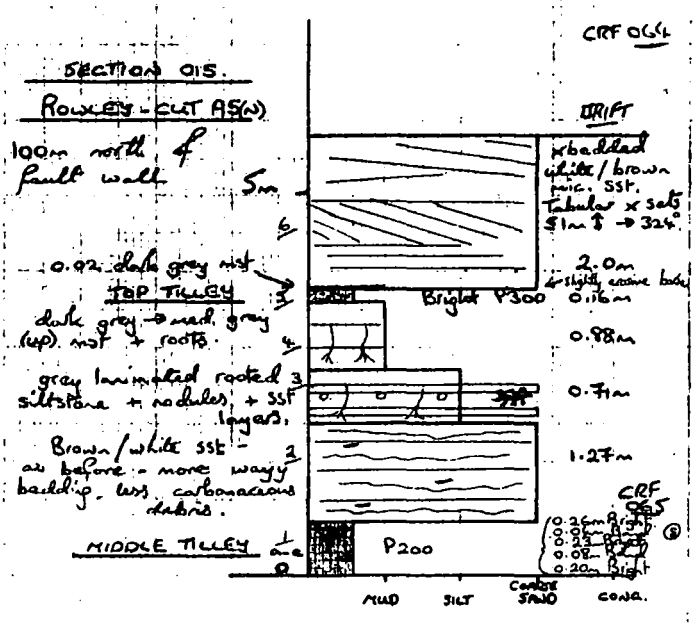


CRF 066

SECTION 015.

ROWLEY - CUT AS(N)

100m north of fault wall



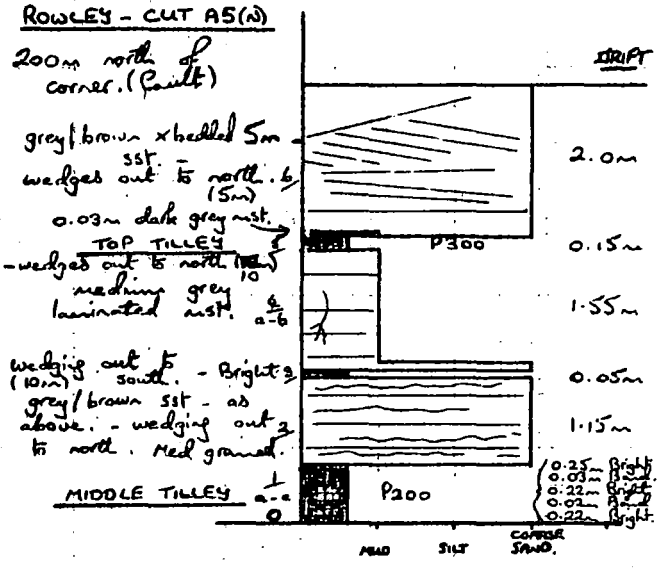
WHOLE SERIES

- 013 - 020 - gradually working north along Cut AS(N) - low backwall. Coaling 8/11/79 - working down to bottom Tilley.
6 Planet ASA 125 h/w shot.
Numerous small faults.
Exposure is continuous.
See field sketches.

SECTION 016

ROWLEY - CUT AS(N)

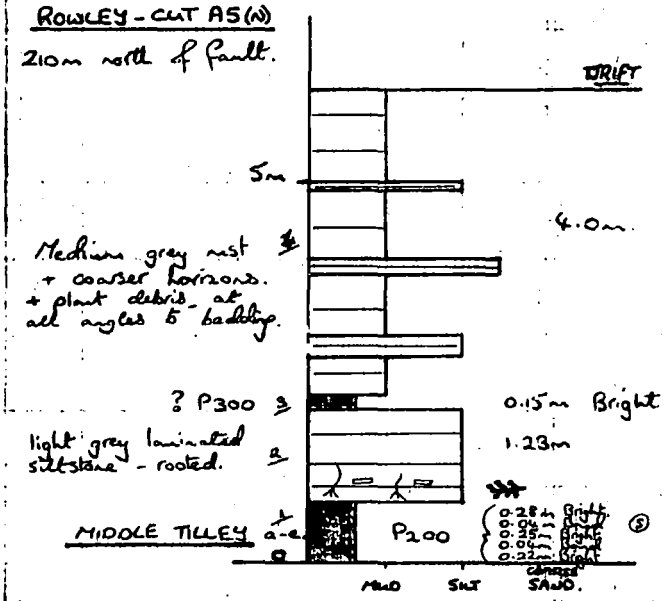
200m north of corner. (Fault)



SECTION 017

ROWLEY - CUT AS(N)

210m north of fault.

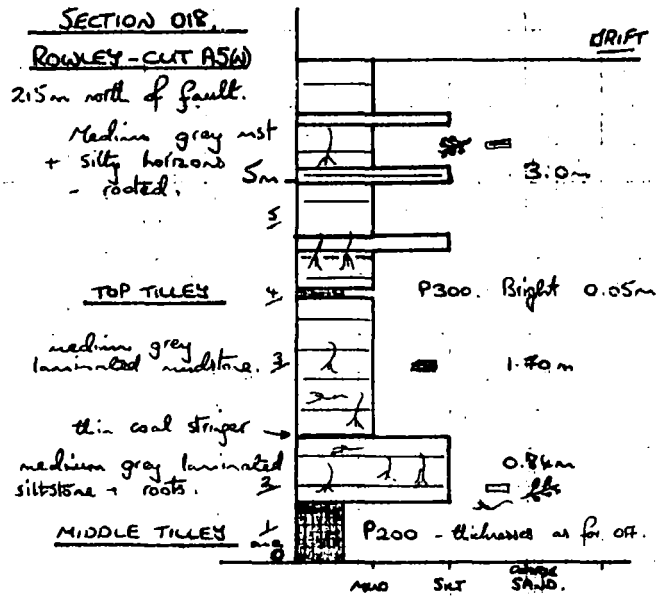


CRF 066

SECTION 018.

ROWLEY - CUT AS(N)

215m north of fault.

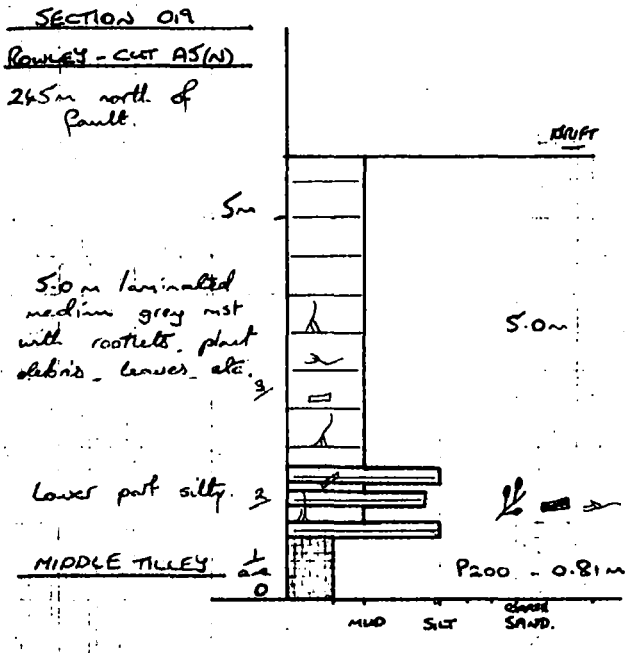


C.R. FIELDING - 8/11/79.

SECTION 019

ROWLEY - CUT AS(N)

245m north of fault.



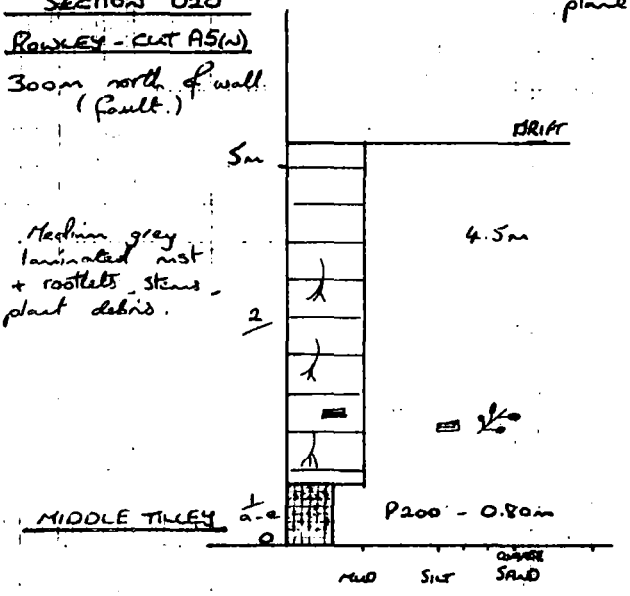
Sample - Top Band of P200 - 255m north of fault.

CRF 067 - Flattened Stigmaria impression on bedding plane.

SECTION 020

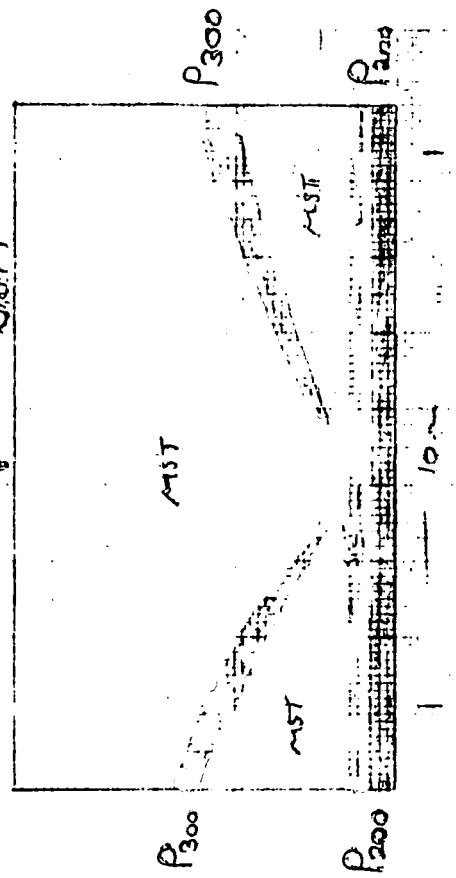
ROWLEY - CUT AS(N)

300m north of wall (fault.)



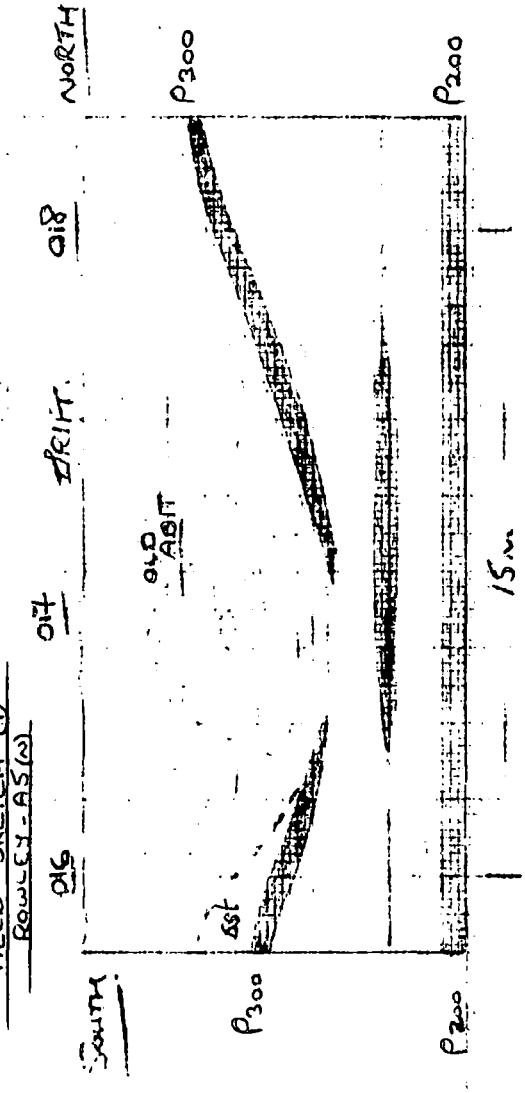
FIELD SKETCH ②

ROWLEY - AS(N)



FIELD SKETCH ①

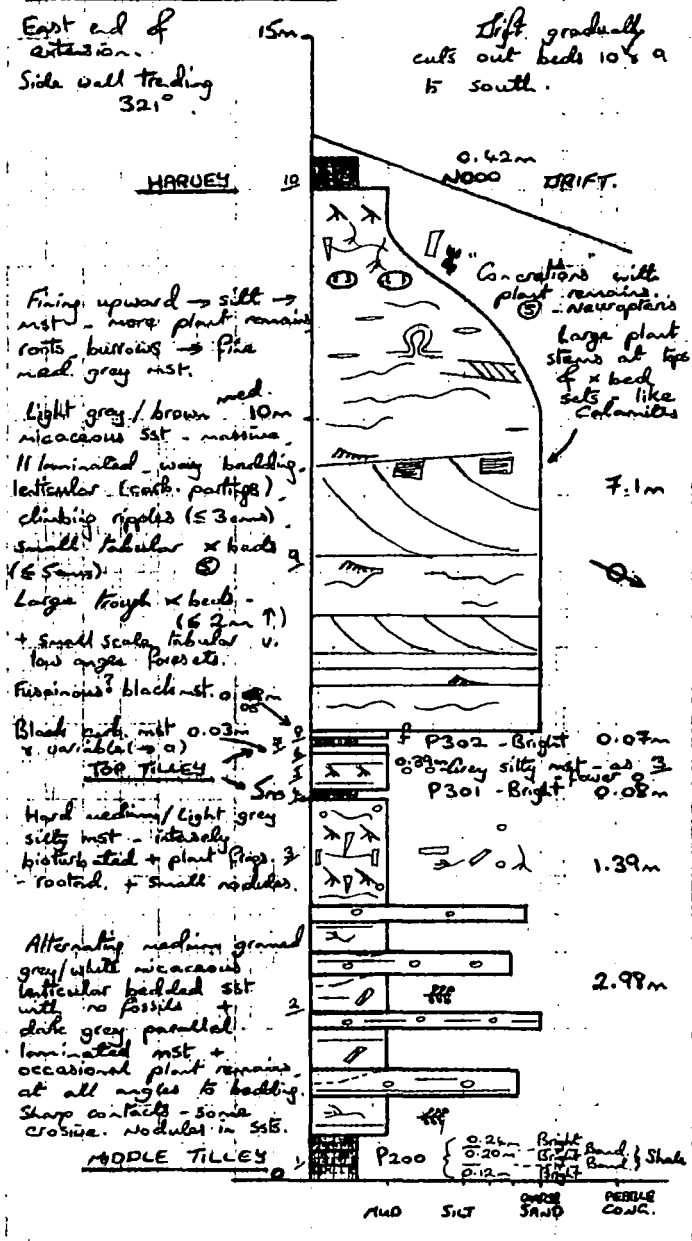
ROWLEY - AS(N)



C.R. FIELDING - 13/11/79.

SECTION 021

- ESH WINNING - CUT K5.



Comments - Combination of back and side walls.
Cooling on P203 - 13/11/79
Shear walls.
Two small faults displace strata.
Little lateral variation - all beds traceable across cut.

2 frames b/w ASA 125 film shot.

Cross bedding data on Unit 9
- 8/111, 6/082, 12/113, 15/133, 18/131, 10/135, 16/135, 6/111, 7/094.

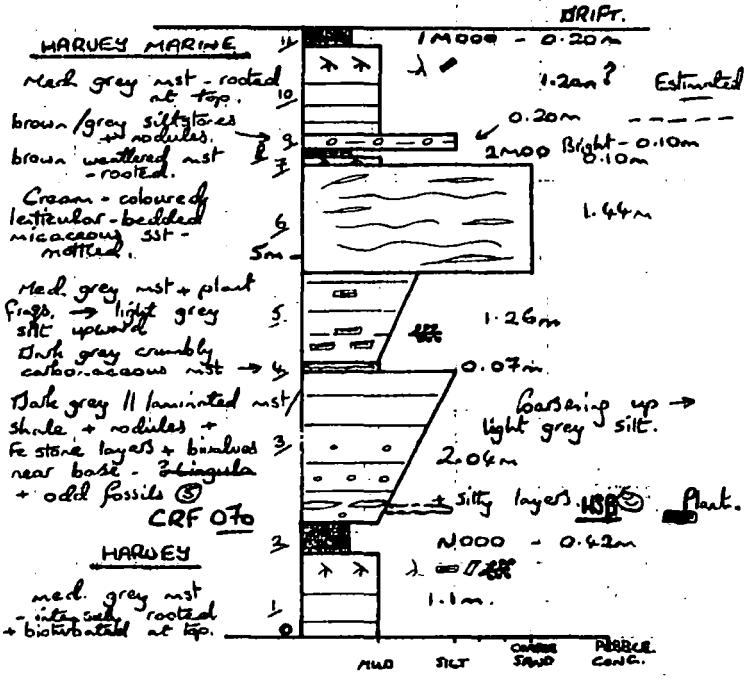
2 samples - Sst, and ? Neuropteris.
CRF 068 CRF 069

C.R. FIELDING - 13/11/79.

SECTION 022.

ESH WINNING - CUT J4.

100 yds west of east end.
Wall trending 235°.



Comments - Backwall - shear.
Cooling on N000 - 13/11/79
Some lateral variation - sst below 1M00 thickens to west and south. Otherwise facies laterally uniform.
5 frames b/w ASA 125 film shot.

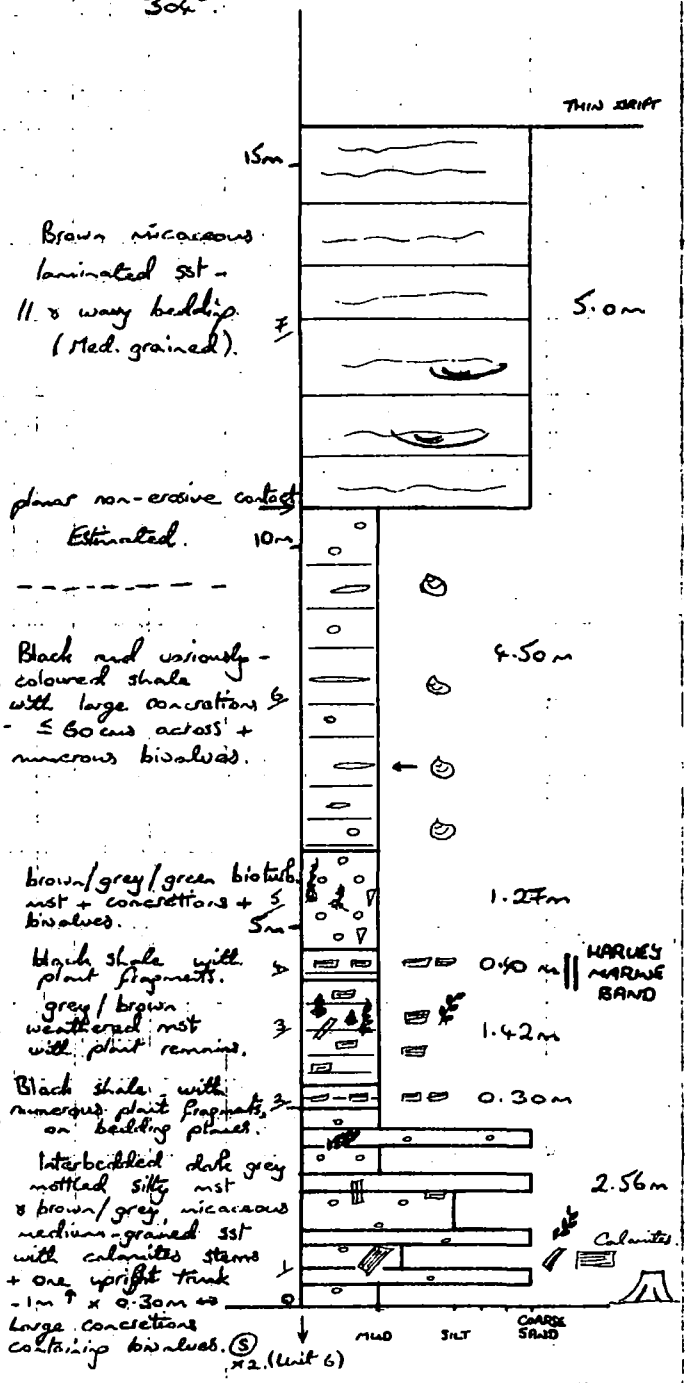
1 sample - odd fossil.

C.R. FIELDING - 13/11/79

SECTION 023.

ESH WINNING - CUT F1.

West end of site.
Backwall - trending 304°.



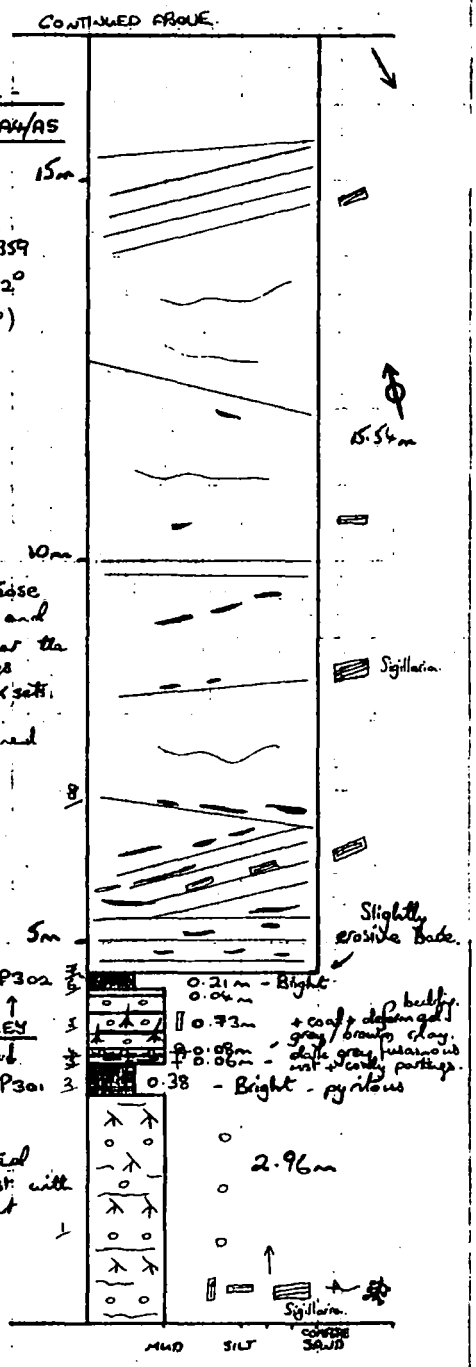
Comments

Section above 1M00 - Harley Marine Seam.
4 frames b/w ASA 125 film shot.
Backwall - coaling finished - now backfilling slowly.
Sloping wall 1 in 1.
2 samples - Concretions.
CRF 071
" 072

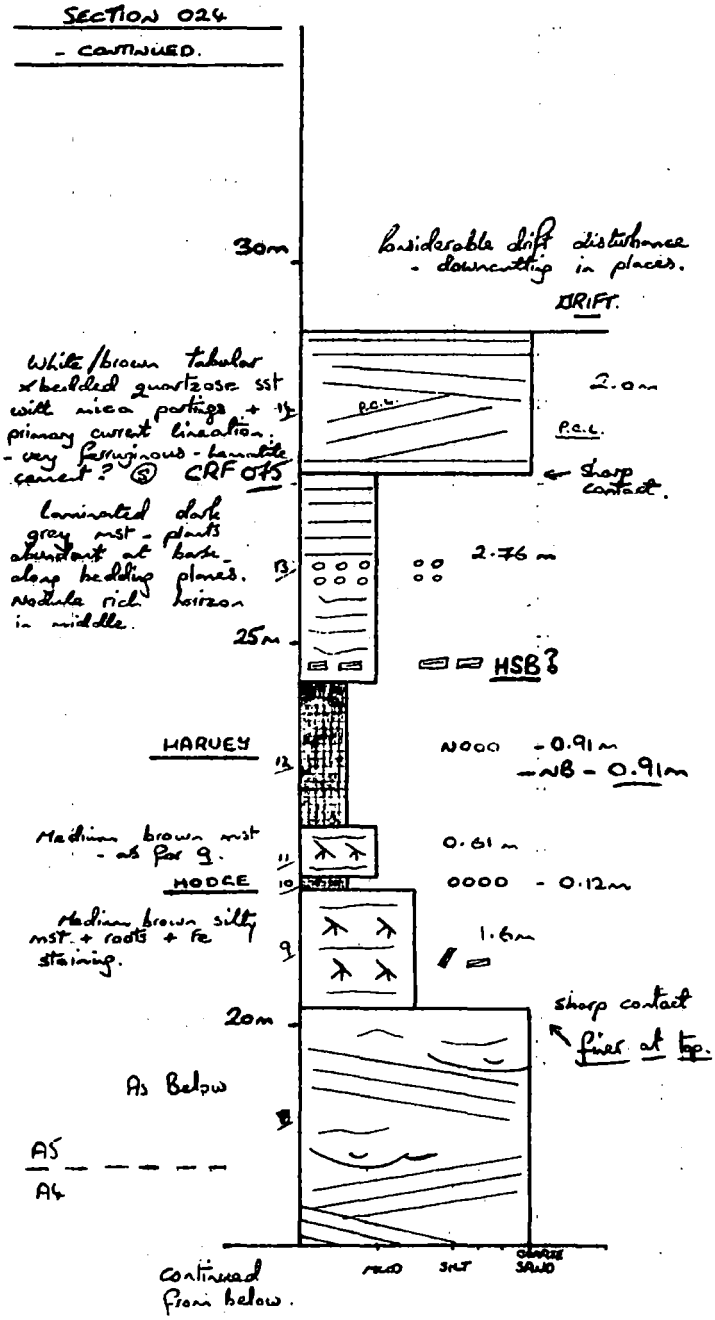
C.R. FIELDING - 16/11/79.

SECTION 024 - DEBORAH - CUT A4/A5 (West end).

Regional Bedding 18/359
Wall orientation 082°
(Plan - 1in 3 _ 010°)



SECTION 024 - CONTINUED.



Comments. Little lateral facies variation.
Shear Backwalls with ramps - Stripping.
8 frames ASA 125 b/w film shot.
3 samples taken :- CRF 073 a_b
CRF 074
CRF 075

× Sets from unit 8 :-

1. 1.5m/14/012°
2. 0.3m/27/013°
3. 0.4m/18/328°
4. 0.2m/23/337°
5. 0.4m/20/351°
6. 0.6m/17/336°
7. 0.25m/30/360°
8. 0.5/22/332
9. 0.4m/6/314
10. 0.3m/28/305°
11. 0.5m/10/351°

n = 11

See also Section 025.

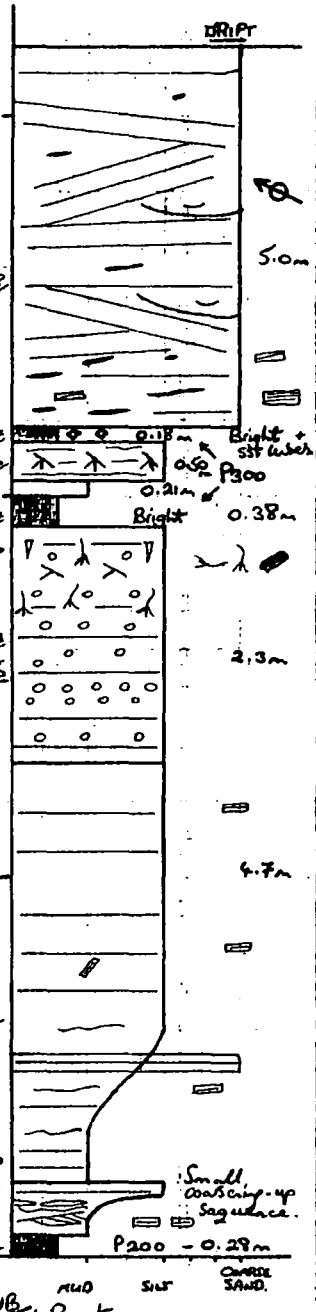
See Correction

C.R. FIELDING - 16.11.79

Considerable drift disturbance.

SECTION 025.

DEBORAH - CUT A4(EAST)



White/brown tabular x bedded micaceous sst with scaly partings - rafts exp. at base. - med. grained. Estimated

- heavily bioturbated x rooted silt + clay particles - ? CONG. - ? FER ④ CRF 077 a, b

TOP TILLEY

Light grey/brown clay. No bedding. ⑤ CRF 078

Fewer nodules at top.

Medium/light grey silt as before - with abundant nodules ⑥ concentrated in certain horizons. CRF 076

- heavily bioturbated toward top.

After 2m - becomes silty gradually. + ole fine sst layer (10 cms).

Medium/light grey mst - lam. + small scale (2 cms) low angle foresets + wavy bedding. Fe stone bands near base.

Bright - MIDDLE TILLEY

P300

P200

NB Info. to P100

Remarks

Dip of top Tilley seam - 13/355°. (Plan - 1 in 6 _ 010°)

P200 ↑ 1.57m strata
P100 ↑ - 0.26m Bright

Little lateral facies variation

70° backwalls - cooling.

5 frames ASA 125 b/w film shot.

3 samples.

x Sets from Unit 8:-

1. NB ripples - symmetrical, smooth-topped - 0.15m ≥ - dipping at 41/310 - up to 0.15m high - 0.3m >
2. 1.0m/18/319°.
3. 0.6m/20/319°.
4. 1.0m/29/357°
5. 0.6m/22/303°.
6. 0.3m/25/004°
7. 0.5m/25/320°
8. 1.0m/I/353° ∧ = 8
9. 1.0m/22/354°

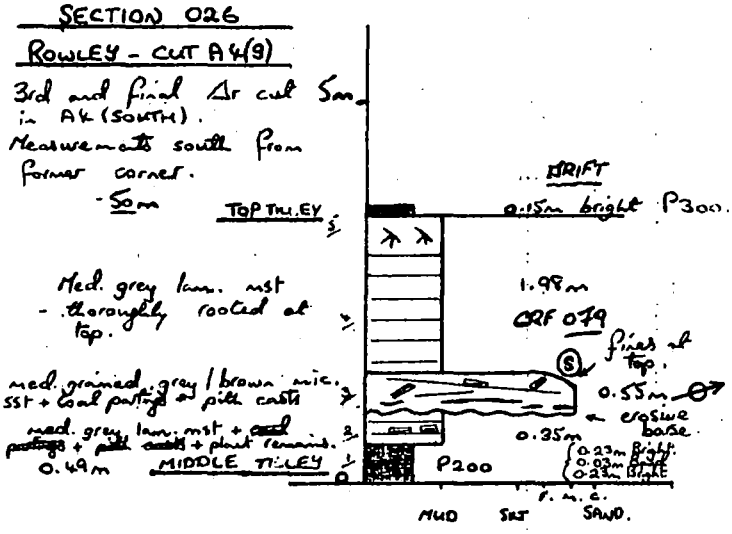
C.R. FIELDING - 22.11.79

SECTION 026

ROWLEY - CUT A4(9)

3rd and final Δr cut 5m in A4 (SOUTH).

Measurements south from former corner.



- 5m

TOP TILLEY

Med. grey lam. mst - thoroughly rooted at top.

med. grained grey/brown mic. sst + coal partings + pith casts

med. grey lam. mst + coal partings + pith casts + plant remains.

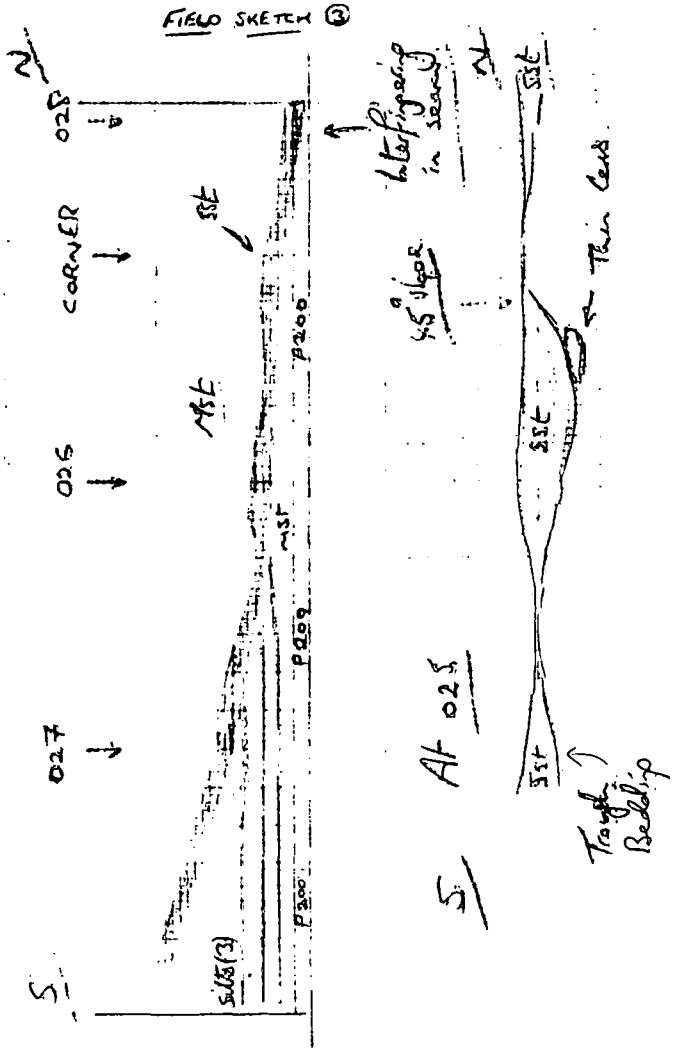
0.49m MIDDLE TILLEY

NOTES 1. at top of Unit 2 a thin lens (0.56m ≤ x 0.14m ↑) of dark grey plant rich sst occurs - precursor of main body.

2. Unit 3 is a lens shape - wedges out in 8m & the reappears (5) with trough (0.3m) x bedding - 8/261 x and 18/080 in mst above. - then ascends cliff gradually as a consistent 0.45m unit. In trough-bedded exposure a thin mst parting appears in the middle. Sample - erosive sst -

SKETCH OF THE AREA AROUND 026/027.

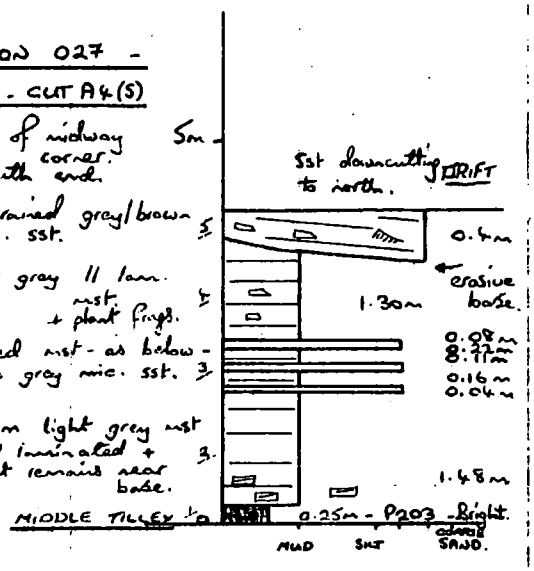
FIELD SKETCH ②



C.R. FIELDING 22/11/79

SECTION 027 - ROWLEY - CUT A4(S)

105m south of midway corner - near south end.



NOTES Progressing north from southern end of cut sst (Unit 5) eroded through Units 4, 3 & 2 until reaching Section 026 - lies over part of Unit 2. Further north - lies directly over P200.

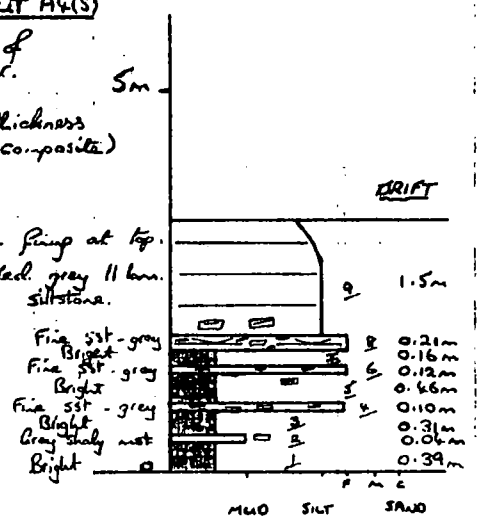
To north of 026 - some low angle x bedding (tabular) displayed - sides of troughs?

See Also Additional notes.

SECTION 028 ROWLEY - CUT A4(S)

30m north of midway corner.

Total seam thickness - 1.44m (composite)



NOTES

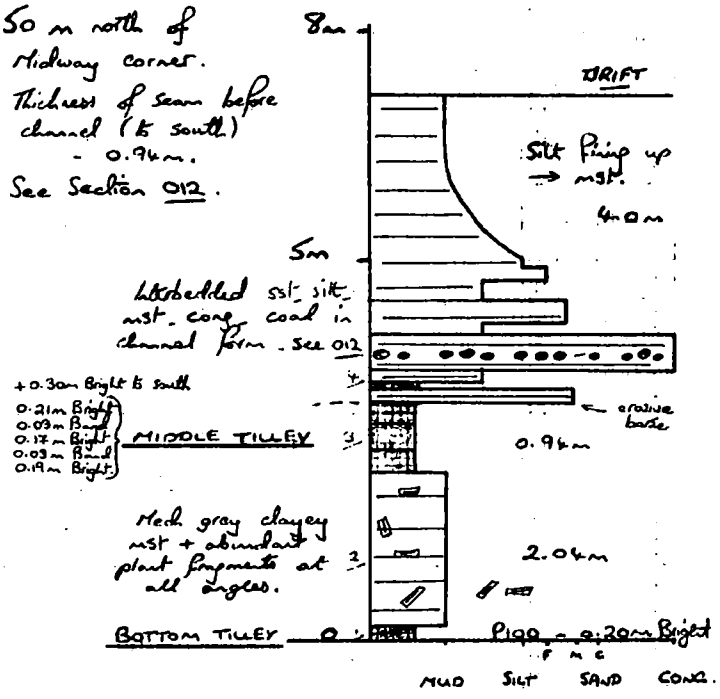
1. Unit 4 grades laterally into med gray mst. - to north.
2. Ssts have occasional plant remains along bedding planes.
3. Unit 4 has a ripple - erosive base. rounded - small symmetrical ripples. 4.5cm ↑ = 2.0 cm ↔
4. Unit 5 - Bright coal displays trough structure - steep channel sides to north - gentler dips to south.
5. Unit 6 - erosive base.
6. Unit 8 - trough bedding displayed.

SECTION 029 ROWLEY - CUT A4(S)

50 m north of Midway corner.

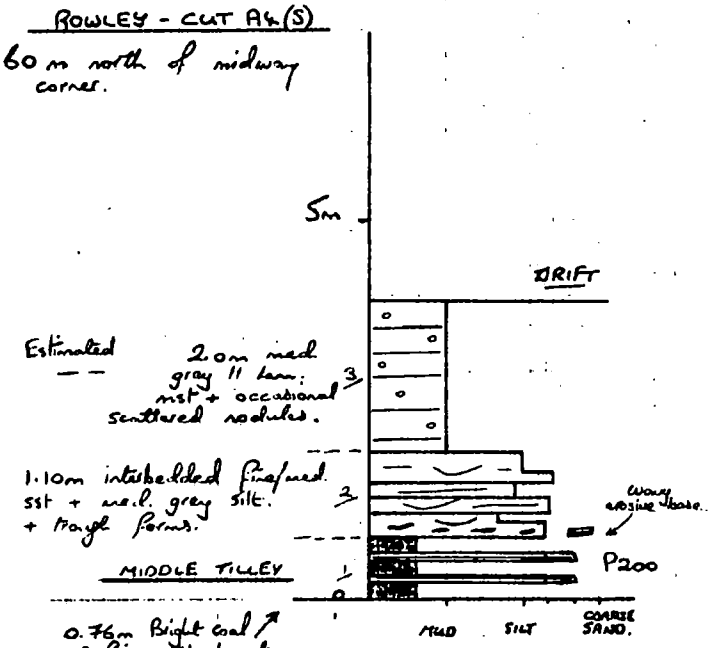
Thickness of seam before channel (to south) - 0.94m.

See Section 012.



SECTION 030 - ROWLEY - CUT A4(S)

60 m north of midway corner.



NOTES - Further channel structure - two thin sst layers within coal - partial washout? - or addition.

Overall comments - boring on P200 & P100 22/11/79 - nearly finished on A4(S).

Low back walls.

Tectonic dip 1 in 30 → 90°.

8 pinned ASA 125 b/w film shot.

See Additional Notes.

C.R. FIELDING - 27/11/79.

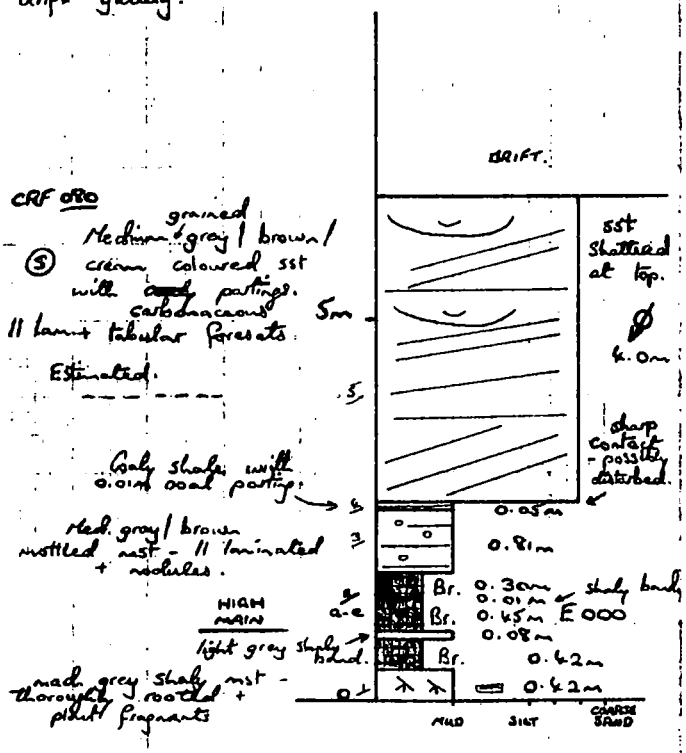
SECTION 031.

IBRETSON'S - CUT 1 (EXT.)

(AREA A.)

Cut trends → 179° 10m

Good exposure in old drift gallery.



Comments

Unit 5 - sst with tabular foresets

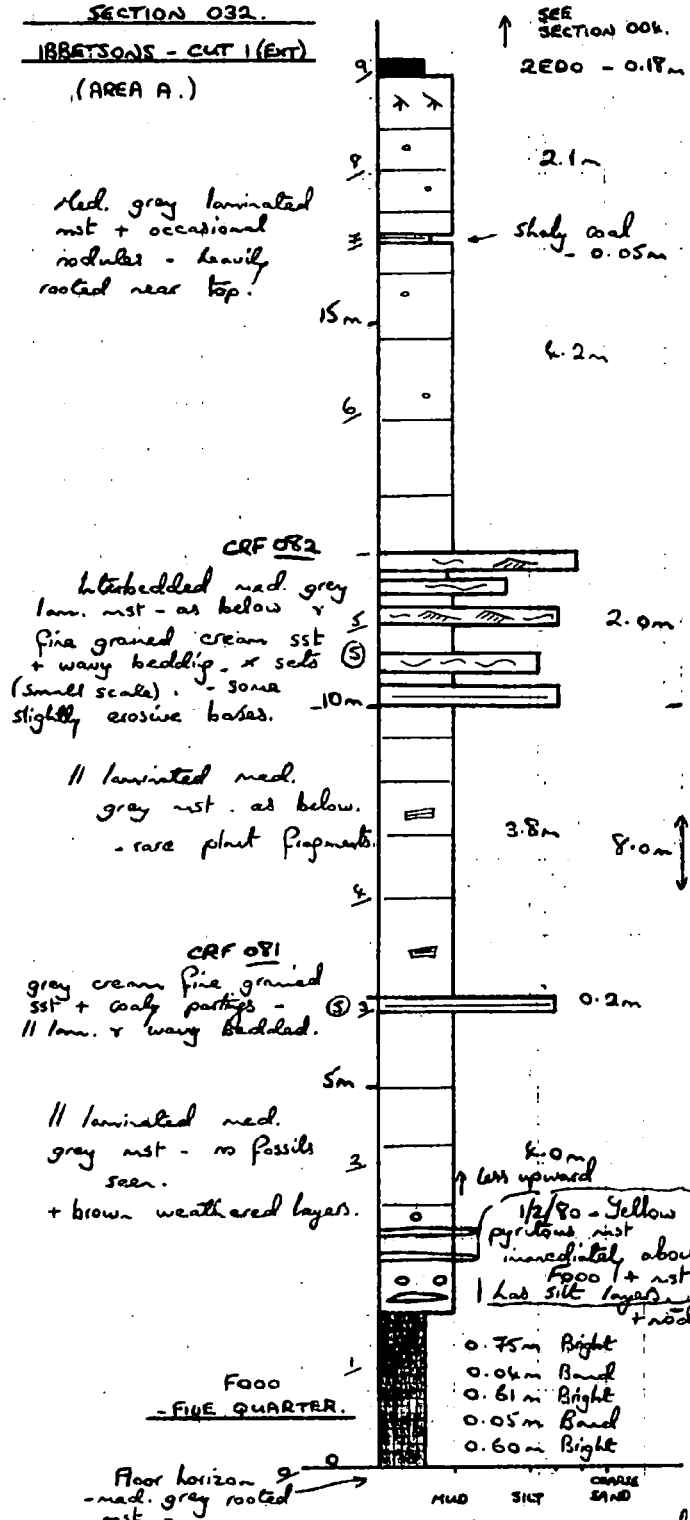
1. 0.3m / 19 / 193°.
2. 0.3m / 21 / 197°
3. 0.6m / 5 / 255°

3 Frames ASA 125 b/w film shot.
1 sample taken - High Main post.
Small cut near the top of A (1) Ext.
High wall.
Two abandoned drift galleries well preserved and exposed.
Baliz on E000 - 27/11/79
Regional dip = 1 in 17 → 011°

SECTION 032.

IBRETSONS - CUT 1 (EXT.)

(AREA A.)



NB Bands in F000 are composed of purple / grey shaly mst.

Comments - High Backwall,
Baliz on F000 - 27/11/79
3 Frames ASA 125 b/w film shot.
2 samples taken,
Little lateral variation in facies
See Borehole Data - in notebook.

C.R. FIELDING - 6/12/79.

SECTION 033.

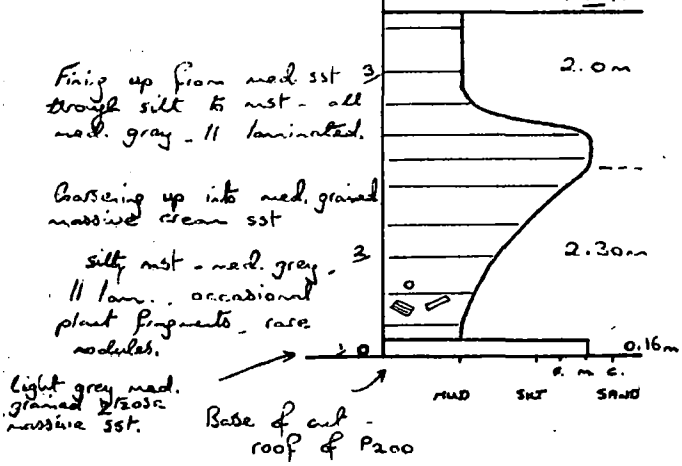
ROWLEY - CUT A6(3)

10yds South of Mid Wall.
- Beginning of Cut A6(3)
Wall trending 180°.

Further south (5m) - laterally variable & discontinuous med. grained massive cream - brown mic sst layers - ≤ 30cms ↕. - wedge out rapidly.

Silts & muds laterally variable in grain size.

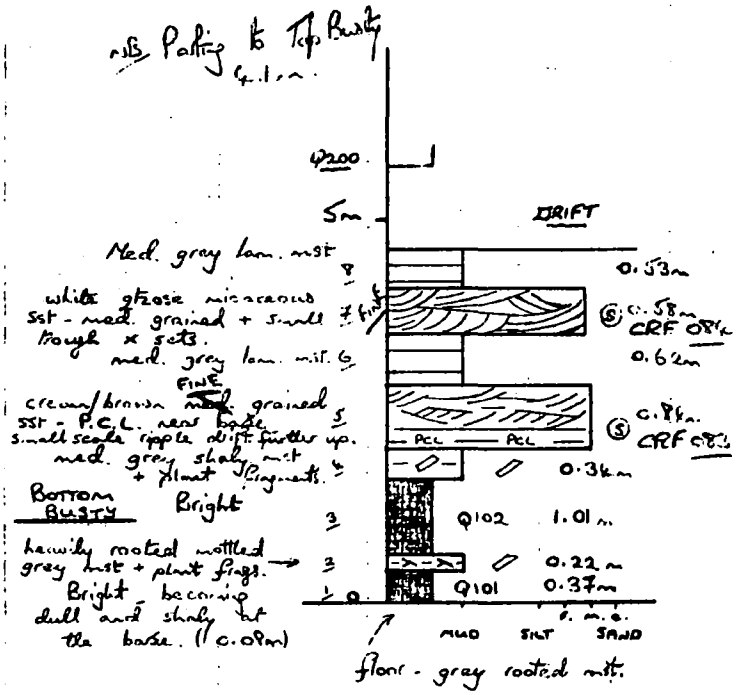
- Some disturbance.



SECTION 035

ROWLEY C7.

NE of road.
Narrow cut to East of glacial channel - cut trends 056°.

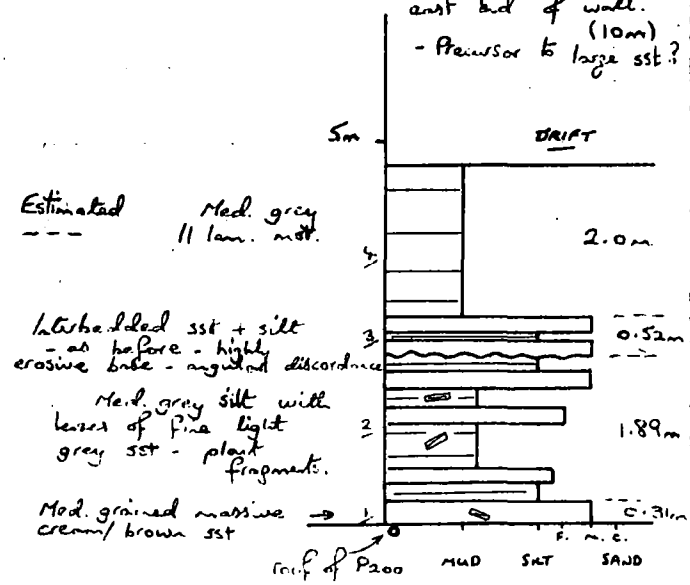


SECTION 034.

ROWLEY - CUT A6(3)

Middle Wall - trending 263°

Unit 3 - comes down from the top of the wall to lie directly over P200 at east end of wall. (10m)
- Precursor to large sst?



Angular discordance 17°/c90 (3) as opposed to 1°/c90 - Unit 2 - no 3d. exposure - but difference marked.
1 frame b/w ASA 125 shot

NOTES

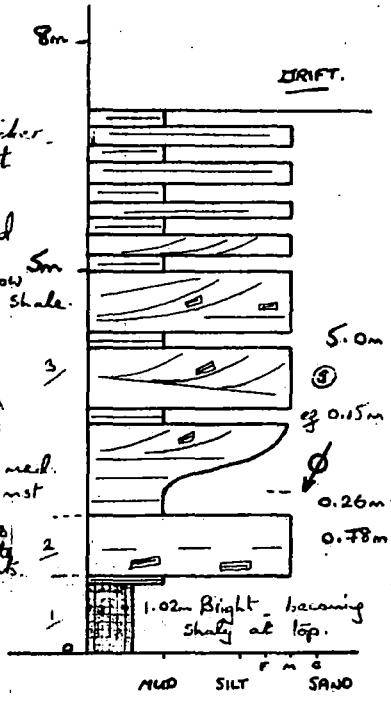
1. 2d sst laterally variable in thickness from 0.05 - 1.0m along the cut.
2. 1m above second sst - trace of φ200 in drift disturbance.
3. 2 samples - 2nd from 1st sst.
4. 6 frames ASA 125 b/w film shot
5. Lens of flaser bedded white med. grained 0 - 0.30m - on SE Wall - med. flasers are red/brown coloured - 2 plates. - between first and second ssts. - last cut to west, rapidly.

General
1. Shear walls - fairly small.
2. Faulting on P200 and φ100.
3. Beginning cuts A6(3) & A(5) N on E west side of road.
4. Up to 50% old workings in φ100.
5. Some minor faulting.

C.R. FIELDING - 17.12.79

SECTION 036.
DEBORAH - A ii

Area/Cut A ii
Side Wall,
trending 028°.



Micaceous and carbonaceous partings in ssts.
Trough x Beds & Wavy bedding.

Trough x Beds - orientations
1. 0.2m / 10 / 190
2. 0.2m / 2 / 230
3. 0.3m / 7 / 239
4. 0.3m / 10 / 227
5. 0.2m / 21 / 207

n = 5.

/ Sample - x Bedded sst. CRF 085
No Photographs.

Some downcutting - both in sst & shale bands - many erosive surfaces. (x Sets)
Sheer back & side walls - coaling on Q000 - 17/12/79

Seam doubled in thickness 5 yards south - drift disturbed.

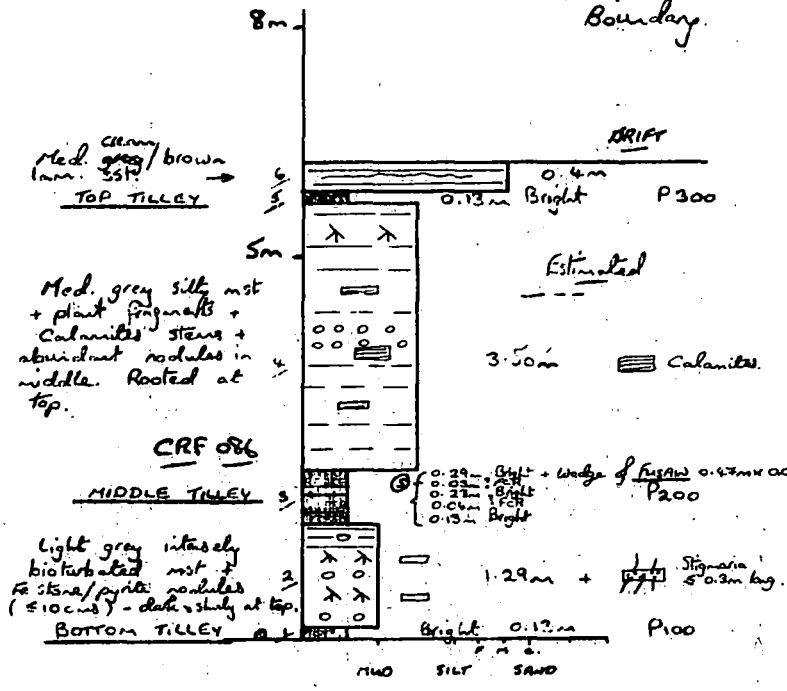
Some larger scale Trough x Beds ≤ 2m ↕
Little lateral facies variation, apart from losing out of x sets (downcutting).

Regional dip 1 in 9 / 028°
= 6.35° / 028°

C.R. FIELDING - 4.1.80

SECTION 037
ROWLEY - CUT A5(N)

Cut A5(N) 10m north of Mill-Fault near north end ← 315m north of N/S Boundary.



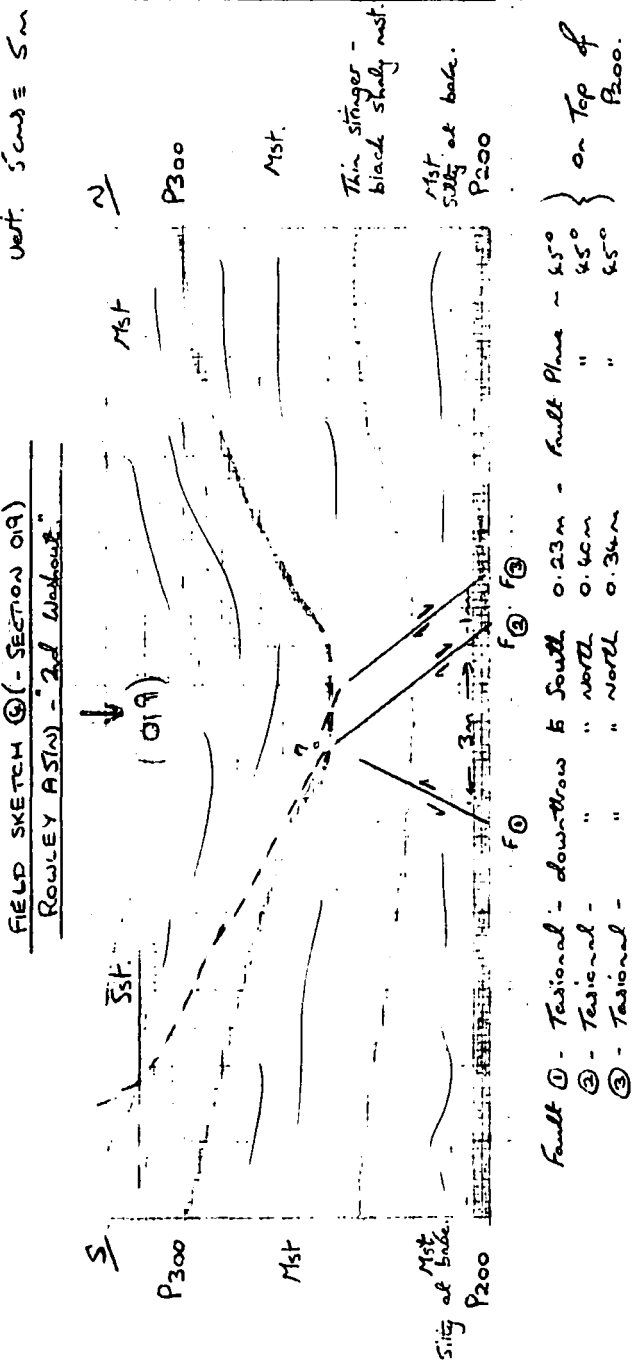
Comments
1. Coaling on P100 - 4.1.80.
2. Sheer face Backwall
CRF 086
3. / Sample - ? FCR - Top Band P200.
4. 3 Frames AJA 125 4/w film shot

Top Band in P200 varies 0.03m → 0.

NB A6(N) South end - sst over P300 - slightly trough-shaped foresets + PCL. + wavy lamination & climbing ripples.
Sets not too well-exposed.
Orientations 0.3m / 10 / 037°
0.3m / 14 / 025°.

Start of Film 4

C.R. FIELDING - 4.1.80.



What formerly appeared to be a simple washout may well be controlled at least partly by small-scale tensional faulting. 3 faults observed.

Faults 2 & 3 may merge and continue up the slope at a gentler angle or may die out. Displacement easily seen in P200 - not so in thin stringer above. Channel hypothesis fits north side - bedding dips in - but not so on South side - bedding horizontal - however slope of P300 more gentle on South side - depositional or tectonic?

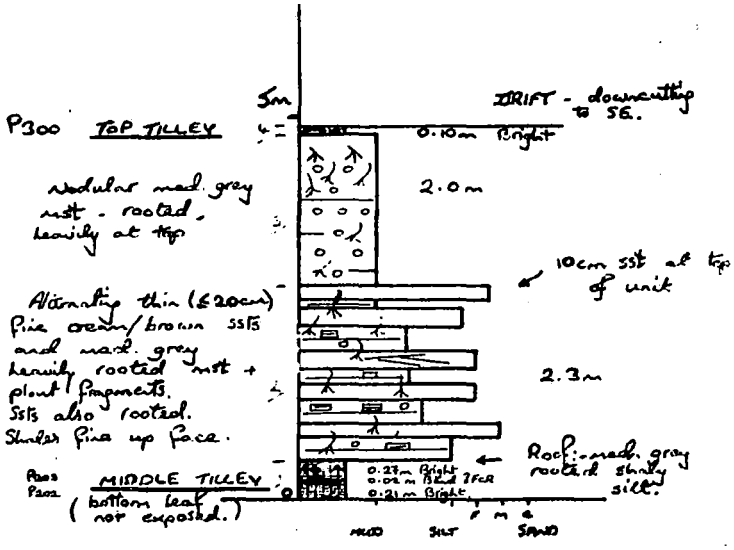
Affected by old workings in Burty? Faults not syndepositional.

C.R. FIELDING - 8.1.80.

SECTION 038

ESH WINNING - CUT H6.

Cut H6 - side wall trending N.45°



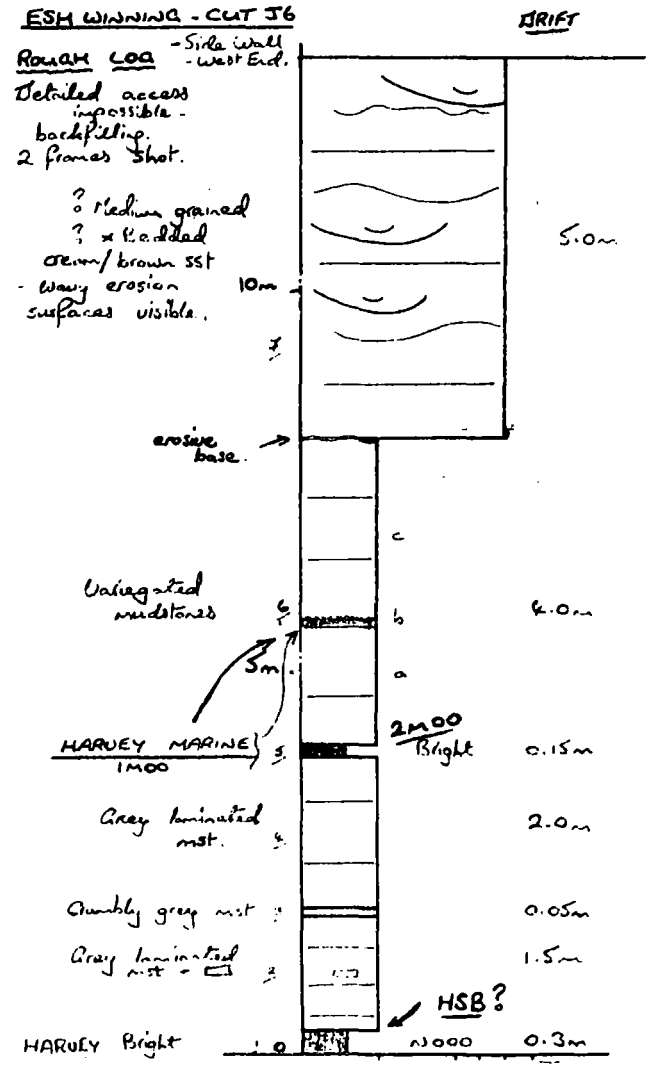
Notes: Thinner sst horizons wedge out to south, thicker ones laterally persistent over 30m. Some very low angle foresets in mst.
Roof of P200 - mostly planar, but wavy in places.
2 frames ASA 125 b/w film shot.

SECTION 039

ESH WINNING - CUT J6

ROUGH LOG - Side Wall - West End.

Detailed access impossible - backfilling.
2 frames shot.

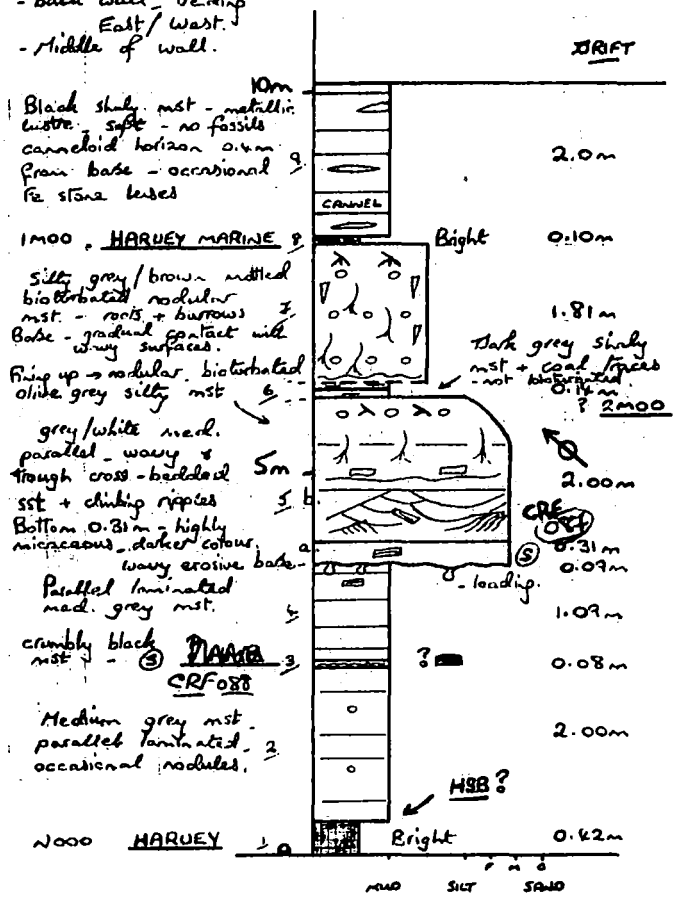


C.R. FIELDING - 8/1/80

SECTION 040

ESH WINNING CUT J6

50m west of 022
- back wall - trending East/West.
- Middle of wall.



Silty grey/brown mottled bioturbated nodular mst - roots + burrows
Base - gradual contact with wavy surfaces.
Fining up → nodular bioturbated olive grey silty mst
grey/white med. parallel - wavy & trough cross-bedded sst + climbing ripples
Bottom 0.31m - highly micaceous - darker colour, wavy erosive base
Parallel laminated med. grey mst.
crumbly black mst - ③
Medium grey mst - parallel laminated occasional nodules.

Trough x Sets in Unit 5

1. 0.2m / 20 / 319°
2. 0.3m / 8 / 345°
3. 0.4m / 10 / 323°
4. 0.4m / 8 / 348.

Vector Mean (Curray 1958)
- Θ = 333.75
- ι = 97.5%
- n = 4

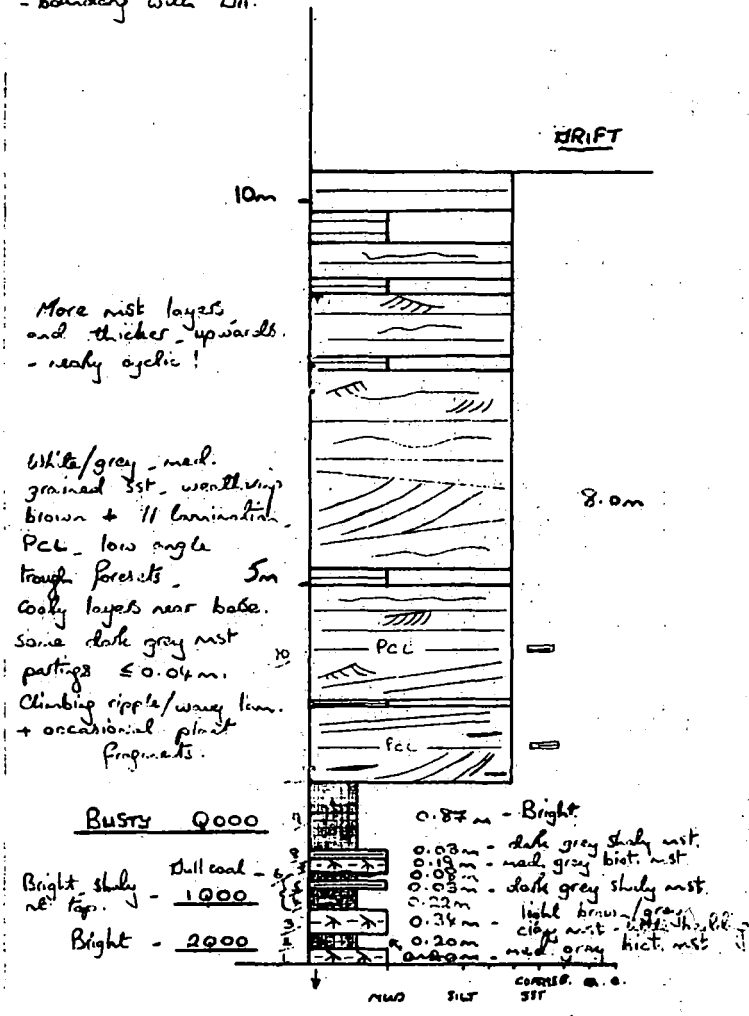
Notes
1. Unit 6 - shaly mst with coaly traces - traced eastward, becomes 2m00 Seam. - bright coal. No trace of this horizon to west - see Section 039.
2. 2 samples. - ? HMB - 3 Sandstone - 5a CRF 087
3. No photographs - see 022.
4. Backfilling 8/1/80
5. Coaling finished in area J - now only working Area K.
6. Shear walls - backfilling
7. Total 6 photographs taken

C.R. FIELDING - 16.1.80

SECTION 041

DEBORAH - Di - CUT 5.

Area Di - Cut 5
SE corner of long cut
- boundary with Dii.



More mst layers and thicker upwards.
- really cyclic!

White/grey - med. grained sst - weathering brown + // laminations
PCL - low angle trough foresets - 5m
Coaly layers near base.
Some dark grey mst partings ≤ 0.04m.
Climbing ripple/wavy lam. + occasional plant fragments.

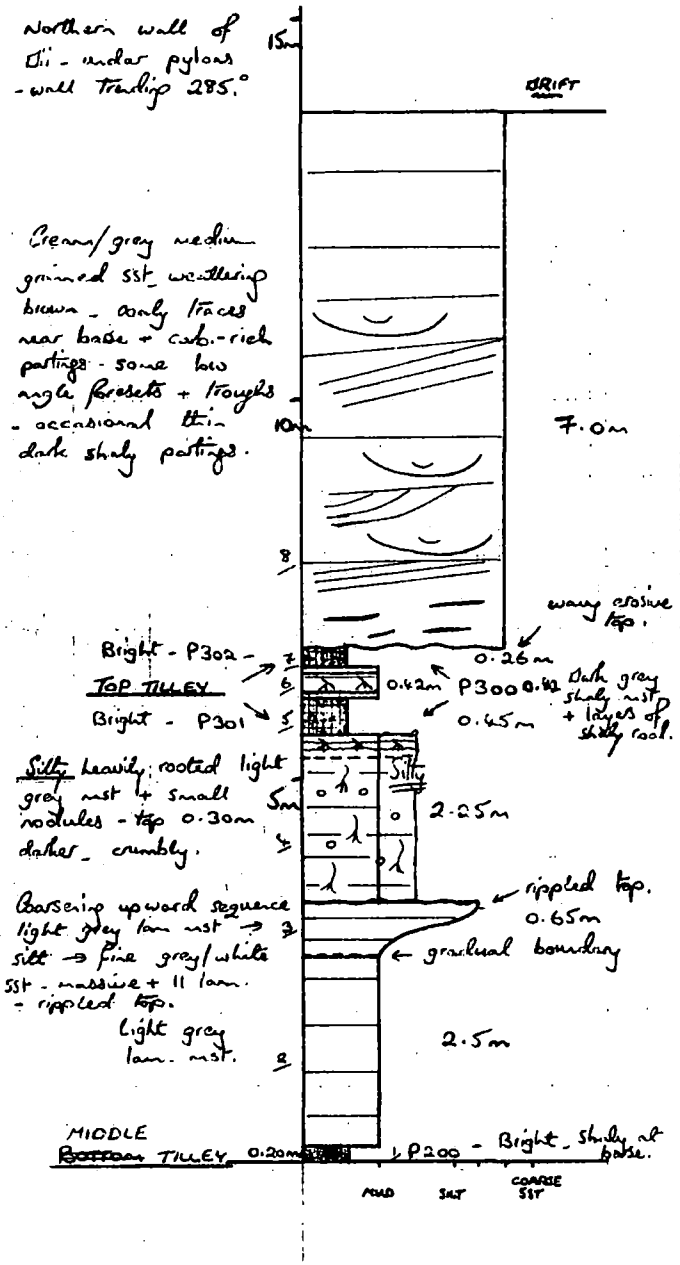
Notes
- No. Samples
- No Photographs
- long narrow cut - coaling on Q000 - 1Q00 - 2Q00

NB 2 seams previously not accounted for - 1Q00 - 2Q00
- Not drilled while prospecting.

C.R. FIELDING - 16.1.80.

SECTION 042

DEBORAH - Dii - CUT



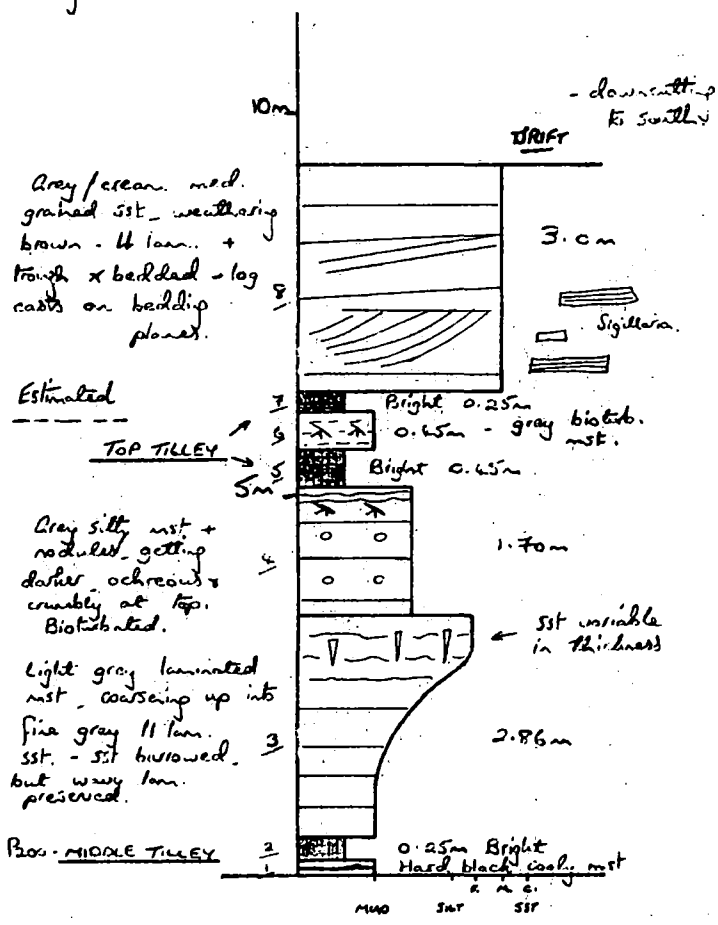
Notes - 1. No Samples
2. 2 frames ASA 125 b/w film shot
3. Bailing on P200 - high back wall.

C.R. FIELDING - 16.1.80.

SECTION 043.

DEBORAH - Bii - CUT 6.

log thin out.



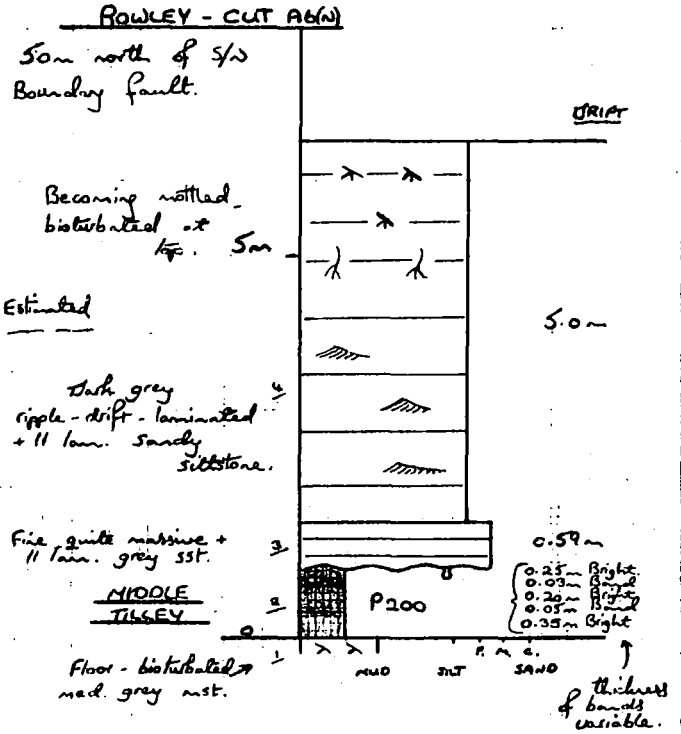
Notes
1. No samples.
2. Lots of photographs - log fragments.
3. Bailing on P200
4. Parity between top of Unit 3 and P300 widens out down-dip → 351°.

C.R. FIELDING. - 25.1.80.

SECTION 044

ROWLEY - CUT A6(N)

50m north of S/N Boundary fault.



Notes: 1. 2 frames b/w ASA 125 shot.

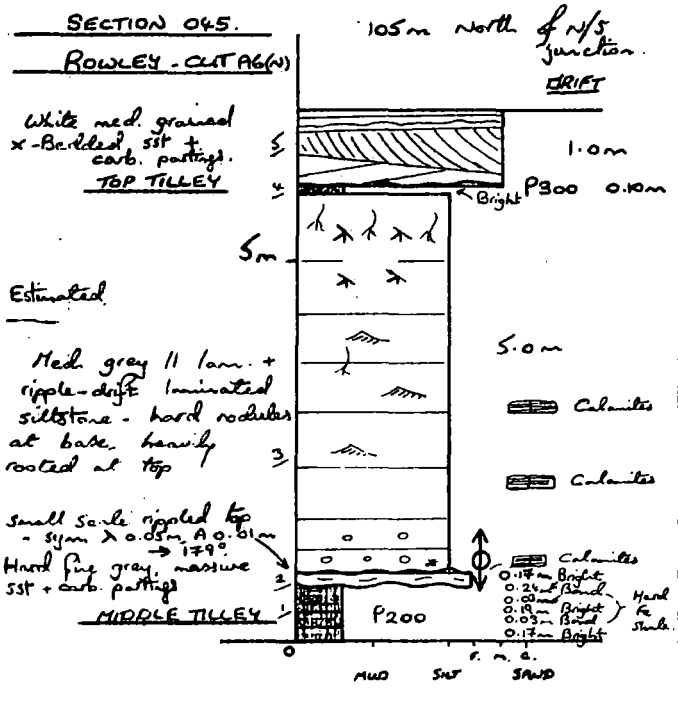
2. Sst thins abruptly → 0 within 2yds to south - also thins gradually to south - varying laterally in thickness.

3. Working north, after 20m sst band up to 0.6m thick - then thins again.

SECTION 045.

ROWLEY - CUT A6(N)

105m North of N/S junction.



1. * Small scale ripples on top - dimensions above.

2. 3 frames - panorama showing ? lateral Accretion - in Unit 5.

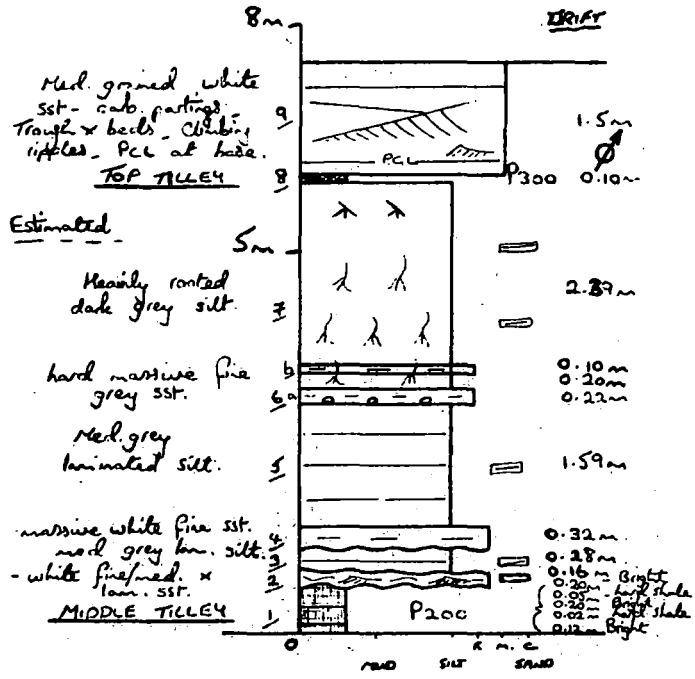
3. 1m to north, wedge of sst comes in abruptly from 0 → 0.5m at 1.58m above P200. - continues to north - wavy base and abrupt top - wavy + x bedding. log casts of Calcrites ≤ 0.5m x 0.03m

C.R. FIELDING - 25/1/80

SECTION 046.

ROWLEY - CUT A6(N)

125m north of N/S Junction



1. Cross-bedding data on Unit 9 (4/1/80) - trough x beds
   1. 0.3m/10/037°
   2. 0.3m/14/025°
   n = 2.

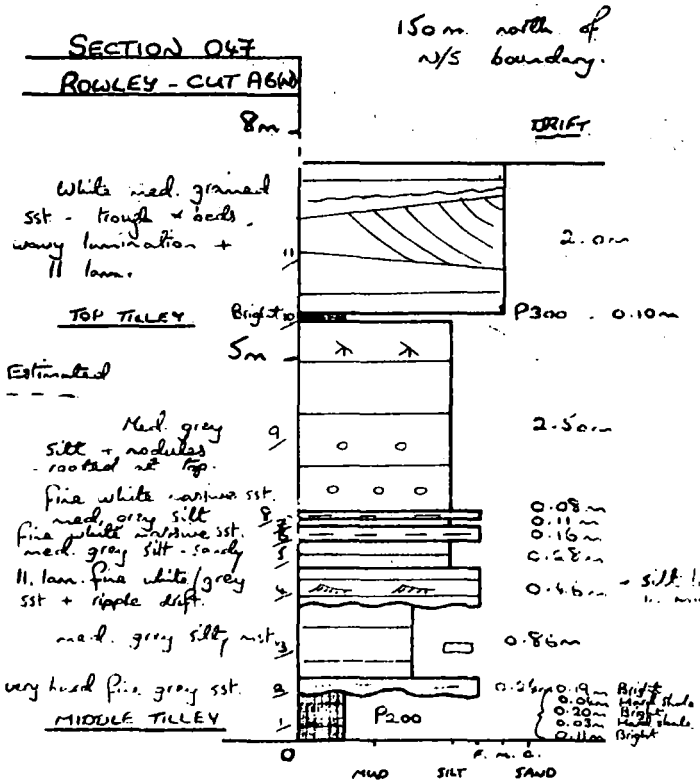
2. Unit 4 disappears rapidly to south - changes grade to silt, rather than pinching out

3. Unit B4 correlates with Section 047.

SECTION 047

ROWLEY - CUT A6(N)

150m north of N/S boundary.



1. Silt parting between P200 + P300 decreases to north.

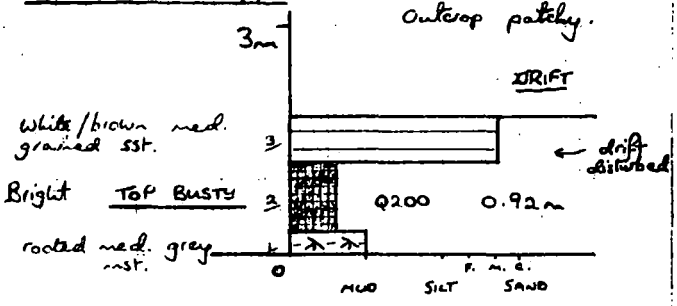
2. 3 frames shot.

3. Units 4 + 6 pinch to the south - and correlate with Unit B4 of Section 046.

C.R. FIELDING - 25/1 and 1/2/80.

SECTION 048.

ROWLEY - CUT B(1)



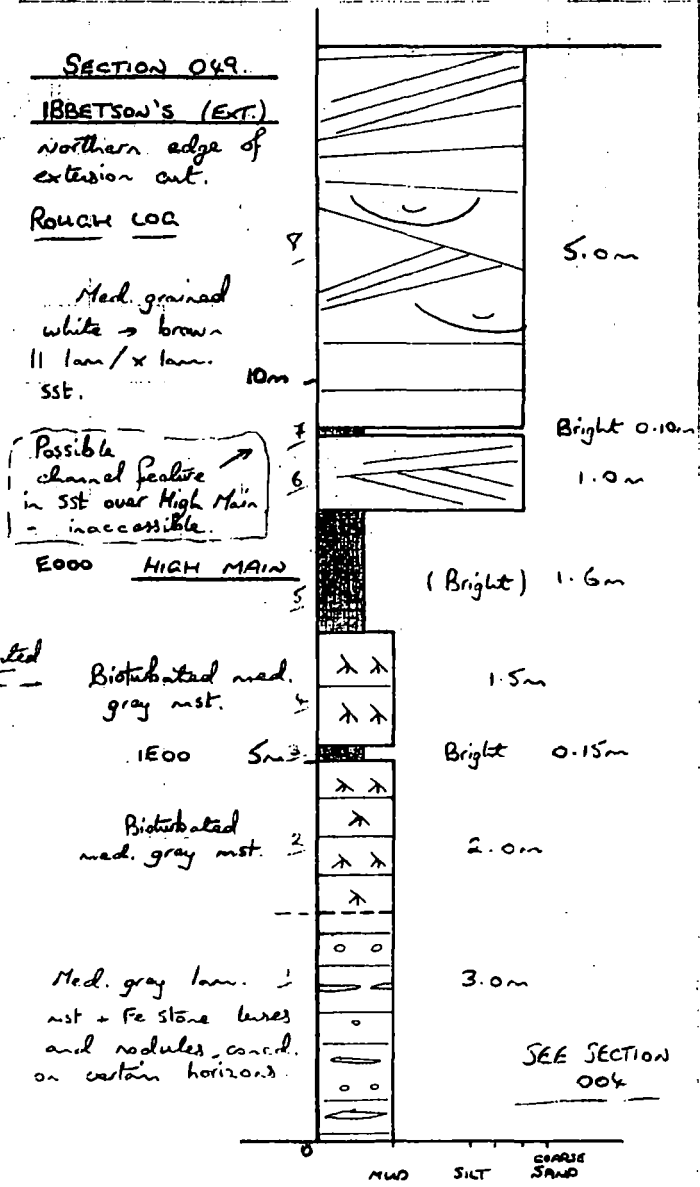
1. Corner of cut - extra coal - not contractual.
2. Total 8 frames b/w ASA 125 film shot.

SECTION 049.

IBBETSON'S (EXT.)

northern edge of extension cut.

ROUGH COA



1. Partly backfilling.
2. 1 sample - yellow pyritous mst from roof of 5ft seam - below section. CRF 089
3. 12 frames ASA 125 b/w film shot.
4. NB ROUGH COA

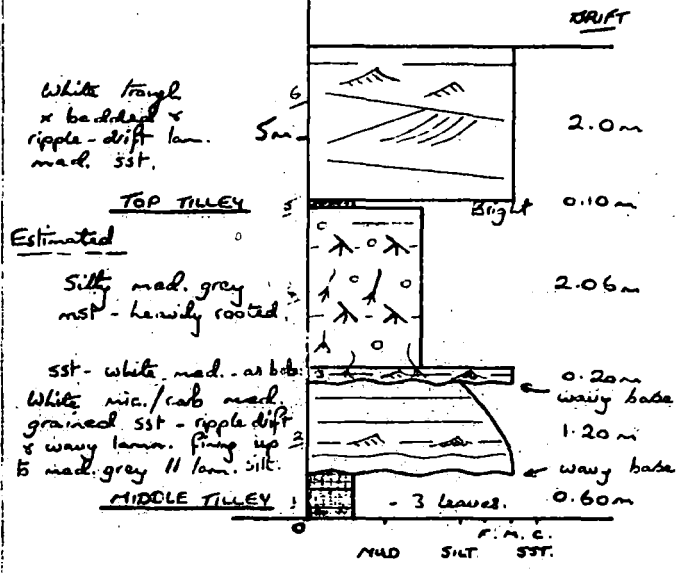
C.R. FIELDING - 5.2.80.

SECTION 051

ROWLEY - CUT A6(N)

25m north of 050.

180m north of N/S boundary.

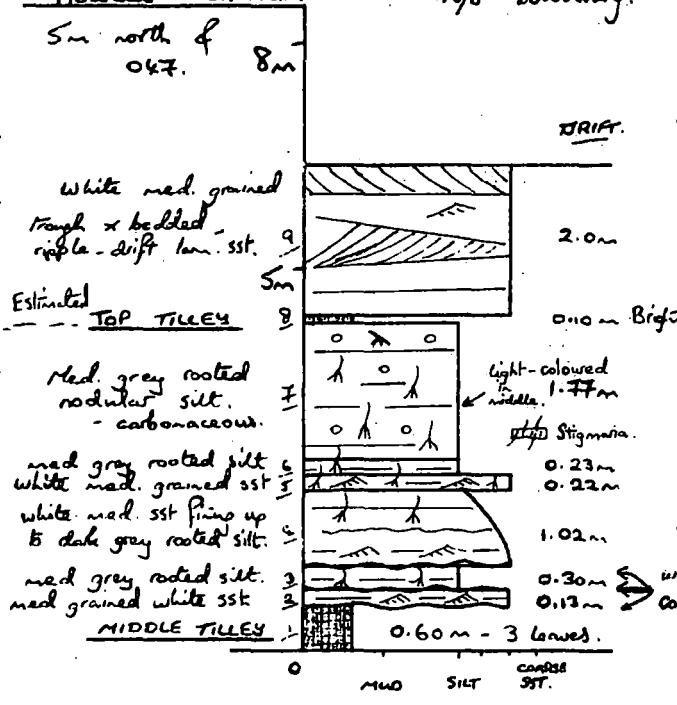


SECTION 050.

ROWLEY - CUT A6(N)

5m north of 047.

155m north of N/S boundary.



4 frames shot.

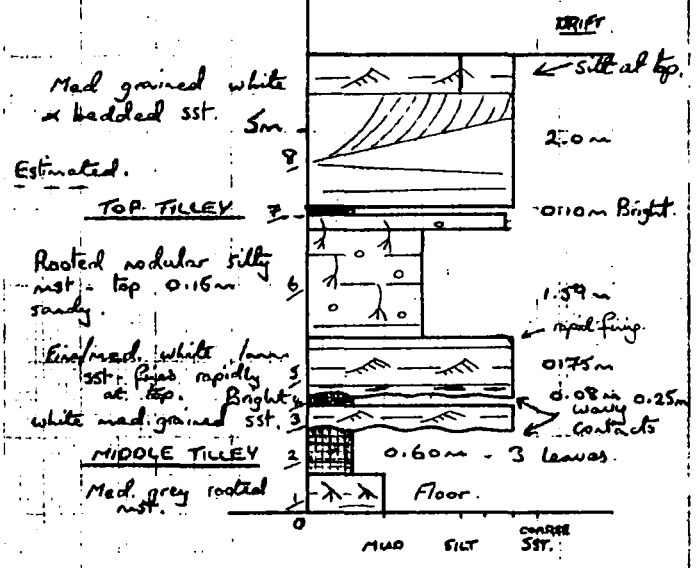
C.R. FIELDING - 5.2.80.

SECTION 052.

ROWLEY - CUT A6(N)

202m north of N/S Boundary.

22m further north.



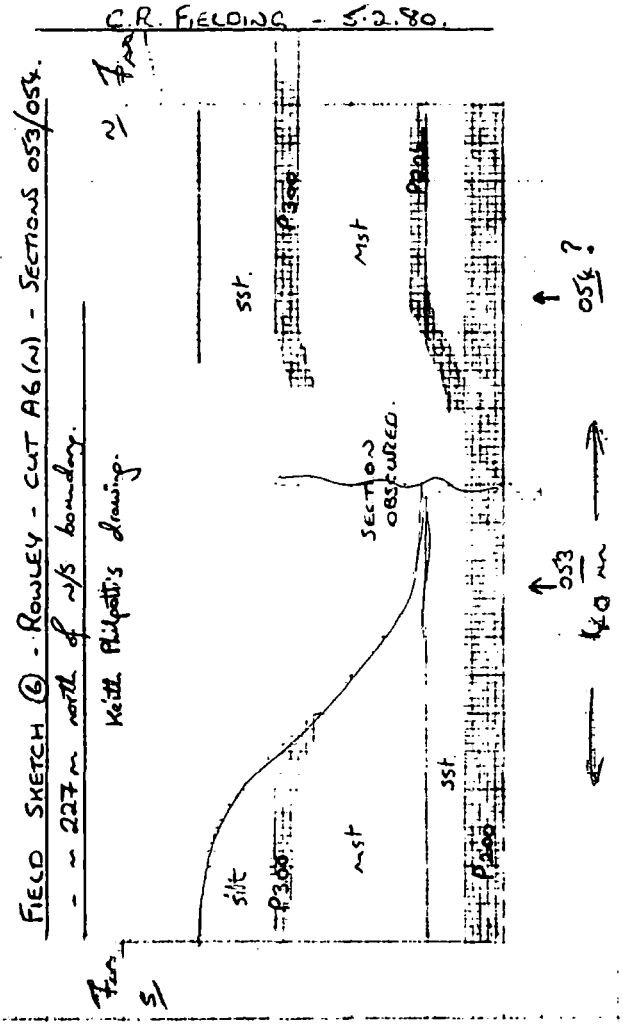
Unit 4 is a laterally inconsistent rider of coal above P203 - variable in thickness.

C.R. FIELDING - 5.2.80.

FIELD SKETCH (6) - ROWLEY - CUT A6(N) - SECTIONS 053/054.

- ~227m north of N/S boundary.

Keith Philpott's drawing.

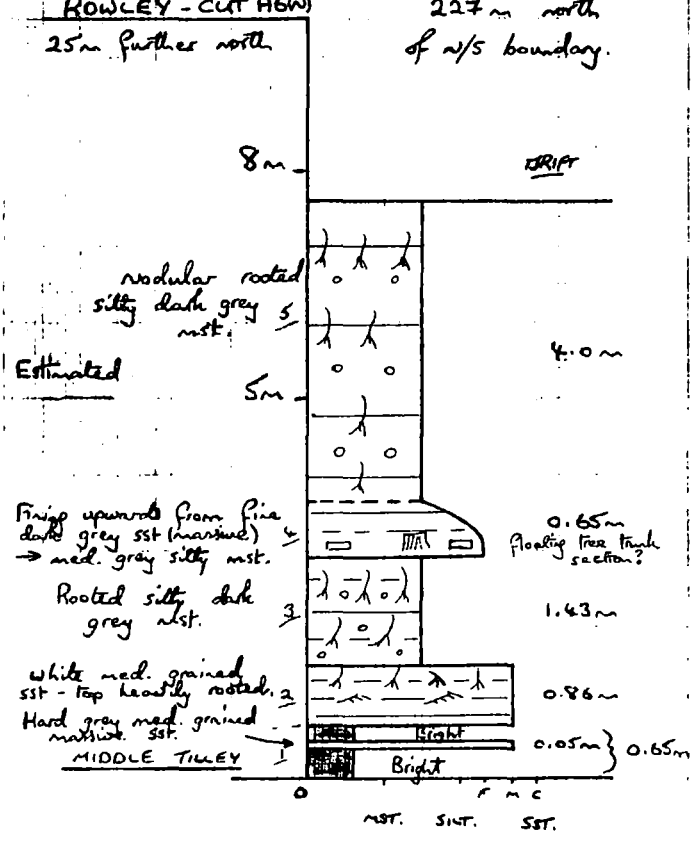


SECTION 053.

ROWLEY - CUT A6(N)

227m north of N/S boundary.

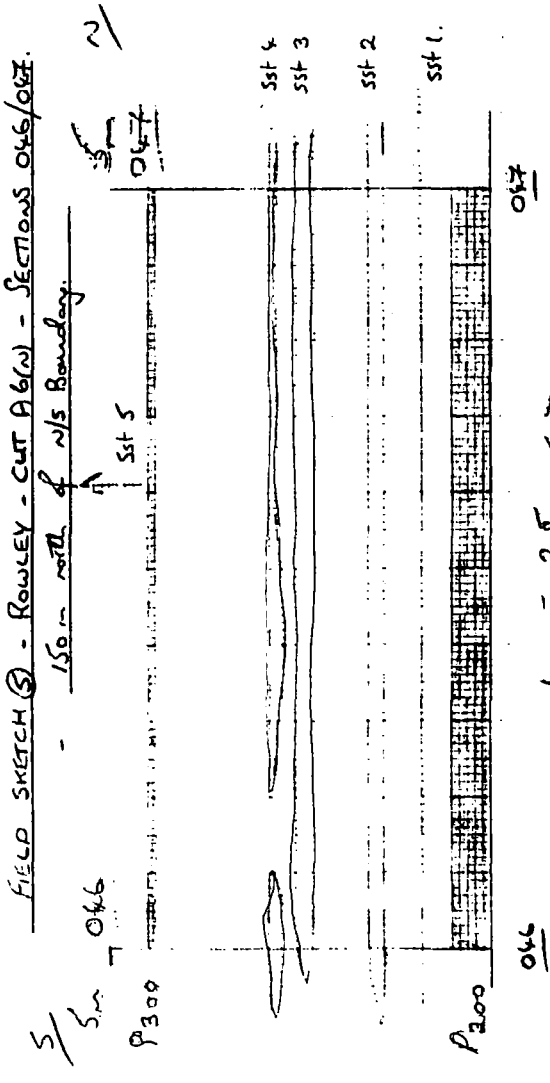
25m further north



NB 10m to south - washout in P300 - down cutting channel feature - see sketch.

FIELD SKETCH (5) - ROWLEY - CUT A6(N) - SECTIONS 046/047.

- 150m north of N/S Boundary.

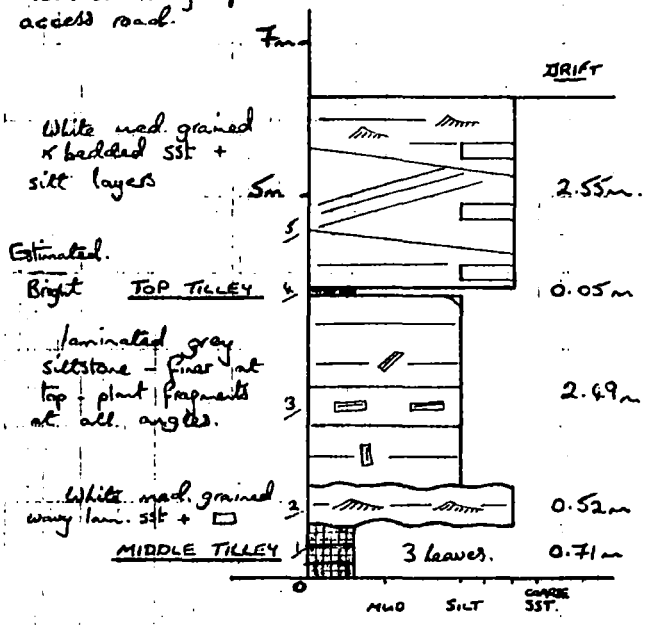


C.R. FIELDING - 12/2/80.

SECTION 054
- ROWLEY - CUT A6(N)

Between two washouts.

240m north of Mid Wall - 10m south of top access road.



Sea working sketch. NB from 053+

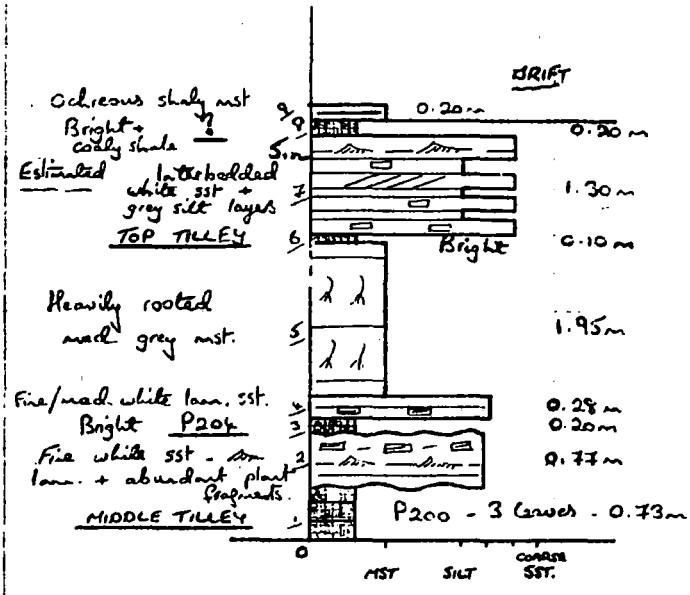
3 samples - 55ta

1. Within P300 rider: 092
2. Above P300 rider: 091
3. Base of channel fill: 090

C.R. FIELDING - 12/2/80.

SECTION 056.
ROWLEY. - CUT A6(N)

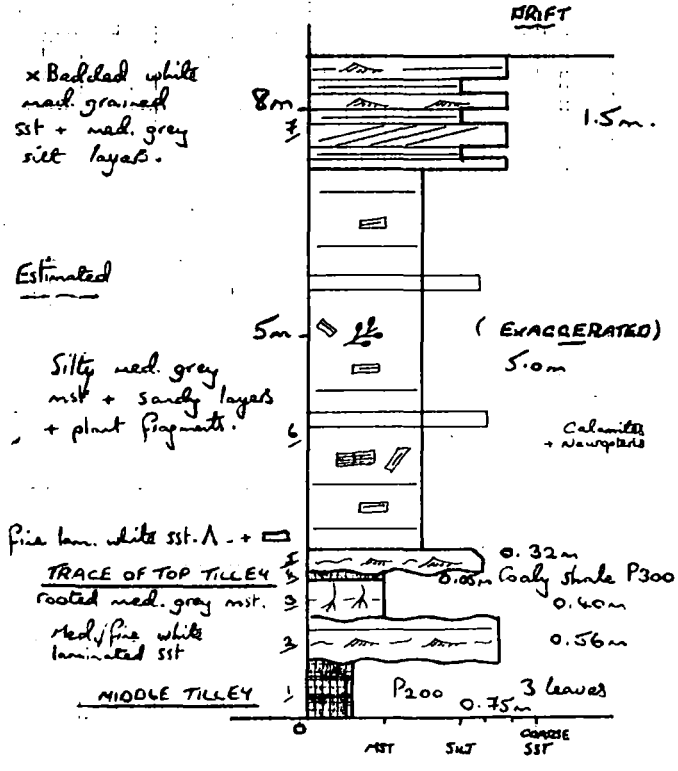
290 m north of Mid Wall.



P204 joins P200 10.m to south.

SECTION 055.
ROWLEY - CUT A6(N)

255m north of Mid Wall - 2nd washout.

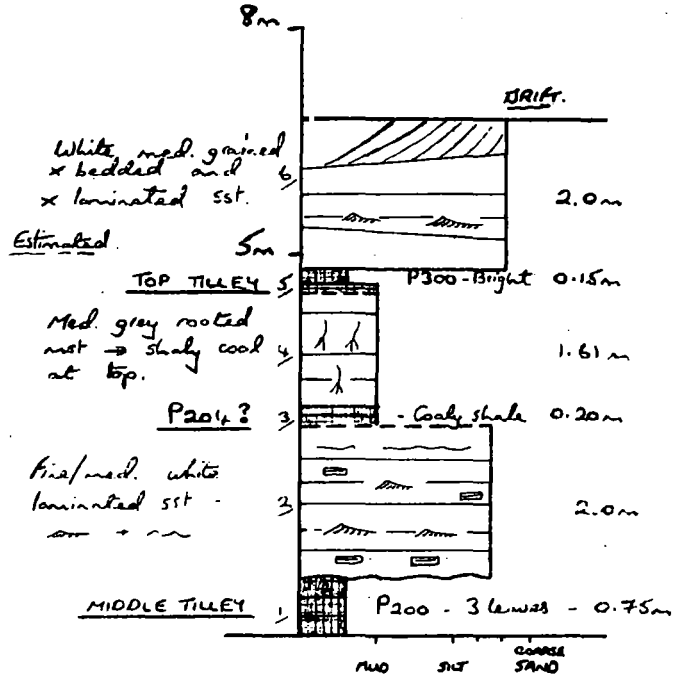


Slightly to north of channel axis.
Sst Unit 5 does not occur on southern margin of channel.

SECTION 058
ROWLEY - CUT A6(N)

- 057 - SEE OVER

339m north of mid wall - by 1m fault - down faulted to north

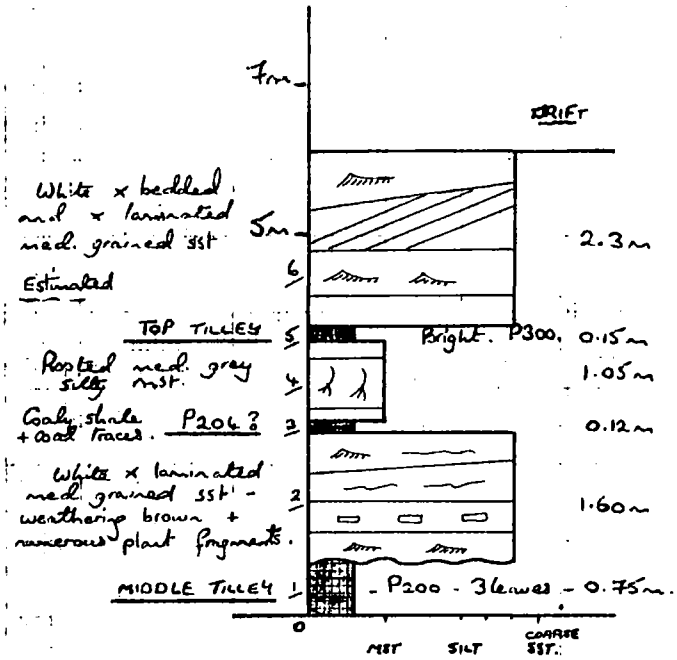


057 - See over

C.R. FIELDING - 12/2/80

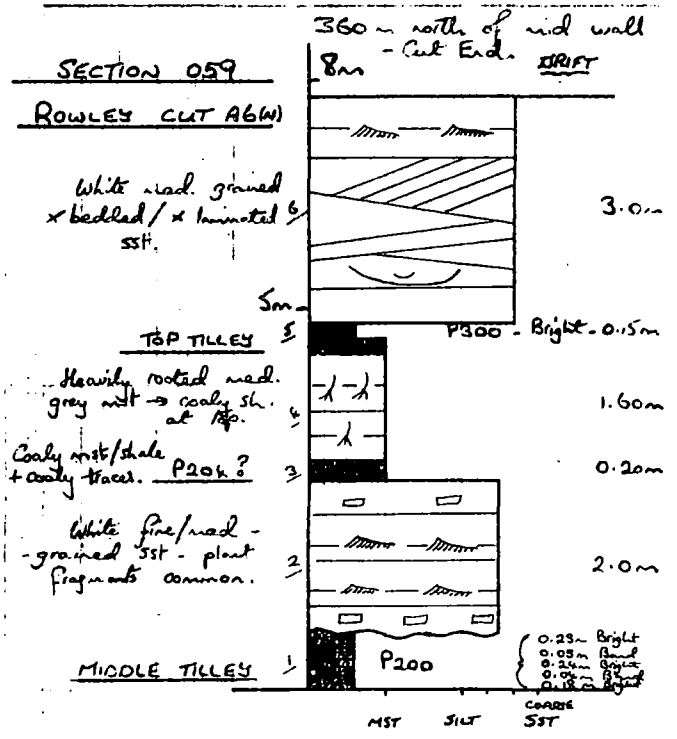
SECTION 057
- ROWLEY - CUT A6(N)

300m north of Mid wall.



SECTION 059
ROWLEY CUT A6(N)

360m north of mid wall - Cut End.

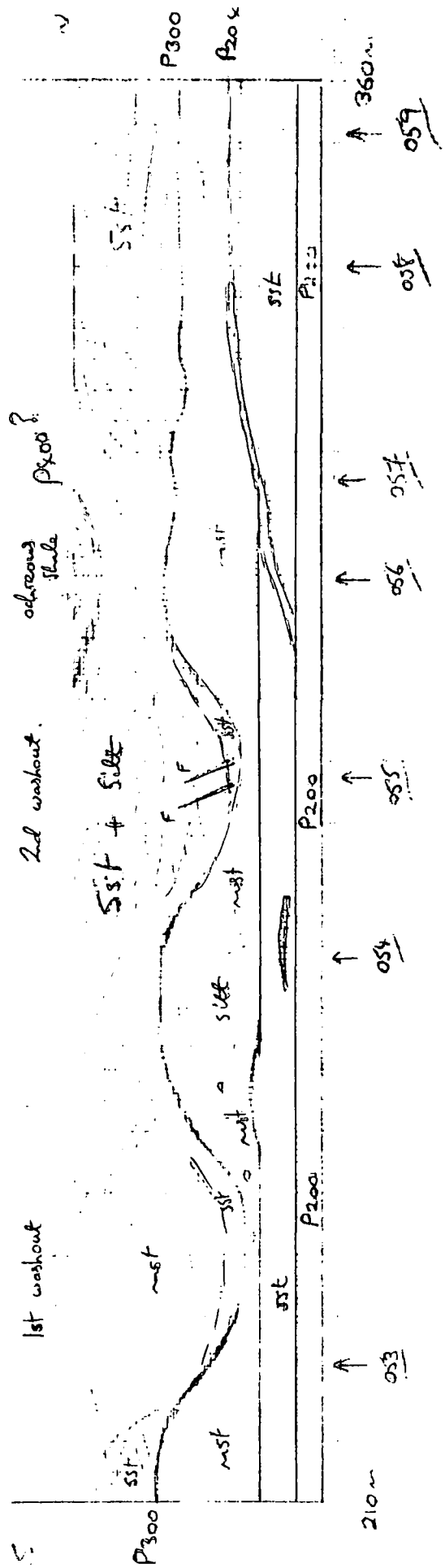


Traverse along A6(N) now complete - see Longitudinal Section + Sketch 7.

Total - 3 samples - No photographs

Presently coaling on P100.

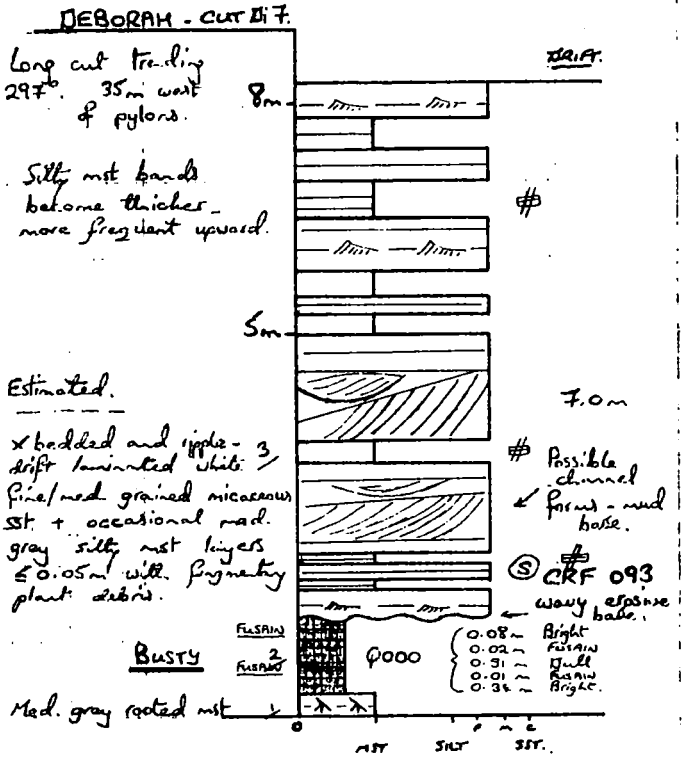
FIELD SKETCH 7 - ROWLEY A6(N) - NORTH END - SECTIONS 053 - 059.



C.R. FIELDING - 19.2.80

SECTION 060

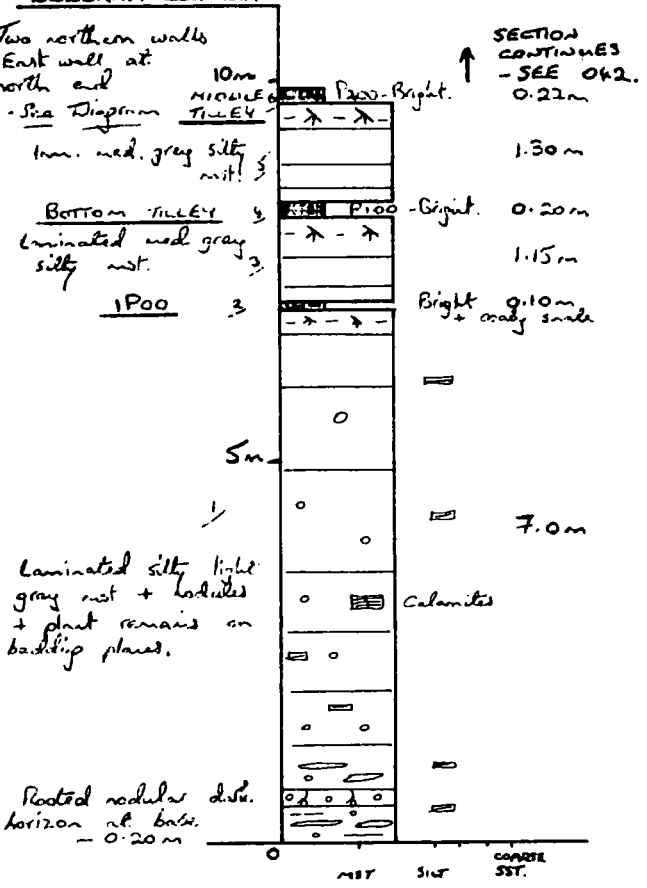
DEBORAH - CUT Di 7.



Notes - 2 frames ASA 400 b/w film shot.
1 Sample - sst - 0.4m above mst base.
x Beds in sst mst dip → West.

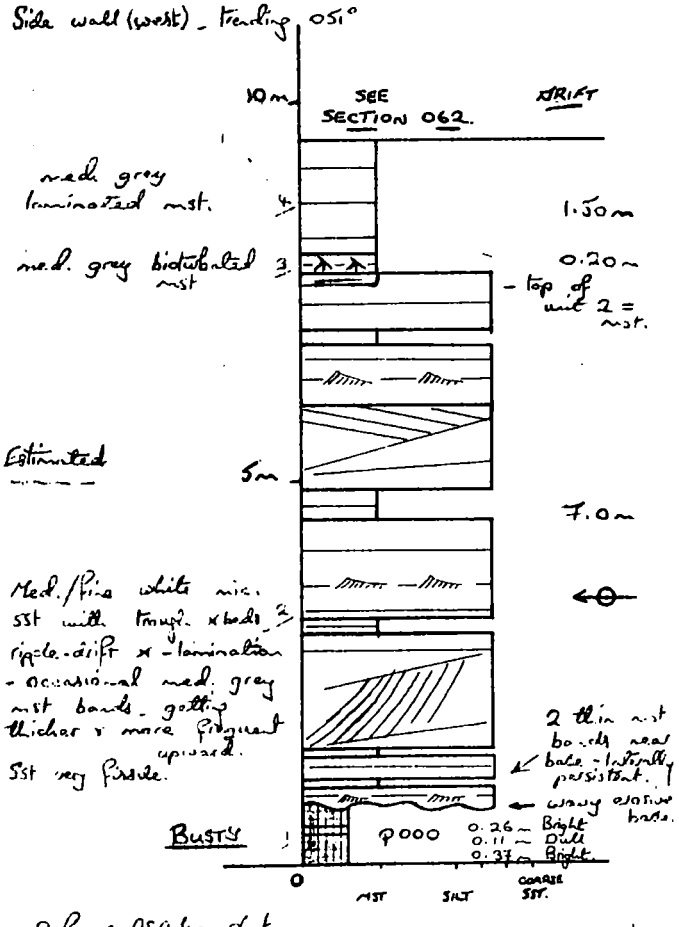
SECTION 062.

DEBORAH CUT Di.



SECTION 061

DEBORAH - CUT Dii



2 frames ASA 400 shot
Fusain not recognizable.

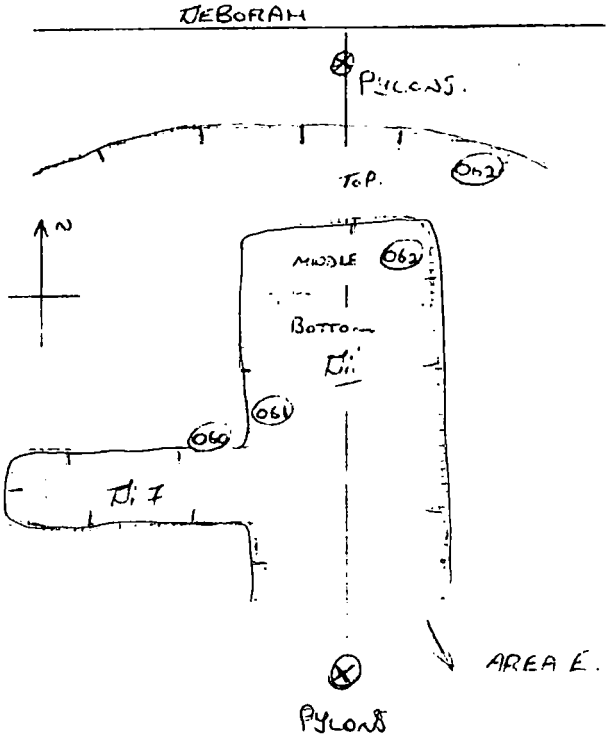
Trough x Beds in Sst 2
1. 0.5m / 23 / 275°
2. 0.6m / 16 / 275°

NB Joins on to top of 061.

Small coarsening-upward sequence lifts toward P300 to west and at E-W north wall - parting decreases in thickness.

6 frames ASA 400 b/w shot.

SKETCH PLAN OF AREA D AT 19/2/80.
DEBORAH

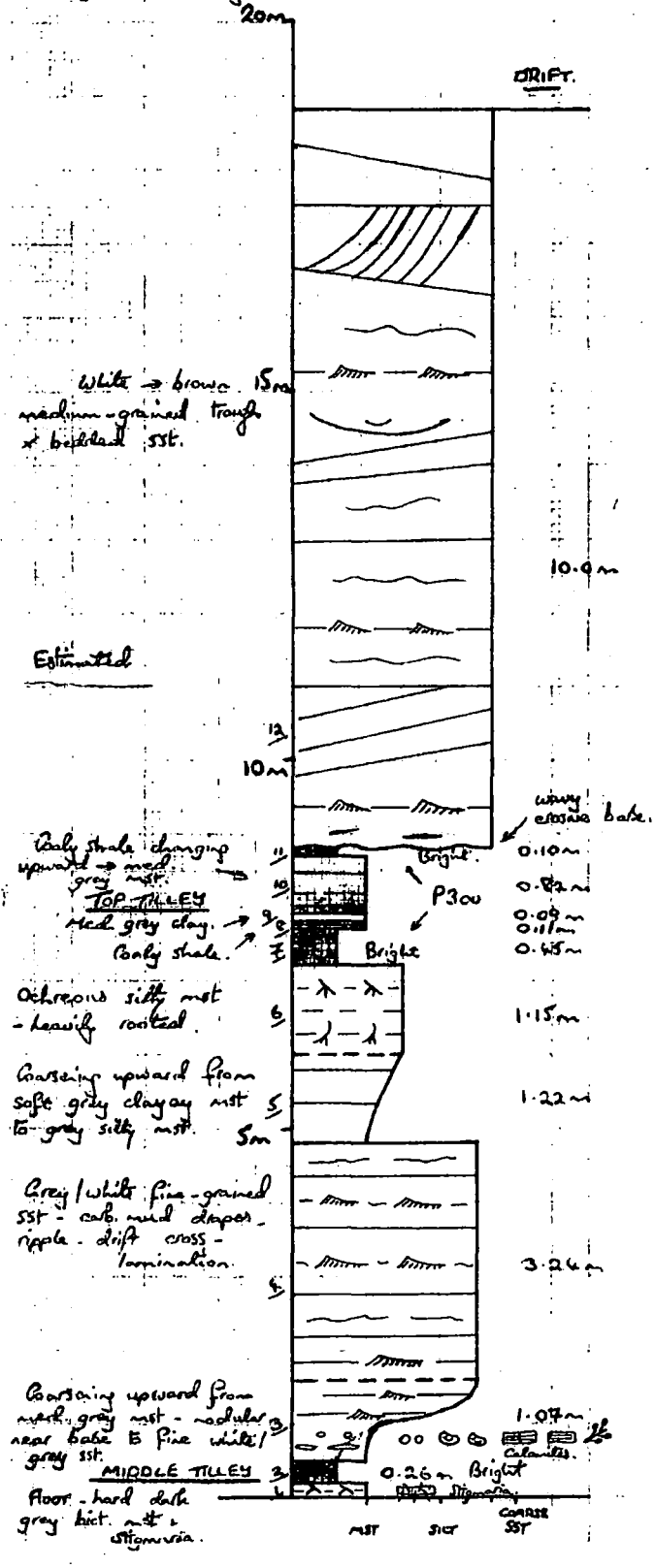


C.R. FIELDING - 19.2.80.

SECTION 063.

DEBORAH - CUT A5.

Long wall trending 267°



Little lateral variation in facies

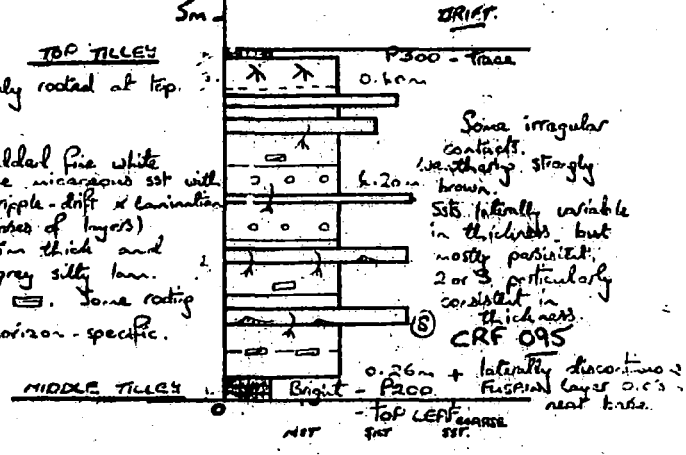
Samples - fossiliferous grey mst. CRF 094

C.R. FIELDING 25.2.80.

SECTION 064.

ESH WINNING - CUT K8.

South end of cut - only first part dug.



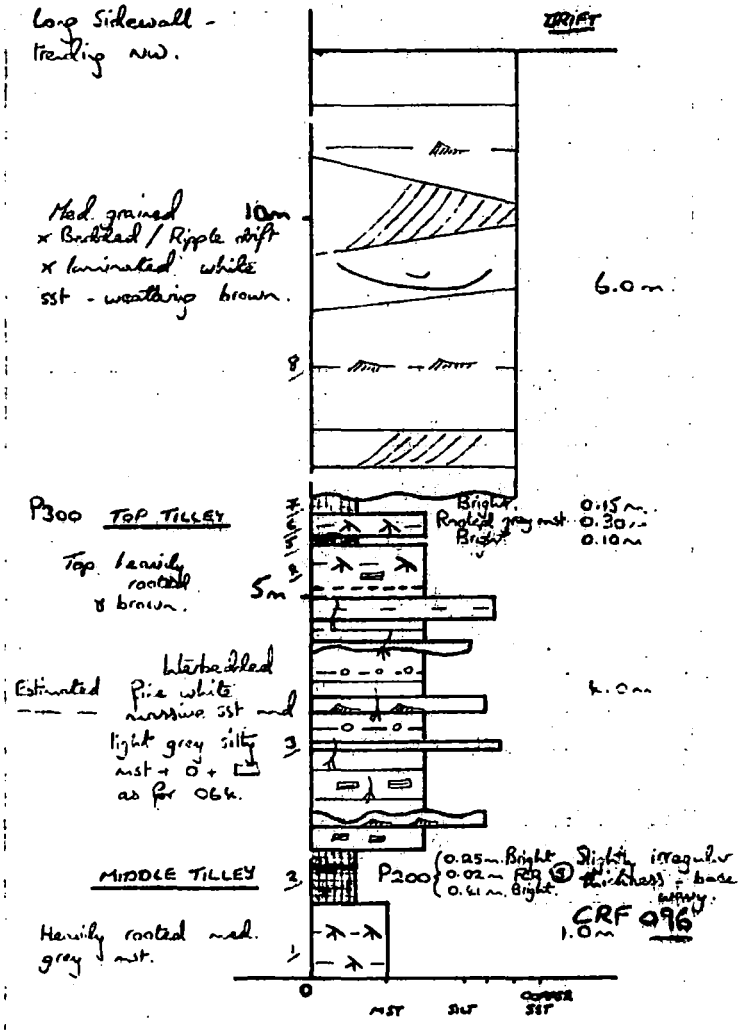
4 frames ASA 400 b/w film shot

1 sample - sst interlayer.

SECTION 065.

ESH WINNING - CUT K7.

Long Sidewall - trending NW.



- coaly traces within.

P200 Band definite FCR - SAMPLE taken.

5 frames ASA 400 b/w film shot.

Shear backwall.

C.R. FIELDING - 26/2/80.

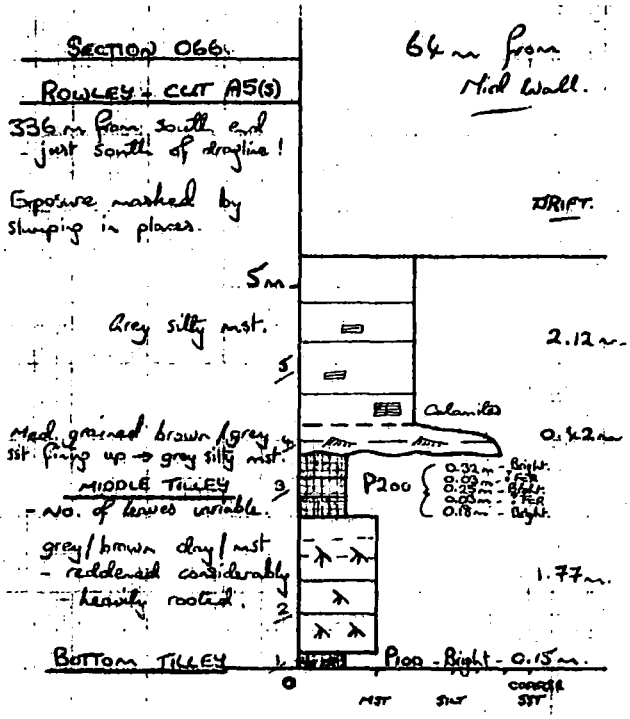
SECTION 066.

ROWLEY - CUT A5(S)

336 m from south end - just south of dragline!

Exposure marked by slumping in places.

64 m from Mid Wall.



Some minor faulting to south.
No. of leaves in P200 increases to south.

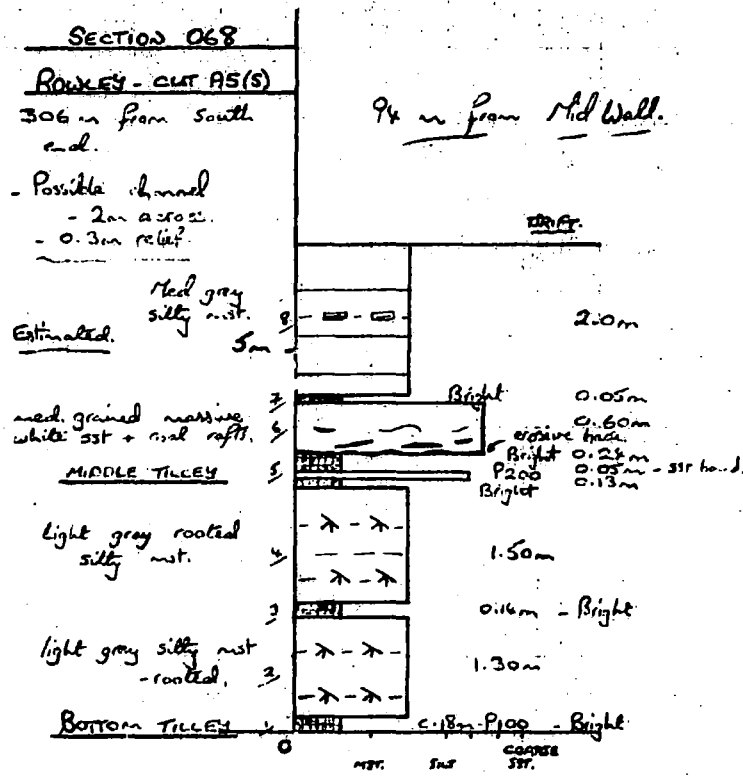
SECTION 068

ROWLEY - CUT A5(S)

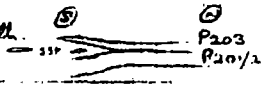
306 m from south end.

94 m from Mid Wall.

- Possible channel
  - 2m across.
  - 0.3m relief?



Unit 7 - rider - dies out to south.
Unit 3 - variable in thickness

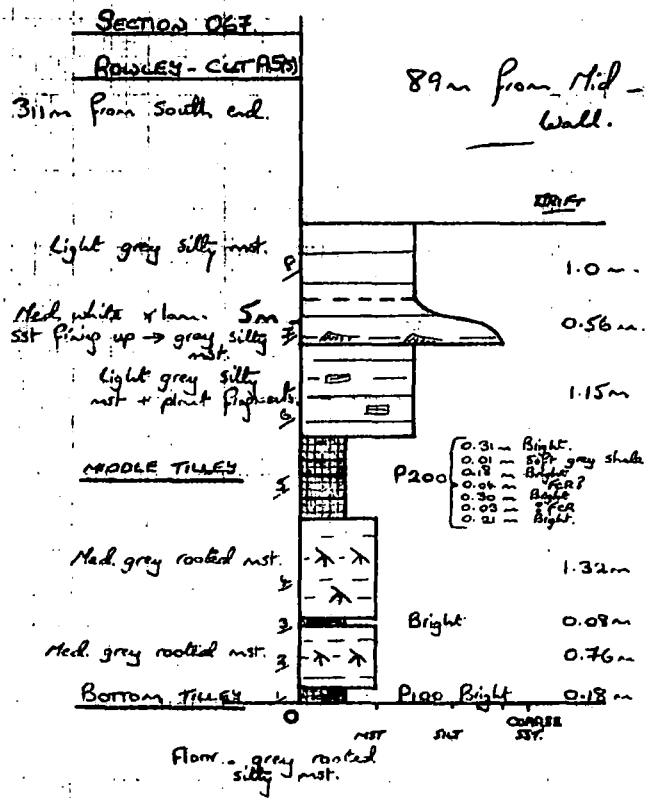


SECTION 067.

ROWLEY - CUT A5(S)

311 m from south end.

89 m from Mid Wall.



Floor - grey rooted silty mst.

Unit 3 dies out → coaly shale within 10m to North.

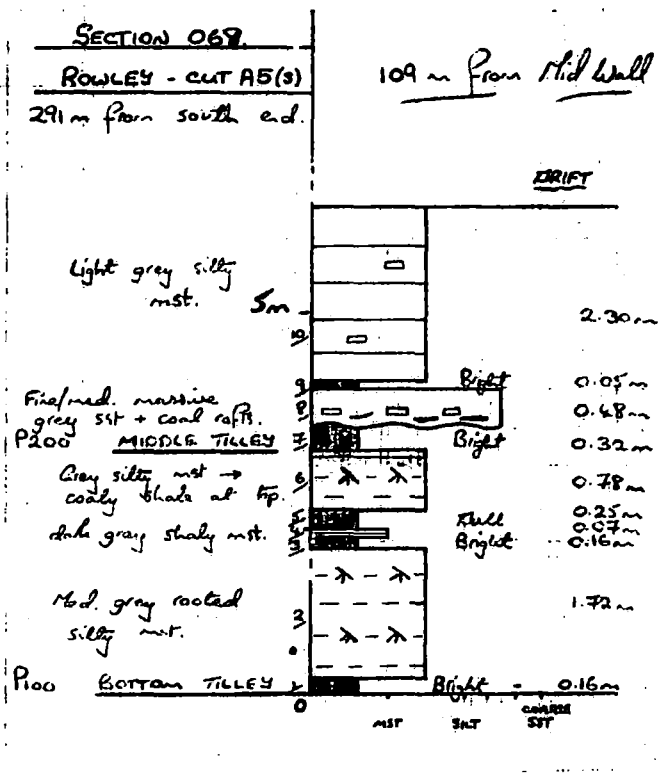
Unit 7 - laterally disappears to south? - probably.

SECTION 068.

ROWLEY - CUT A5(S)

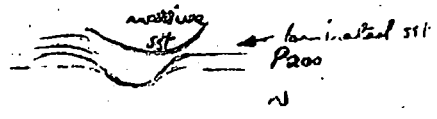
291 m from south end.

109 m from Mid Wall



NB Presence of steeply dipping slickensided contacts with coal leaves - dip planes?

5m to south - P200 proper almost completely cut out by narrow (1m wide) sst channel - top rider dies out - 2 fronds



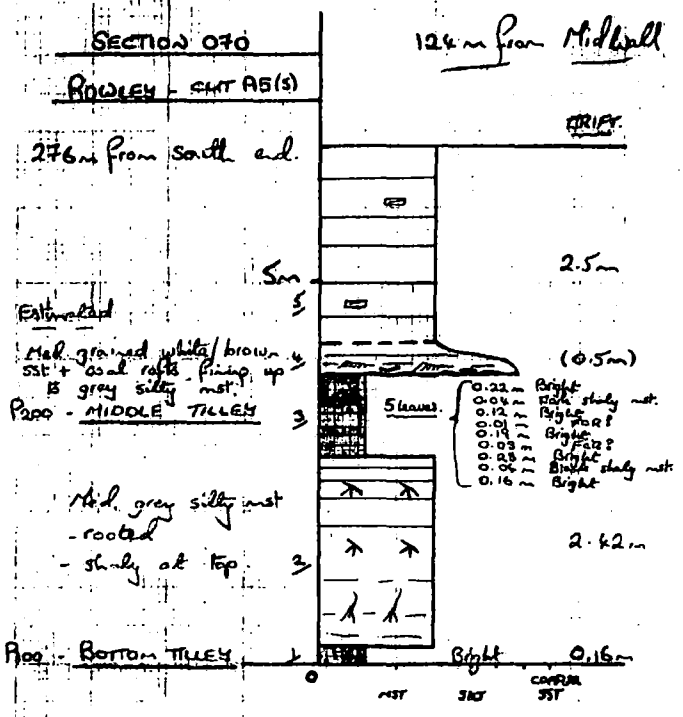
C.R. FIELDING - 26/2/80

SECTION 070

ROWLEY - CUT A5(S)

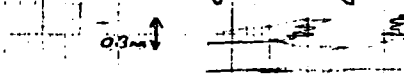
124 m from Mid Wall

276 m from South end.



NB 1. Basal laminated sst first seen in previous channel continues.

2. 266m South of S. end - another 1m wide downcutting sst body - 2 photos taken



3. 246m north of S. end - Same again - "Channel" 3m across, 1m deep - top 2 leaves cut out - asymmetrical with shallow dip on S. side.

4. 229 m north of south end - most of seam taken out by sst channel 5m x 1m - interfingering of coal & SST to north. Massive unit in channel - leaves out 5m to N x 10m to S.

Trough X Sets 1. 0.2m/13/070° 2. 0.3m/18/102° 3. 0.2m/10/083°

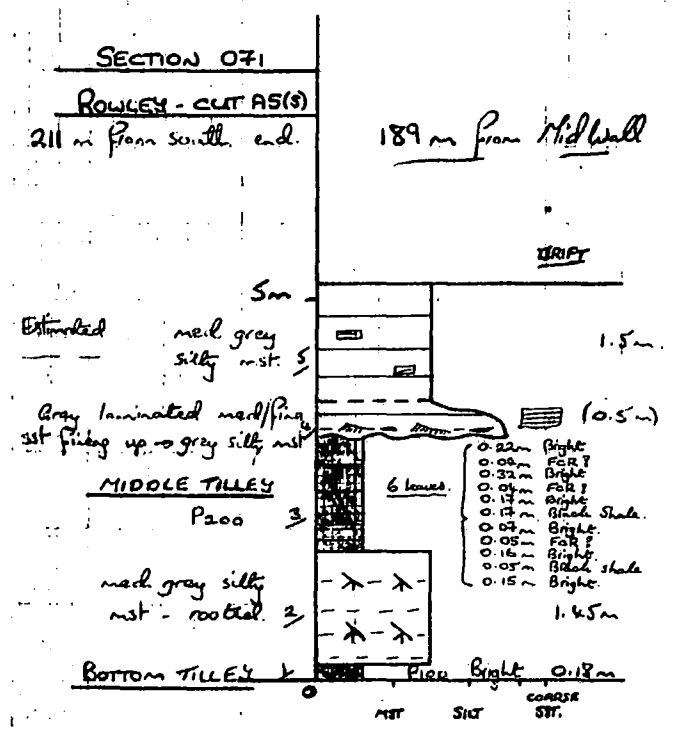
n = 3.

SECTION 071

ROWLEY - CUT A5(S)

211 m from South end.

189 m from Mid Wall



2 photos.

Small slip plane present in mid seam

176m north of south end - further washout comes in - interfingering sst & coal layers. - continues for 320m - old workings the obscures section.

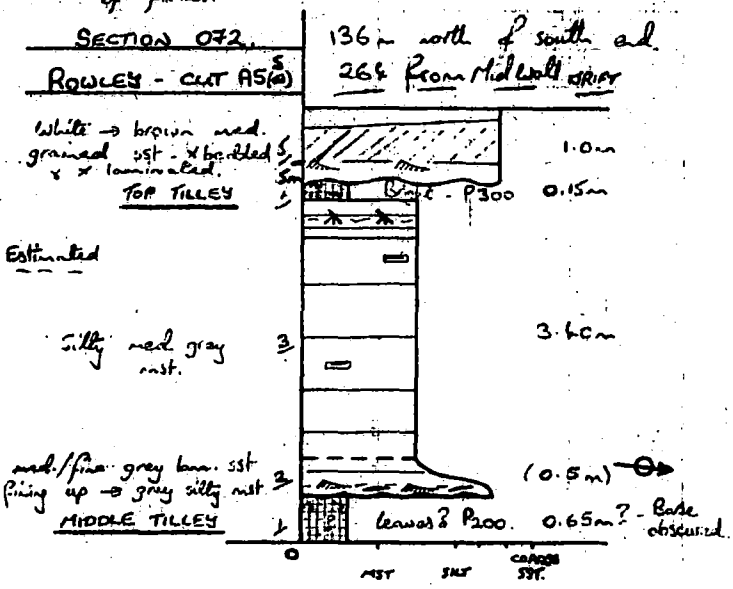
136m north - Outcrop of P300 appears in top of face.

SECTION 072.

ROWLEY - CUT A5(S)

136 m north of south end.

266 From Mid Wall

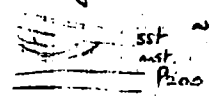


101 m north of south end - sst over P200 has graded laterally into silt. 1m sst band 1.3m from top of P200 (dies out laterally to north). - continues southward. P200 normal thickness - 0.63m

86 m north of south end - sst lifting up face

80m " : x sets in sst (locally thickened)

- 2m ↕/10/076°?



56m from end - P300 cut out by drift.

36 m " - 1m sst band reaches top of face.

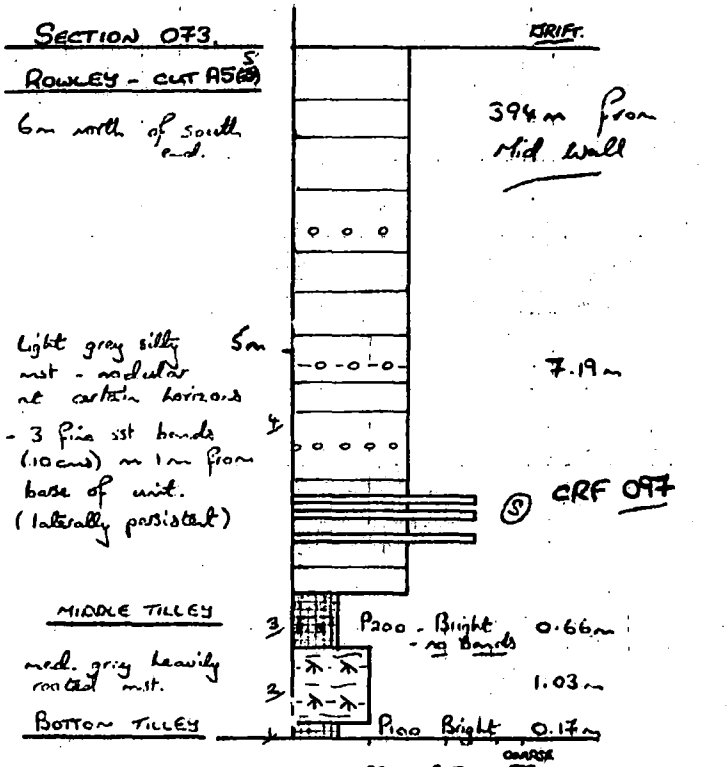
16 m " - trace of P300 reappears at top of face. - drift disturbed

SECTION 073.

ROWLEY - CUT A5(S)

6m north of south end.

394 m from Mid Wall



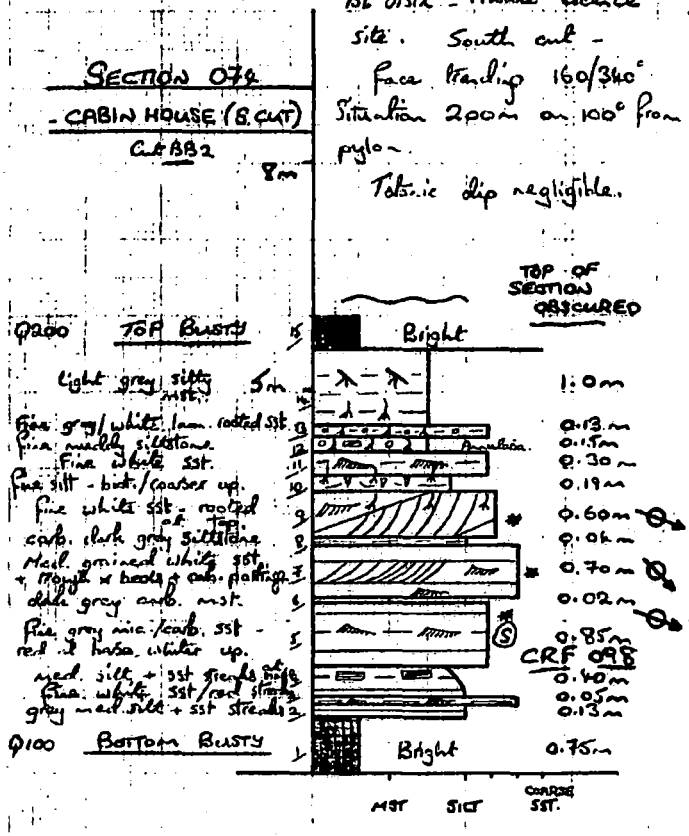
1 sample. thin sst.

Entire unit - 3336 m long. (from base Unit)

C.R. FIELDING - 3.3.80.

SECTION 074
- CABIN HOUSE (S. CUT)
Cut BB2

1st visit - Private licence site. South cut - Face trending 160/340°
Situation 200m on 100° from pylon.
Tectonic dip negligible.



Rarldning = ripper streaks - dark brown/purplish colour.
SAMPLE - SST

* DIRECTIONAL DATA -

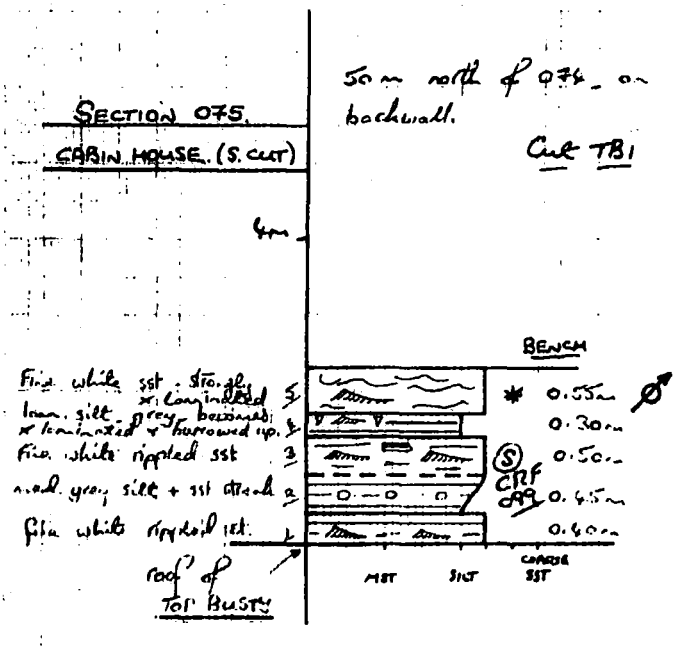
Unit 9 - Trough cross bedding
1. 0.18m x 110m ⇔ /5/137
2. 0.13m x 070m ⇔ /12/104
~ = 2

Unit 7 - Trough cross bedding.
1. 0.15m x ?/25/154
~ = 1

Unit 5 - Ripple RXL → 124
~ = 1

SECTION 075.
CABIN HOUSE. (S. CUT)

50m north of 074 on backwall.
Cut TB1

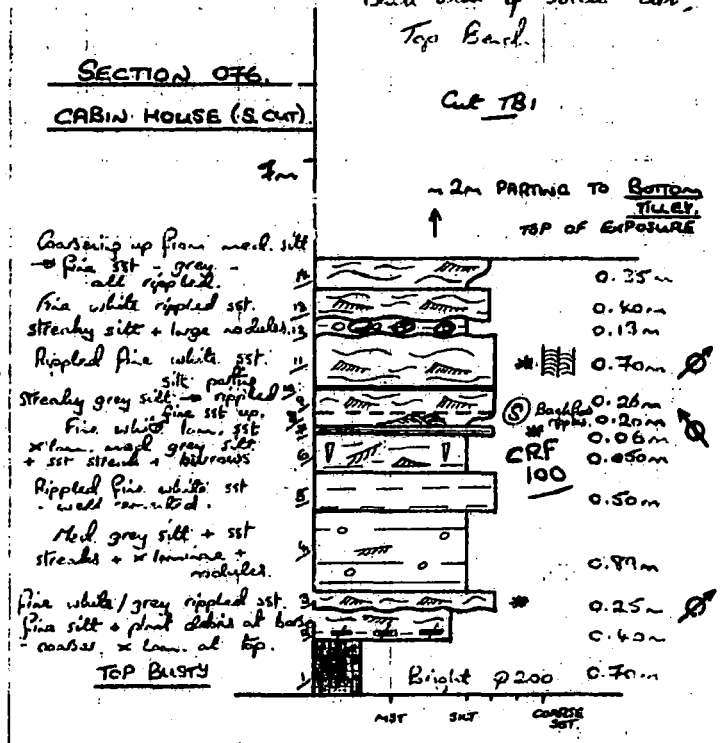


* DIRECTIONAL DATA
Unit 5 - ripple x/lamination
→ 042° ~ = 1

Back wall of south cut.
Top Bank.

SECTION 076.
CABIN HOUSE (S. CUT)

Cut TB1



NB Units 3 & 5 are laterally discontinuous - 3 disappears by 20m south - and 5 steps within 2m south - both continue to north.

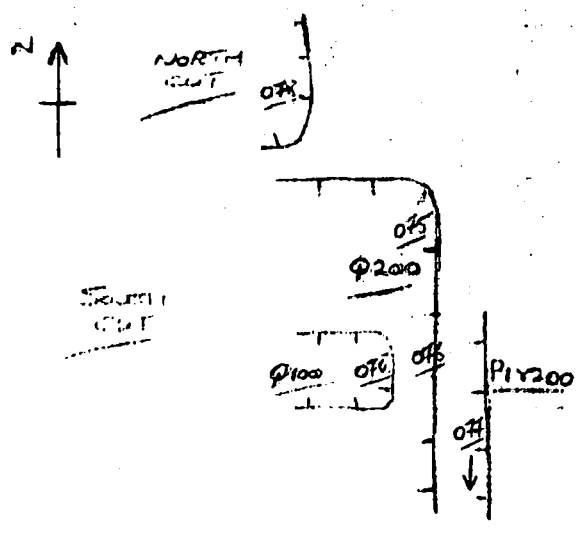
* DIRECTIONAL DATA -

Unit 11 - Rib & furrows troughs → 040° ~ = 1

Unit 7 - ripple crest orientation 246°
vigerality → 336° ~ = 1

Unit 3 - Ripple x lamination → 040° ~ = 1

SKETCH PLAN OF WORKINGS AT CABIN HOUSE - 3.3.80



C.R. FIELDING - 3.3.80.

NB Also, further 10m south, same section occurs - sst is not channel-filling

SECTION 077 A.

CABIN HOUSE - S. CUT.

Cut TC1

Trace of sst.

Grey rooted silt - coarser up

med. grey sandy silt - rooted

Bioturbated carb. black shale

BOTTOM TILLEY

mottled yellow/grey rooted silty mst

DRIFT

Trace

0.65m

0.08m

0.16m

Bright Proll 0.26m

0.6m

MST SILT COARSE SST.

Top of sst units

SECTION 077 B.

CABIN HOUSE. - S. CUT

(10m south)

DRIFT.

MIDDLE TILLEY

Brown/black silt

Strongly rooted rippled ssts

sst as before + trough x-beds + rootlets

Med./fine rippled white sst.

Med. grey silts

BOTTOM TILLEY

Proll - Bright

CRF 101 0.30m

0.18m

CRF 102 0.60m

0.60m

0.58m

0.70m

0.25m

MST SILT COARSE SST.

* DIRECTIONAL DATA.

Unit 3 - climbing ripples → 330° - 360°.

n = 2.

C.R. FIELDING 4.3.80.

Total 5 samples.

3 frames b/w ASA 400 film shot.

Northern Cut

Cut BB1

SECTION 078

CABIN HOUSE (N. cut)

21. Dark grey rooted silt

20. Fine/med white sst + horiz. burrows + shale clasts at base

Med. silt → coarse 0.8m

19. Silt up - med. grey + nodules at top

Fine grey silt → mst up

18. - top = coaly shale

17. Fine grey/white lam. sst. 0.20m

16. Fine/med. dark grey silt 0.41m

15. Coarse lam. dark grey silt 0.25m

14. Fine white rippled sst 0.15m

13. Coarse dark grey silt 0.07m

12. Med grained white massive sst 0.22m

11. Rippled fine white sst. 0.28m

10. Brown/grey med silt 0.11m

Fine/med. white sst. micaceous - mostly rippled. some x Bedding. 1.35m *

Lam. sst. streaked silt 0.13m

Rippled fine white sst 0.18m

Coarser silt grain 0.07m

fine silt 0.15m

dark grey med. silt + sst streak 0.40m

Fine white sst + plant frag. 0.09m

Darker grey biot. fine silt → coarser silt with sst streak up. 0.45m

BOTTOM BUSTY

Bench for extraction of Top Busty - base of seam quite close above

BENCH

Shales

Q100 - Bright 1.35m

MST SILT COARSE SST.

* DIRECTIONAL DATA

Unit 9 - trough x Bedding ≤ 0.10m ↕ → 140°

n = 1.

Unit 3 - orientated plant debris → 120/300°

n = 1 (bidirect.)

SECTION 079

DEBORAH D3 cut 1.

Long wall face dip 030°

2m north of seam fault disturbance.

8m

DRIFT

Estimated 5m

Lithologies similar up section - ssts less arch.

sst 1.0m

sh. 0.03m

sst 0.95m

sh. 0.03m

sst 0.94m

sh. 0.03m

sst - shale - as before 0.07m

sst - as before 0.04m

0.72m

med. grey shale 0.36m

Fine/med. white sst + calc pebbles. some rippling 0.80m

thin clayey grey mst 0.02m

BUSTY

Q000 - Bright 1.05m

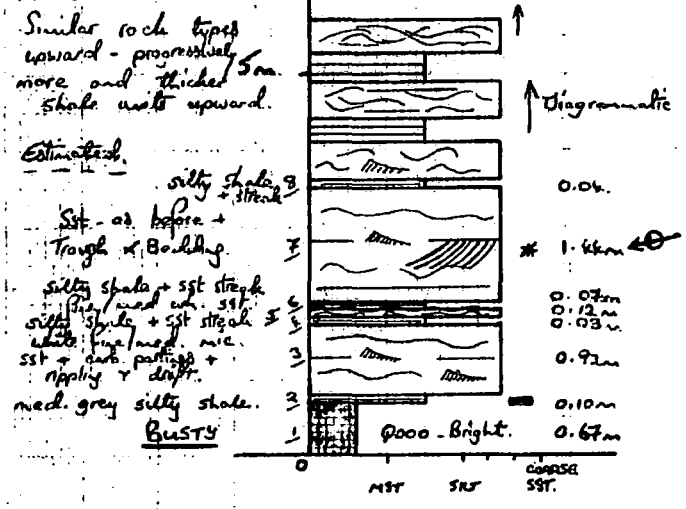
MST SILT COARSE SST.

C.R. FIELDING - 4/3/80.

4 frames - 2 panorama over Di + ii
2 slump in Di ii

SECTION 080
DEBORAH Di - CUT 8.

Long wall trending 292°
NB Dip steepens dramatically from 5° → 20° toward backwall & north.

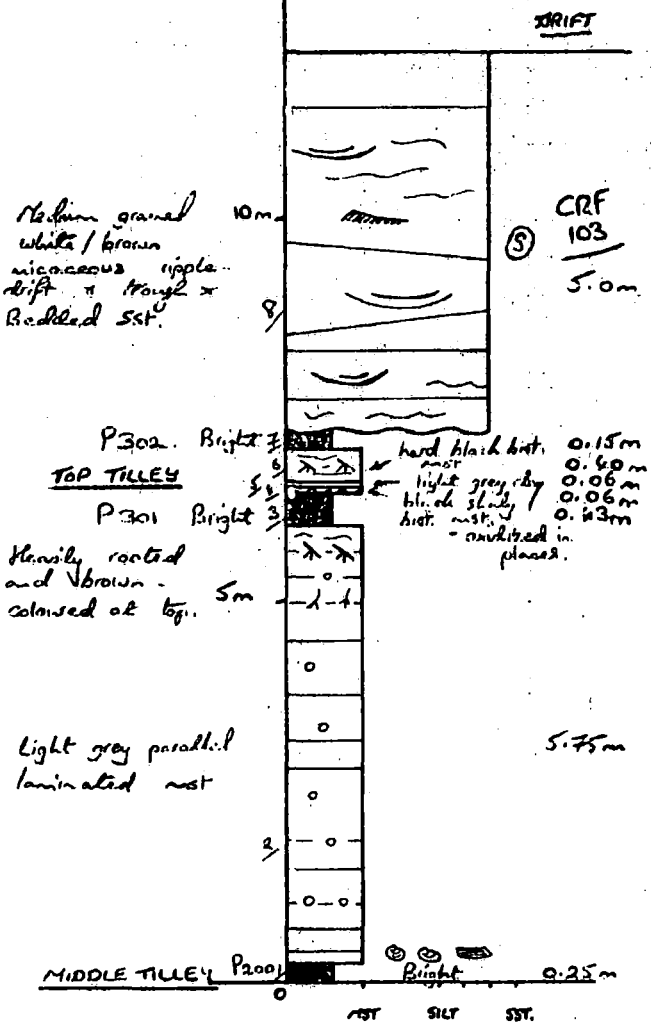


* DIRECTIONAL DATA -
Unit 7 - trough cross-bedding.
1. 0.3m x 1.5m ⇔ / 18° / 307.
2. 0.1m x 3 / 14 / 281.
n = 2.

Corrected orientations - 16/270 ~ Avge - 256°
18/288

SECTION 081
DEBORAH Bi - CUT 7

Long wall trending 270°
Some slumping disturbance.
2 frames.

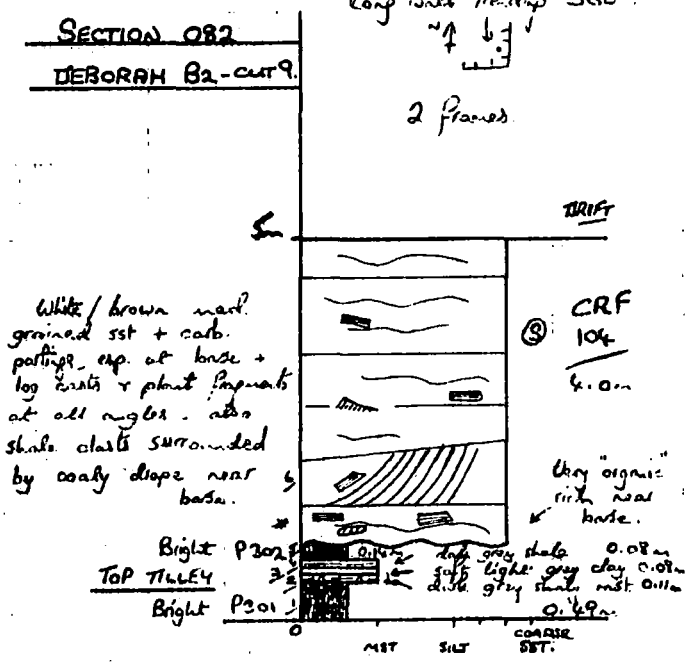


Total 5 samples
8 frames ASA [illegible] b/w film shot
- film 8 finished.

SECTION 082
DEBORAH B2 - CUT 9.

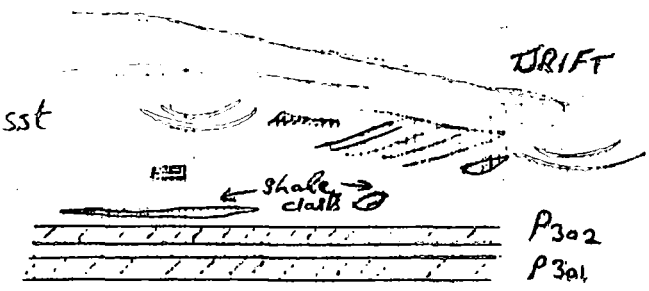
Long wall trending 360°

2 frames



* Discontinuous shale bed. 2m ⇔ - 0.05m ↓ at 0.05m above P302 further obs. out.

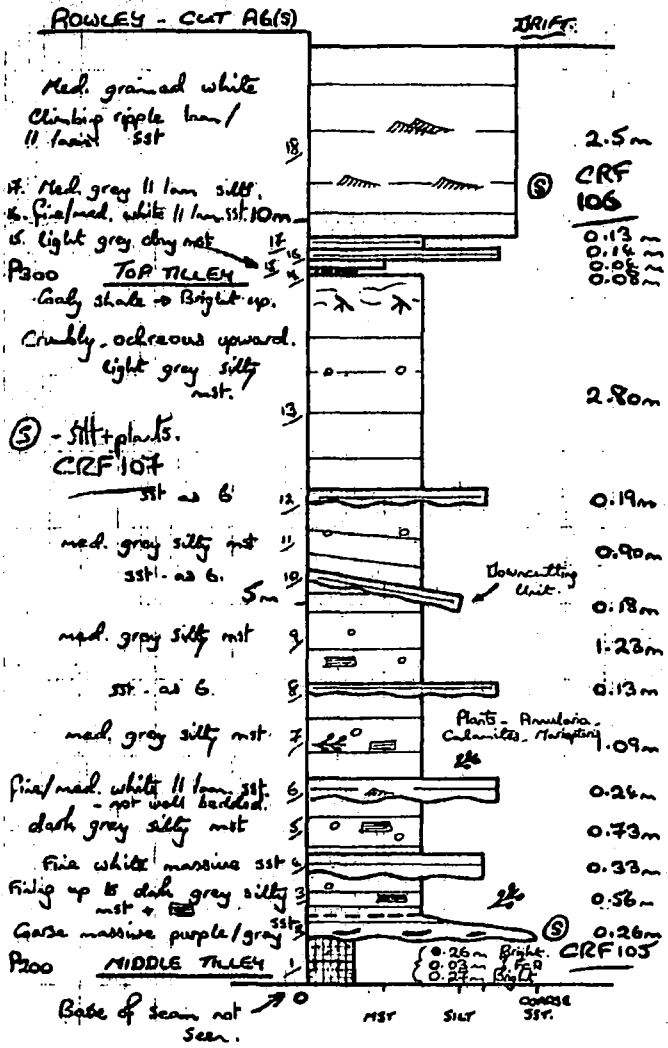
SKETCH - SECTION 082



C.R. FIELDING - 11.3.80 EXAGGERATED - SEE SECTION 117

SECTION 083. Middle wall, west end.

ROWLEY - CUT A6(S)



NB 1. Thin sst units are laterally variable in thickness and discontinuous.

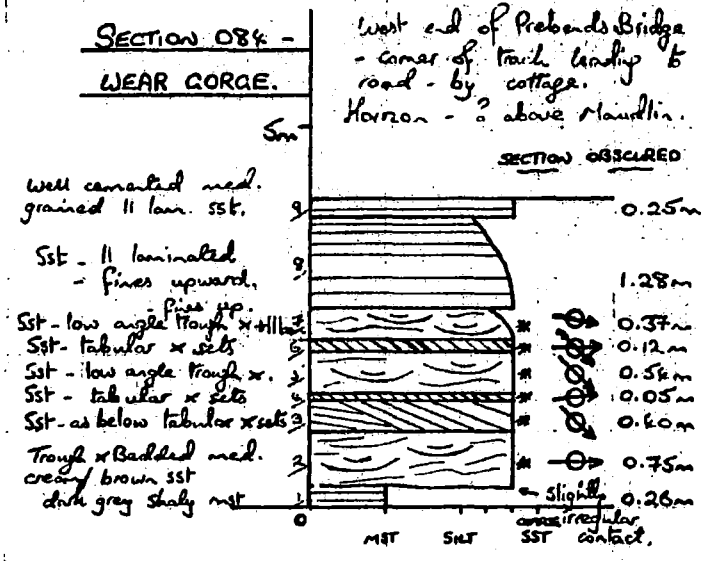
2. Top Tilley post grades laterally to north into silty mst. (then back to sst up A7(N).).
3. Units 15 - 17 all laminated fine/med. white sst in places - particularly to north.
4. Middle wall - west end - face trending 263°.
5. East end of wall - similar lithologies - not well exposed.
6. Up to 100m south - similar lithologies - sst beds ≤ 1m thick - then start of washouts again. Silt + plants -
7. 2 samples - Sst over P200 - Top Tilley Post. -
1 frame b/w ASA 400 35m shot

C.R. FIELDING - 17.3.80

SECTION 084 - WEAR GORGE.

West end of Prebends Bridge - corner of track leading to road - by cottage.
Horizon - ? above Maudlin.

SECTION OBSCURED



NB 1. Trough x sets become noticeably more asymptotic upward.
2. Unit 4 is cut out 5m to east.
3. Unit 6 thickens to the east → 0.25m.

* DIRECTIONAL DATA

Unit 7 - Low angle trough x sets
0.15m/12/105° ∧ = 1. θ = 105°

Unit 6 - tabular x sets. θ = 092
0.12m/14/092° ∧ = 1.

Unit 6 - Low angle trough x sets. θ = 133°
0.23/17/133° ∧ = 1.

Unit 4 - tabular x sets - θ = 075°
0.05m/22/080°. 0.05/23/071° ∧ = 2.

Unit 3 - tabular x sets - θ = 141°
0.3m/15/143°. 0.35/16/140° ∧ = 2.

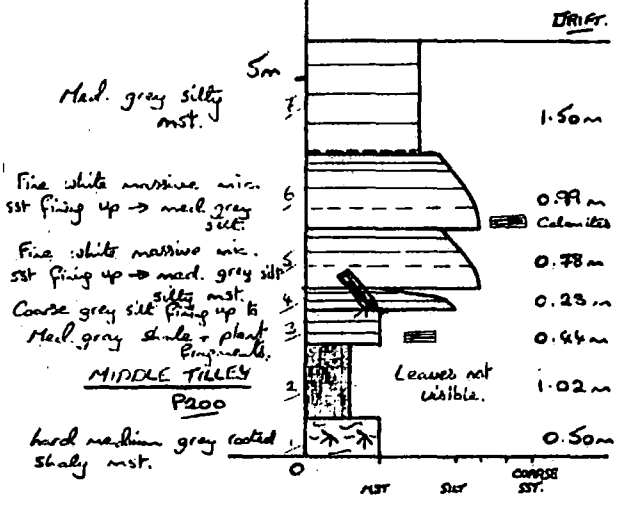
Unit 2 - Trough x Sets -
0.32m/16/107°. 0.82m/18/068.
0.70m/19/093° ω = 1.8m. ∧ = 3.
θ = 089°

(CRF 108)

C.R. FIELDING - 20.3.80.

SECTION 085. - ROWLEY A6(S)

160 m South of Mid Wall.



NB 1. At this point 1.6 m the top and base of P200 rises up - doming effect - probably depositional. Channel sediments to south.

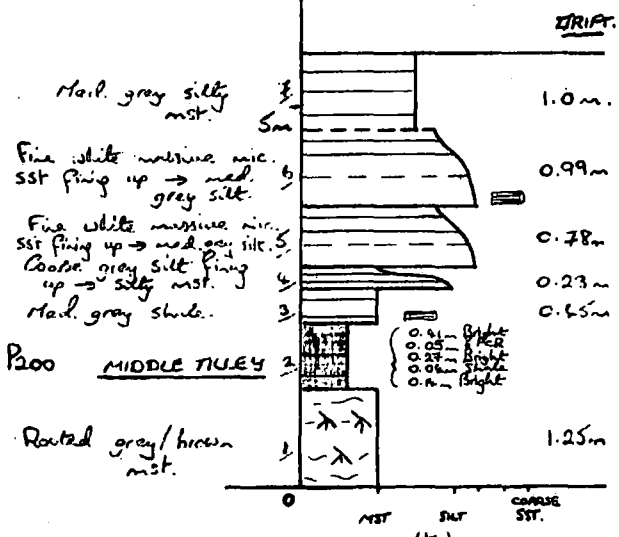
2. To north facies as for Section 082 - interbedded grey silty mst & fine sst.

3. 75m south of Mid Wall with top 2m above roof of P200 - bent-over Calamites

DIRECTIONAL DATA * trunk - bent toward 136°. 0.12m thick (flattened). 1m + long. Dip 38°. coalified in places.

SECTION 086 - ROWLEY A6(S)

150m south of mid wall. - Base of seam has risen approx. 1.25m

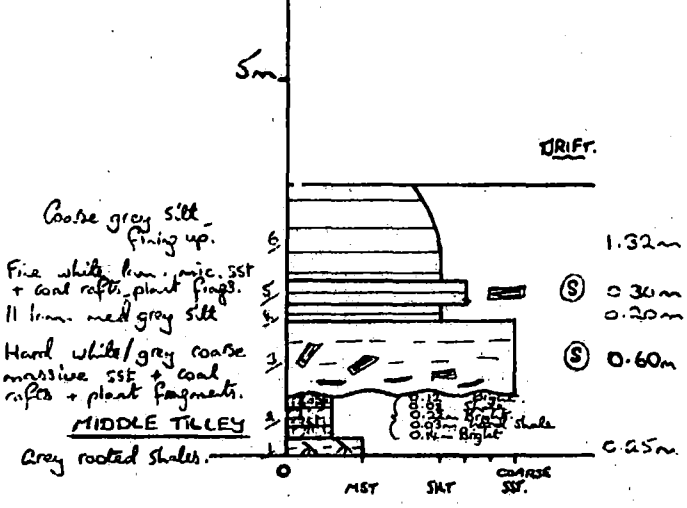


NB 1. At 160m south, seam (top) has risen another 0.5m - movements - 5m thickening up.

P200: 0.48 Bright; 0.05 ? FOR; 0.30 Bright; 0.06 Shale; 0.20 Bright

SECTION 087 - ROWLEY - A6(S)

165m South of Mid Wall. Partial washout. Top of coal feature - in 2m relief.



NB 1. Thin sst over P200 in previous sections are subsequent to the channel - do not merge.

2. Partial washout feature - doming of sst - lots of plants. 2 samples - CRF 110, CRF 109.

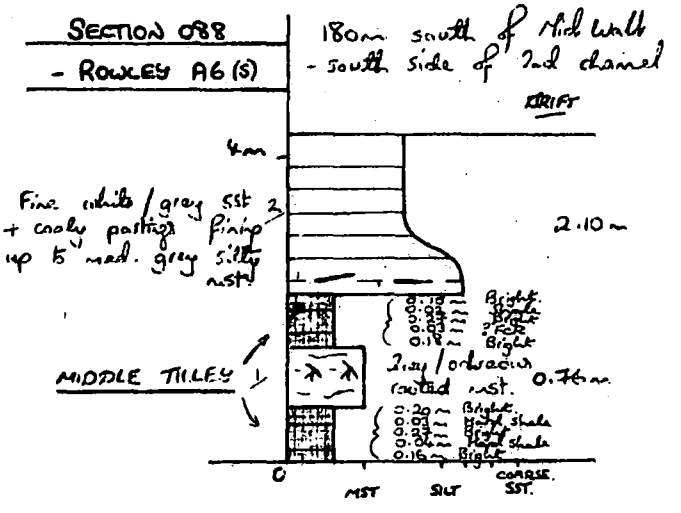
Top 1½ leaves cut out - leaves must split, because 3 leaves are present under the washout, through channel. Seam bands because sst to north & south at margins of washout. - splay effect with top leaves while channel 5m across.

3. Seam falls down gradually to previous level over next 60 m.

4. At 177m, another similar channel, partially observed - 3m across.

SECTION 088 - ROWLEY A6(S)

180m south of Mid Wall - South side of 2nd channel

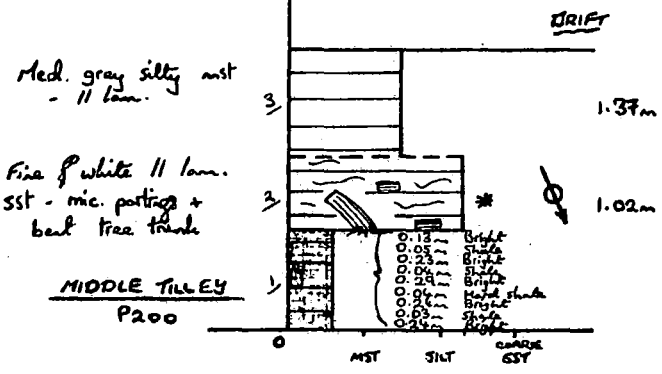


NB Limit of ochreous mst which splits P200 thins → no in 5m to south - observed to north.

C.R. FIELDING 20/3/80.

SECTION 089. - ROWLEY A6(S).

40m south of mid-wall. P200 datum falling.



* DIRECTIONAL DATA :- Unit 2 - bent tree trunk. - 0.12m long × 0.5m wide - Bent toward 159°, dipping at 24°. n = 1.

NB Very small channel (0.30m across) in top of P200 - 2m to south - orientated E-W.

210m south of Mid Wall - more sst bands in P200 - ≤0.30m thick - 5cm 0.92m thick, & lenses.

215m south - another channel, ~3m wide - thin fine sst layers in silty mst over sst. Sst over P200 more or less laterally continuous.

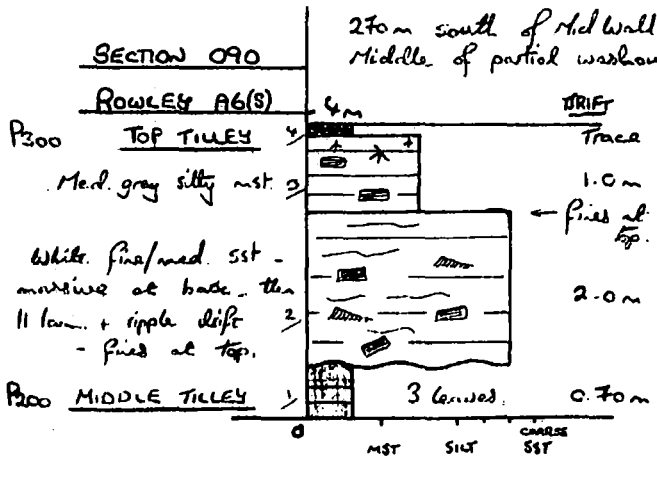
217m - Old collapsed working - P200 level back to previous base level.

250m - Face still collapsed.

270m - Another channel washout - dimensions uncertain, but showing splaying out of P200 leaves. Large sst body over P200 comes in at ~2k3m by lateral coalescing from silt - thickens up gradually - by 270m is 2m thick.

SECTION 090 - ROWLEY A6(S)

270m south of Mid Wall. Middle of partial washout.

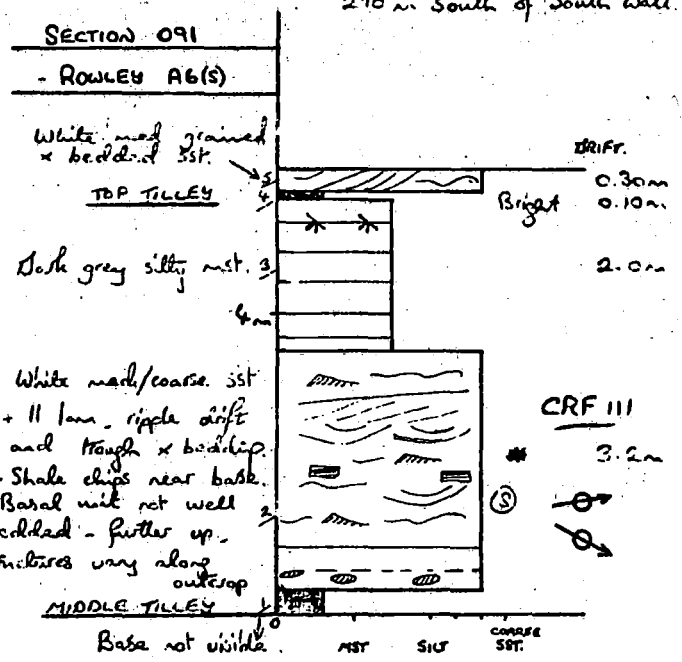


Top leaf of 5cm removed.

South of washout, sst thickens to south.

SECTION 091 - ROWLEY A6(S)

290m south of south wall.



\# DIRECTIONAL DATA :-

Unit 2 - Trough Cross-bedding θ = 123°

0.6m (× 1.5m wide) / 12° / 123° n = 1

Unit 2 - Ripple drift

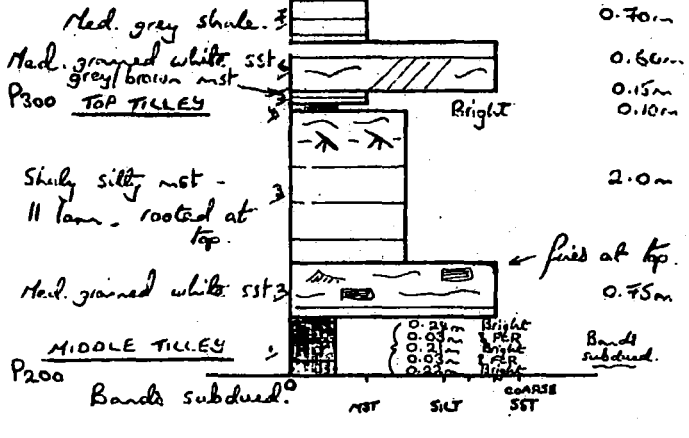
→ 072°, 079°, 097° n = 3.

θ = 082° / 98 %

Sst thins down again to south.

SECTION 092. - ROWLEY A6(S)

330m south of Mid Wall.

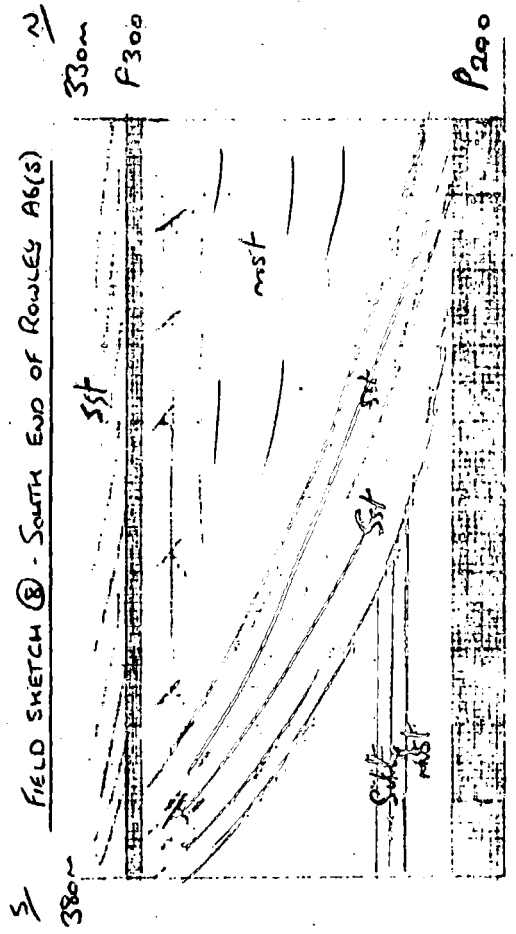


Sst continues to thin to south. P300 comes down the face at 330m, then starts to rise to south.

By 360m, sst band is 2m above P200, rising up the face - under = silty mst with occasional nodules and thin sst bands. Similar facies to end of cut at 440m. 2-3 sst bands, 0.10m thick, at 1.40m over P200 roof.

Thick white med. grained sst under Unit 2 rising up face - prin. P3cm (i.e. cut out at top)

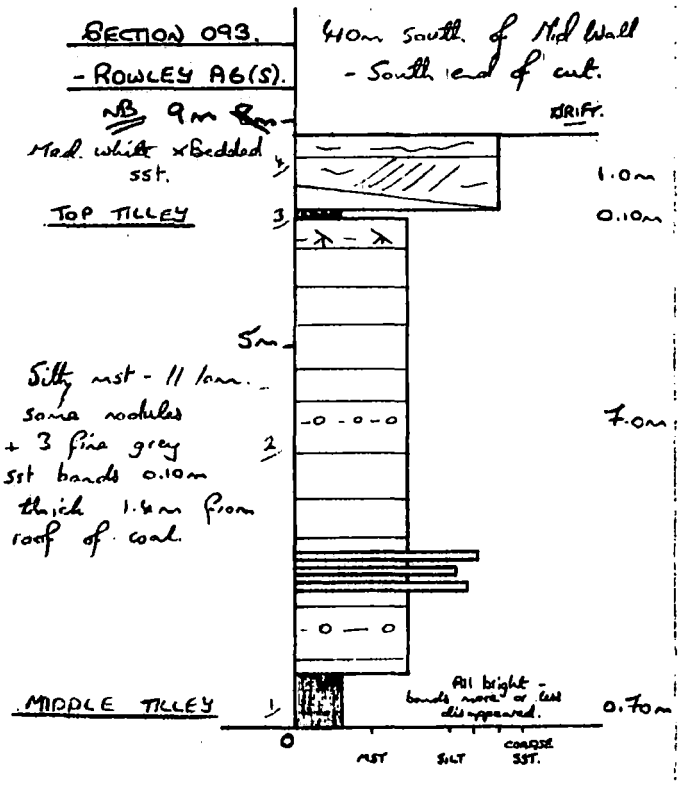
C.R. FIELDING - 25.3.80.



NB By 350m Top Tilley Post is mostly sandstone with thin interbedded shales - appears to drape over to NE. Face ~8m high.

SECTION 093.
- ROWLEY A6(S).

40m South of Mid Wall - South end of cut.

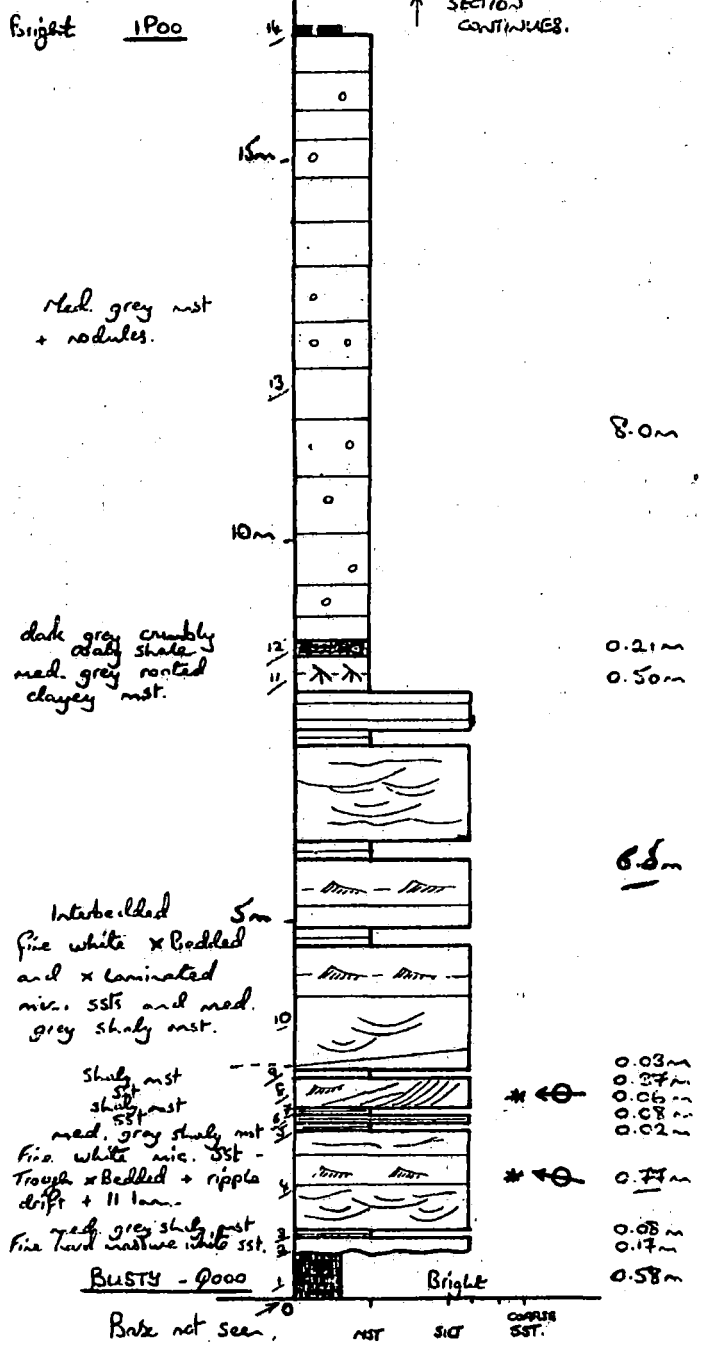


P300 x TTP rising up face to South into side wall.

C.R. FIELDING 25.3.80.

Back wall under Pylons.

SECTION 094.
DEBORAH - Bii.



NB 1. See also xBedding data for TTP - Cut 10/ Area Bii - Section not taken - See over

* DIRECTIONAL DATA.

Unit 4 - Trough x Bedding
- 0.2m / 7 / 271° n = 1.

Unit 8 - Trough x Bedding
0.3m / 13 / 275°
0.2m / 11 / 203
0.2m / 14 / 280.

12/242

CORRECTED
16/255
17/262
13/272
n = 3

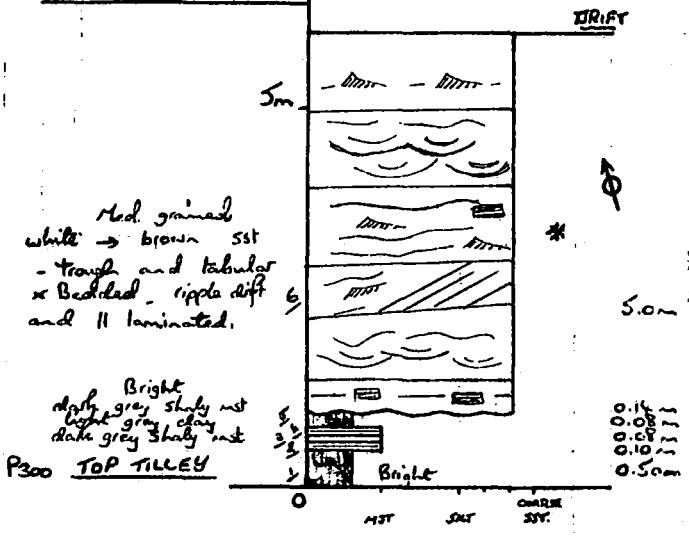
θ = 263° / 99%

4. From 28 ASA 400 H/W film shot.

C.R. FIELDING - 25.3.80.

SECTION 095 - DEBORAH - B11/10

Cut 10, area B11 - long wall.



* DIRECTIONAL DATA :-

Unit 6 - Trough foresets ≤ 0.5m ↑

1. 22/345 2. 20/349 3. 13/338
4. 17/339 5. 29/338. ∧ = 5.

Tabular foresets - asymptotic based.

1. 36/358°. ∧ = 1.

Corrected measurements

1. 10/324 2. 15/329 3. 25/334 4. 17/339
5. 16/346.

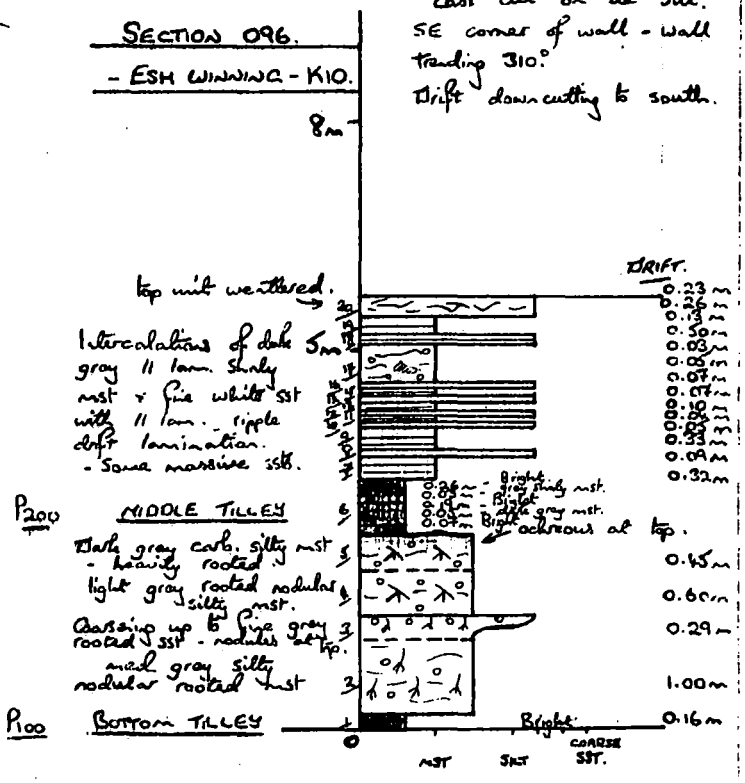
θ = 334½° c = 99%

1. 31/356°

C.R. FIELDING - 27/3/80

SECTION 096. - ESH WINNING - K10.

Last cut on the site. SE corner of wall - wall trending 310°. Drift down cutting to south.

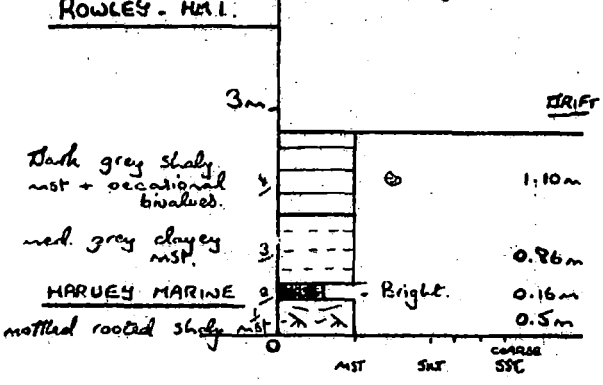


NB Unit 3 thickens, coarsens to NW and thins, fines to

C.R. FIELDING - 27.3.80

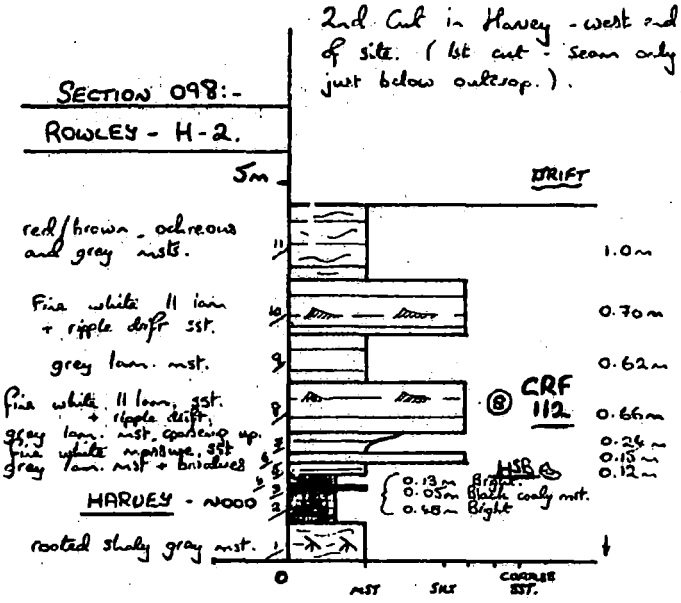
SECTION 097 - ROWLEY - HM1.

West end of site - 1st Cut in Harvey Marina.



SECTION 098:- ROWLEY - H-2.

2nd Cut in Harvey - west end of site. (1st cut - seam only just below outcrop.).

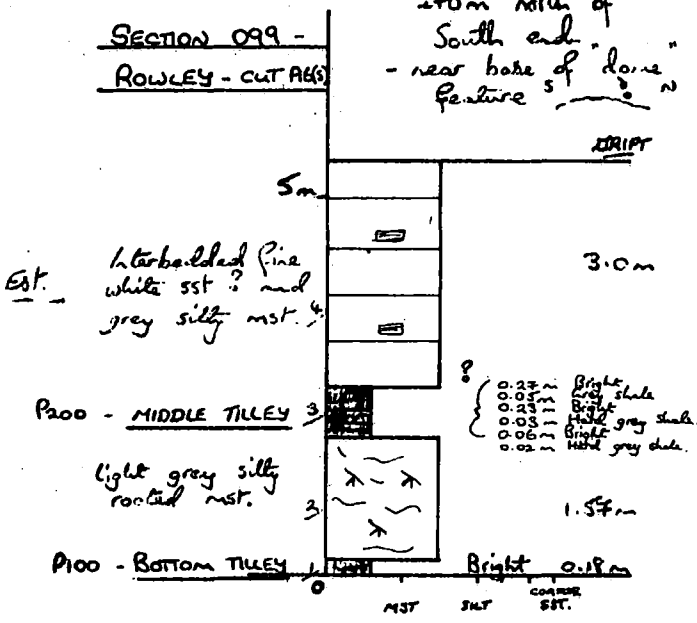


NB One sample - sst over Harvey.
Sstb are laterally variable (even discontinuous) in thickness.

C.R. FIELDING - 17.4.80.

SECTION 099 - ROWLEY - CUT A6(S)

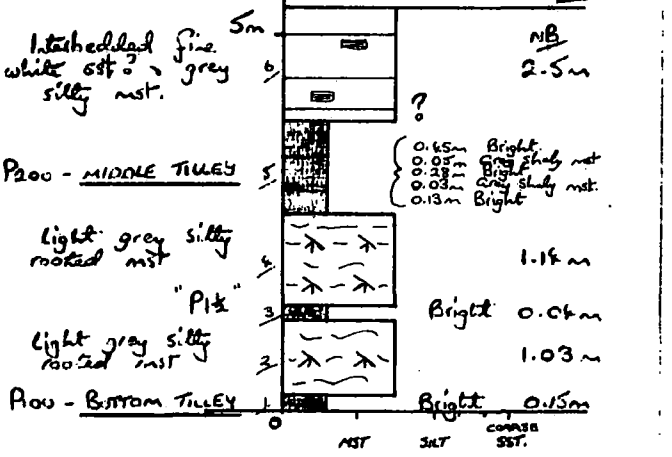
270m north of South end - near base of "dome" feature



NB 10m north is at base of "dome" - P100 - P200 parting = 0.95m.

SECTION 100 - ROWLEY - CUT A6(S)

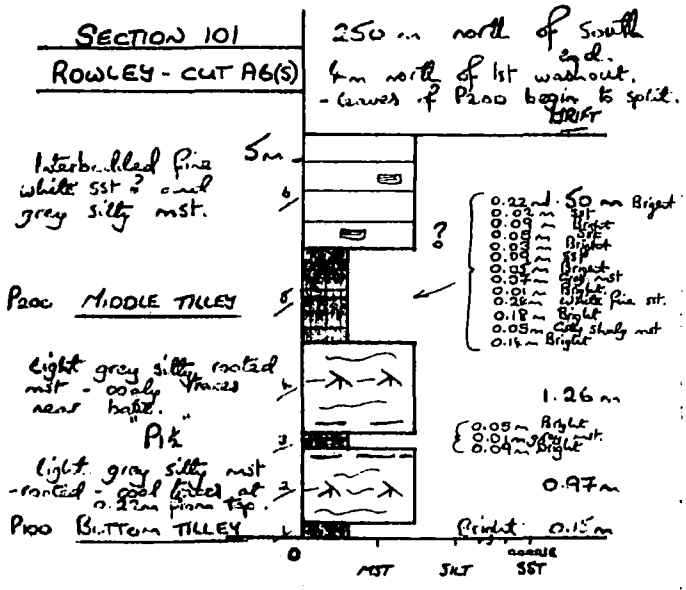
260m north of South end NB Logged thickness slightly inaccurate



NB Unit 3 dies out rapidly to a coaly trace to N.

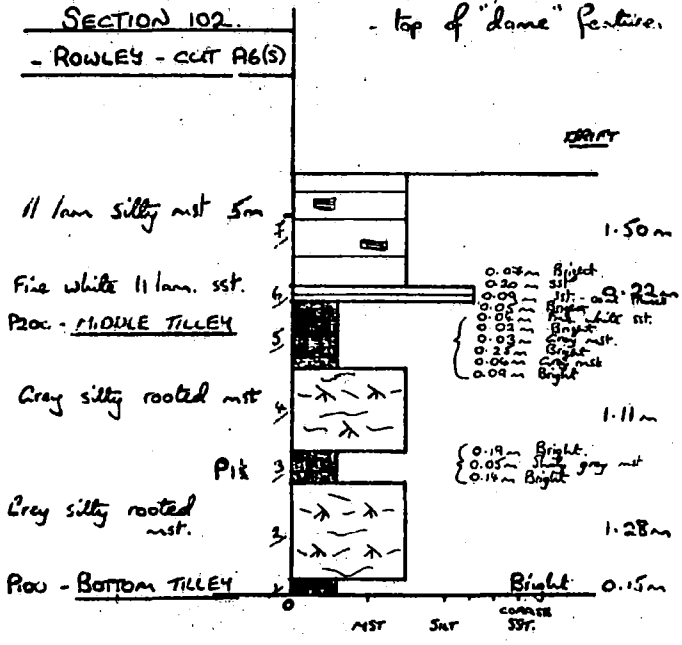
SECTION 101 - ROWLEY - CUT A6(S)

250m north of South end. 4m north of 1st washout. - Leaves of P200 begin to split.



SECTION 102 - ROWLEY - CUT A6(S)

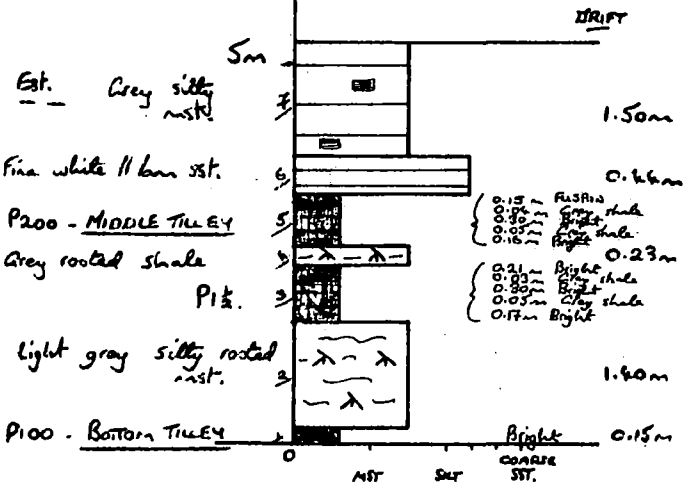
240m north of south end. - top of "dome" feature.



NB - 1st washout continues as interbeds of sst in P200 as far as Section 102.
- P1½ has a shaly band in the middle south of Section 101.
- 5m further - 2nd washout.

SECTION 103. - ROWLEY - CUT A6(S)

230m north of south end - past 2nd washout - level of seam falling.

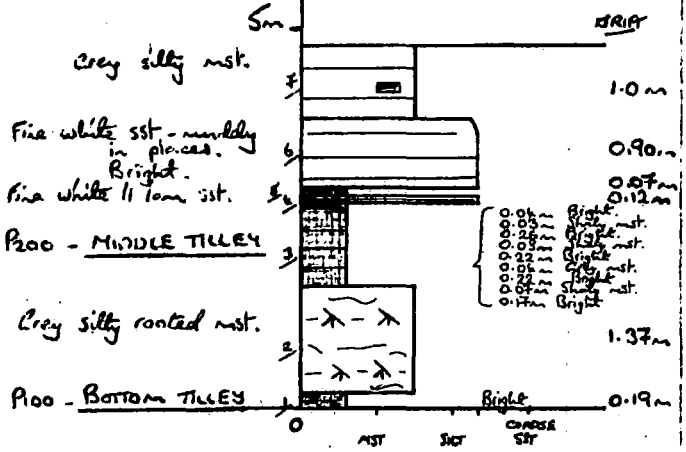


NB 1. Bands in P1½ discontinuous - 0.45m continuous coal at 3m South.
2. Fusain band passes laterally into Bright.

C.R. FIELDING - 17.4.80.

SECTION 104 - ROWLEY - CUT A6(S)

220m north of south end. - Level still falling - just before 3rd partial washout.

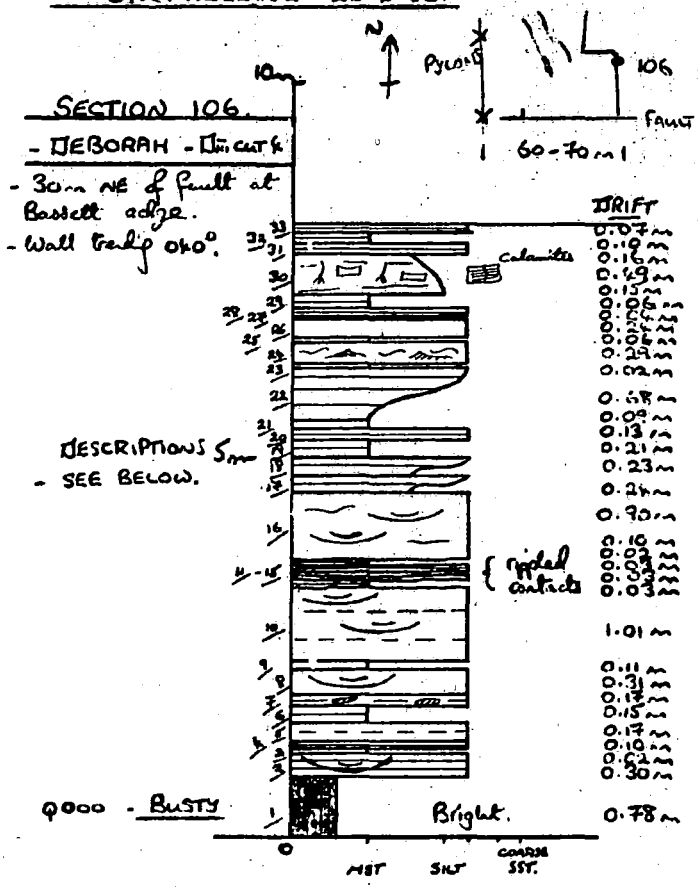


NB 1. Pit has joined up with P200.

C.R. FIELDING - 23.x.80.

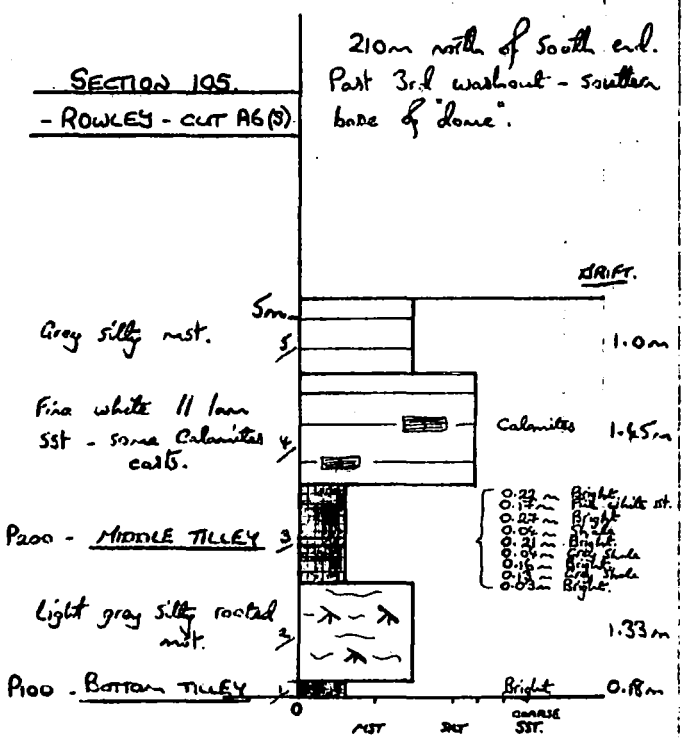
SECTION 106 - DEBORAH - DIAGONAL CUT

- 30m NE of fault at Bassett adge.
- Wall trend 040°.



SECTION 105 - ROWLEY - CUT A6(S)

210m north of South end. Past 3rd washout - Southern base of "dome".



NB 1. By this point Leaf 6 has died out. Leaf 5 dies out and reappears. The band between leaves 3 & 5 is discontinuous. Leaf 1 disappears shortly after.
2. Shortly after 5th washout - shallows and at least 25m wide - obscured by slumping.

DESCRIPTIONS

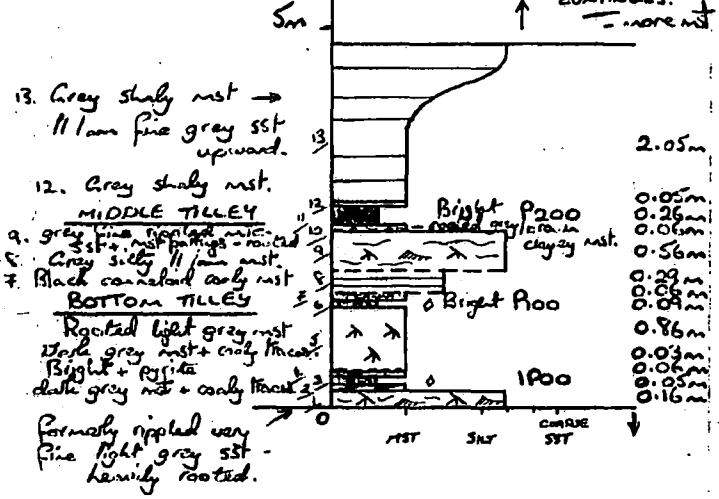
	Unit	
	33	- sst - fine grey 11 lam - little mica.
	32	- grey shaly mst.
	31	- sst - fine grey 11 lam.
	30.	- grey coarse silt - flips up + plant frags. + Calamites + roots in situ.
	29	- grey mst.
	28	- sst - fine grey 11 lam.
	27	- mst - silty grey 11 lam.
	26	- sst - fine white hard not mic.
	25	- mst - light grey.
	24	- Rippled fine white sst + shaly partings.
	23	- mst - fine grey.
	22	- mst - well lam. grey + sandy streak - more sst up → fine white/grey sst.
	21	- mst - grey.
Cross Bedding visible	20	- sst - fine grey well lam.
	19.	- mst - grey well lam.
	18	- grey silty mst → fine grey rock - too mic. sst.
	17.	- " "
*	16.	- sst - brown weathered trough x Bedded mic.
	15	- grey mst + sst streak
	14	- mic. fine grey wavy lam. sst
	13	- grey mst.
	12	- sst - fine grey crystalline.
	11	- grey mst + sst streak
*	10	- sst - fine grey poor lam. well cemented - coarse mica
	9.	- mst - dark grey - poorly laminated.
*	8	- sst - hard massive white less mica
	7	- sst - fine grey very mic. fissile + shale clasts + coaly + shaly partings.
	6	- mst - grey - shaly.
	5	- sst - fine cream poorly lam. well cemented - less mica.
	4	- sst - fine cream/grey very mic. fissile.
	3	- mst - dark grey - shaly
*	2	- sst - fine cream/grey very mic. well lam shaly partings - fissile.
	1	- BUSTY - Q000 - Bright.

C.R. FIELDING - 23.4.80.

Area Diii - Cut 3 - Eastward extension of Area Diii past pylons.
North End of cut - 47m from east pylons.



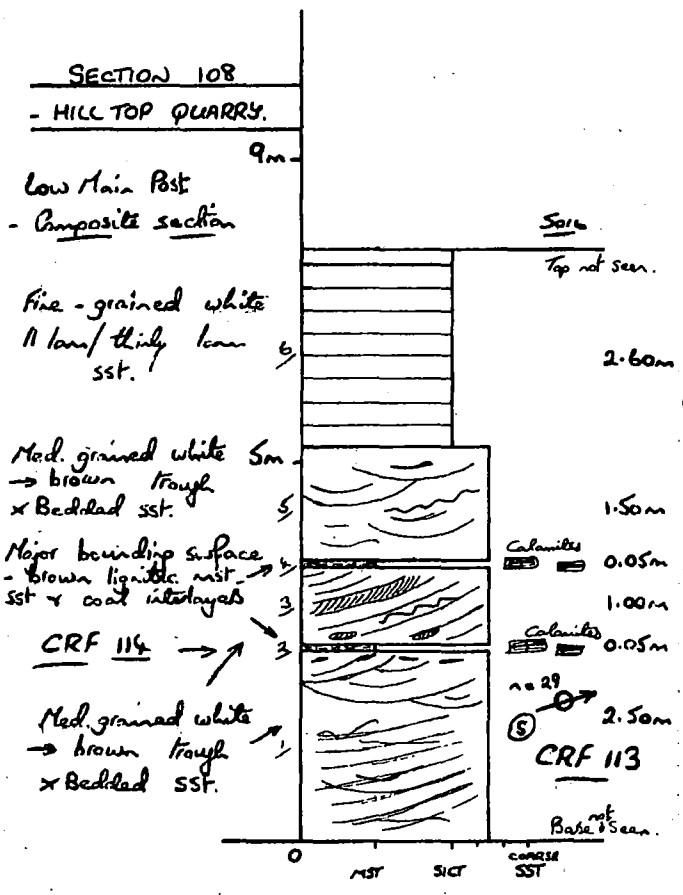
SECTION 107
- DEBORAH - Diii cut 3.
Sidewall trending 010°.



NB 1. Unit 9 - sst thickens to west - 1.28m thick 20m to west.

C.R. FIELDING - 29.4.80

SECTION 108
- HILL TOP QUARRY.



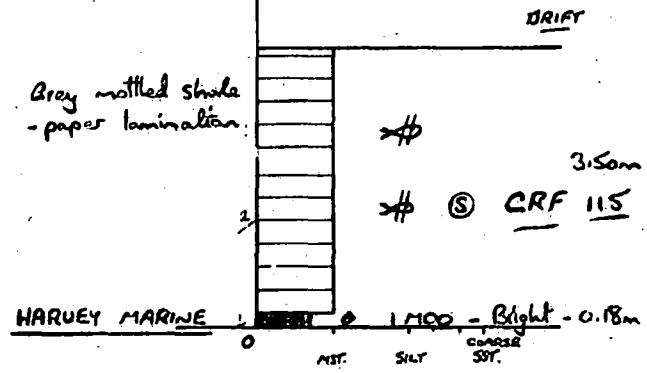
11 photos taken
1 sample.

SEE NOTES ON HILL TOP QUARRY.

C.R.FIELDING - 2.5.80.

South end of cut - 30m north of huts.

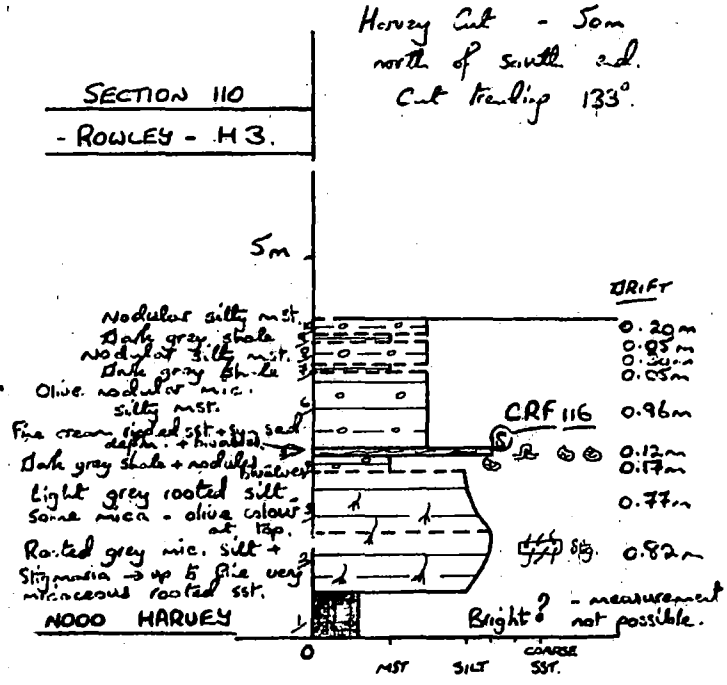
SECTION 109
- ROWLEY - HM2



SAMPLE - Shale with fish scale.
Little lateral variation along cut.
2 photos.

SECTION 110
- ROWLEY - H3.

Harvey Cut - 50m north of south end.
Cut trending 133°.



Sample - sst + bivalves - shells probably drifted - very fossiliferous sst laterally continuous at same level + thickness.

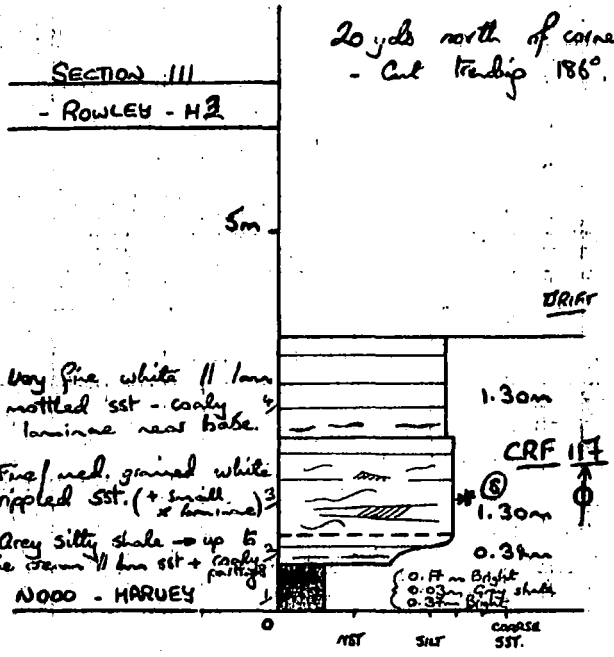
2 photos.

Following north along cut - sst continues for 50m - then slump - then cut corner - face then trends → 186°

C.R. FIELDING - 2.5.80.

SECTION 111 - ROWLEY - H2

20 yds north of corner. - Cut trending 186°.



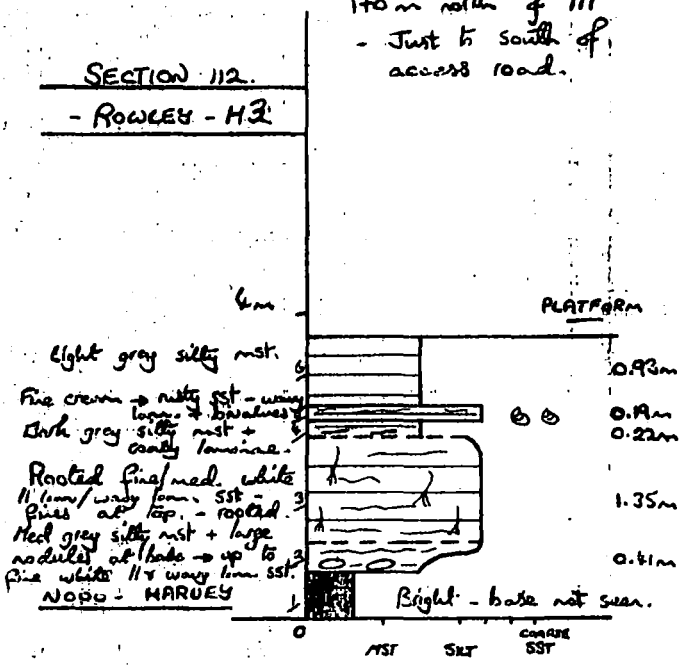
* DIRECTIONAL DATA :-

Unit 3 - Ripple drift - 010° n=1

Cross lamination - 360° n=1.

SECTION 112 - ROWLEY - H2

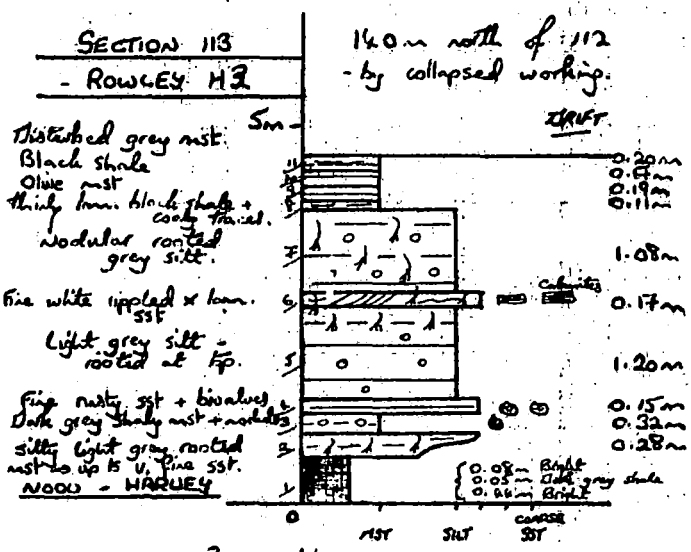
170 m north of 111 - Just to south of access road.



Nodules in Unit 2 ≤ 10 cms long.

SECTION 113 - ROWLEY H2

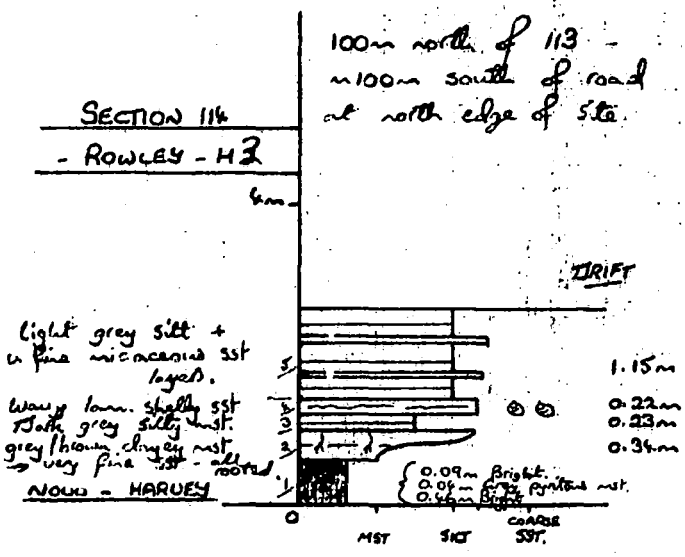
140 m north of 112 - by collapsed working.



2 Frames H/w shst.

SECTION 114 - ROWLEY - H2

100 m north of 113 - 100 m south of road at north edge of Site.



C.R. FIELDING - 2.5.80.

Cut TB2

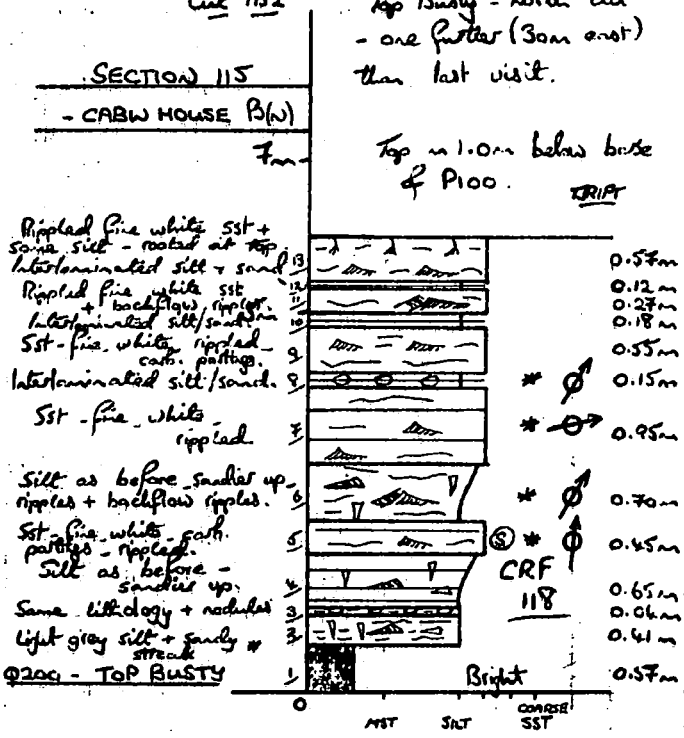
Top Busty - north cut - one further (30m east) than last visit.

SECTION 115

- CABIN HOUSE B(N)

7m

Top at 1.0m below base of P100.



NB 2 frames b/w ASA 125 shot.

* Unit 2 - Micaceous + occasional sst lenses, some ripple form sets - burrows

Sample - fine white sst - Unit 5.

* DIRECTIONAL DATA.

Unit 5 - Ripples - 015° n = 1
Unit 6 - Ripple - 040° n = 1 - others consistent.
Unit 7 - Ripple - 070° n = 1
Unit 8 - Ripples - 010° - 030° n = 2
Ripple crest 300 ↔ n = 1

Cut TL2

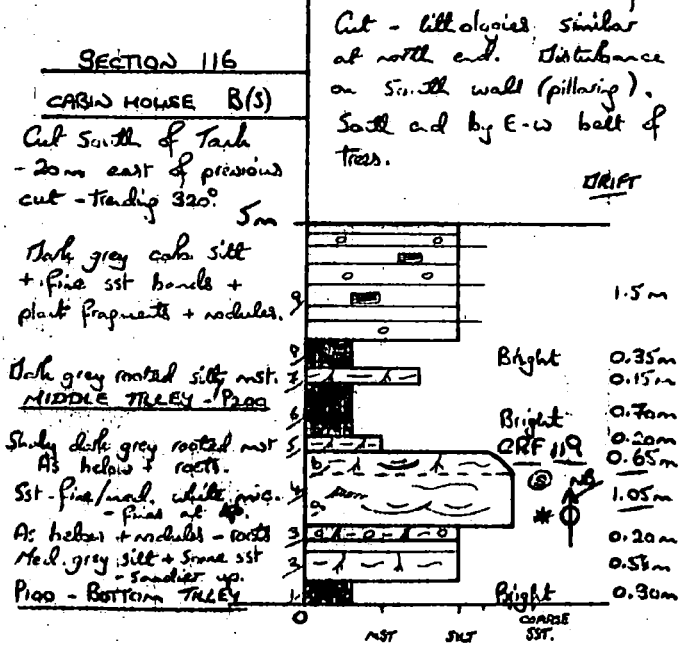
Section at south end of Cut - lithologies similar at north end. Disturbance on South wall (pillaring). Sealed by E-W belt of trees.

SECTION 116

CABIN HOUSE B(S)

Cut South of Tank - 20m east of previous cut - trading 320°

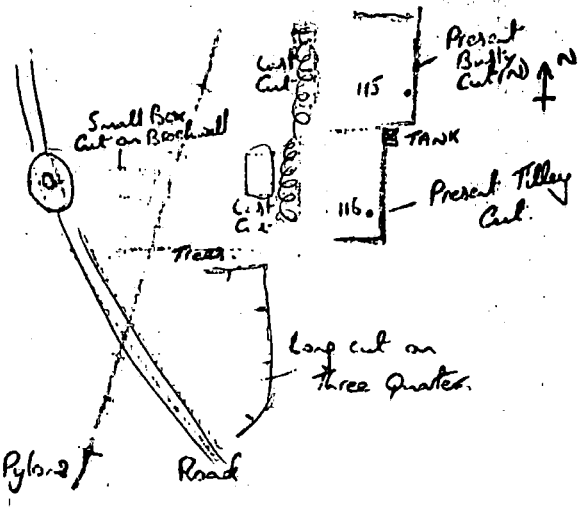
5m



Sample - fine sst - Unit 4a

* DIRECTIONAL DATA - Unit 4a - Small troughs - 358° - 360° - n = 2. - ≤ 0.3m ↑

SKETCH MAP OF CABIN HOUSE - 2.5.80.



Both T. Threequarter + Blackwall + BTG cuts close to outcrop - both expose Sst m + ≤ 2m Shelly mst.

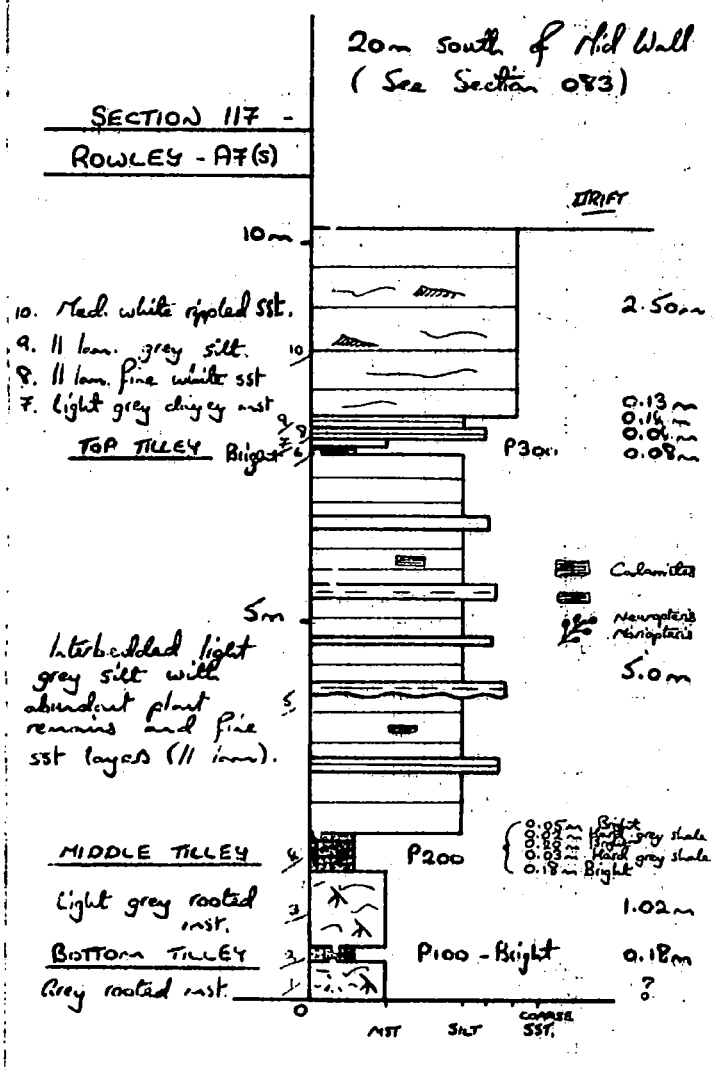
C.R. FIELDING - 8.5.80.

Working south.

20m south of Mid Wall (See Section 083)

SECTION 117 -

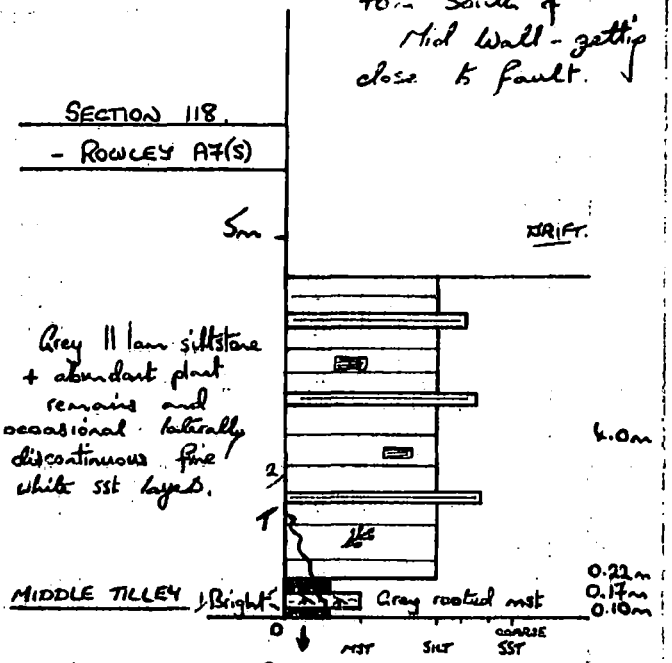
ROWLEY - A7(S)



Sst layers in unit 5 mostly discontinuous laterally.

C.R. FIELDING - 8.5.80.

SECTION 118. - ROWLEY A7(S)



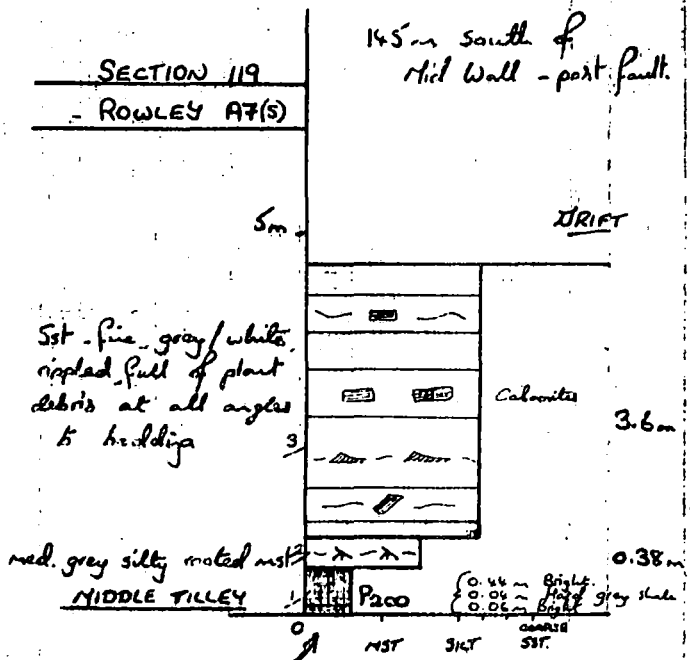
Base not seen.

From south of Mid Wall - getting close to fault.

NB Coal and mst above somewhat tectonised.

At 130m south - fault plane runs into wall - considerable slumping - downthrow to east - fault plane trends → 013°.

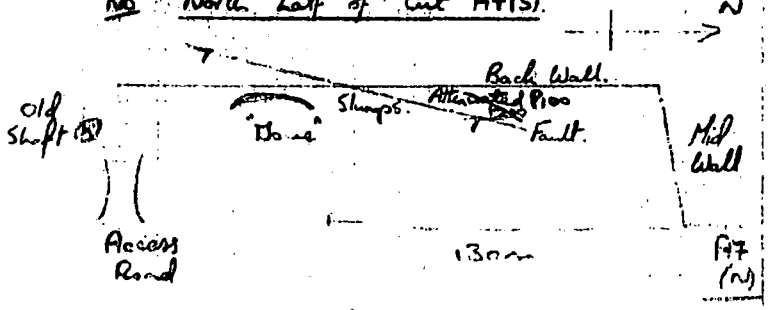
SECTION 119 - ROWLEY A7(S)



Floor a grey/brown rooted clayey mst.

145m south of Mid Wall - past fault.

NB North half of Cut A7(S).

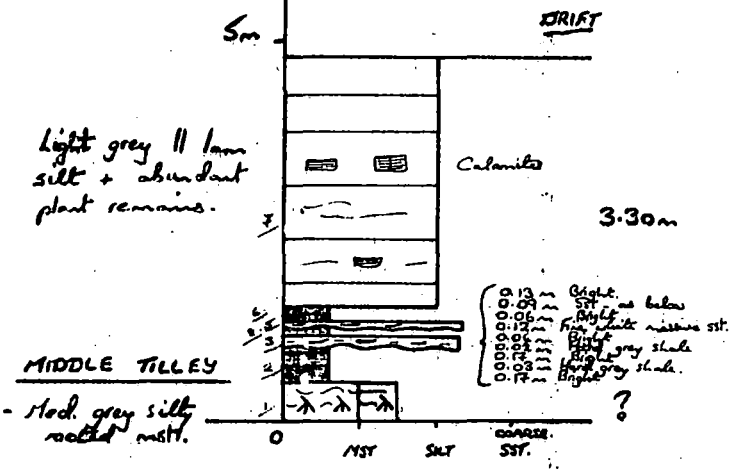


Ant-ll also subparallel second fault - to East.

170m south - new top of dome feature - relief apparent again - though distorted by fault. Interfingering of P200 and sst up to 5m north then obscured by slumping.

SECTION 120 - ROWLEY A7(S)

170m south of mid wall.



6th leaf dies out to south.

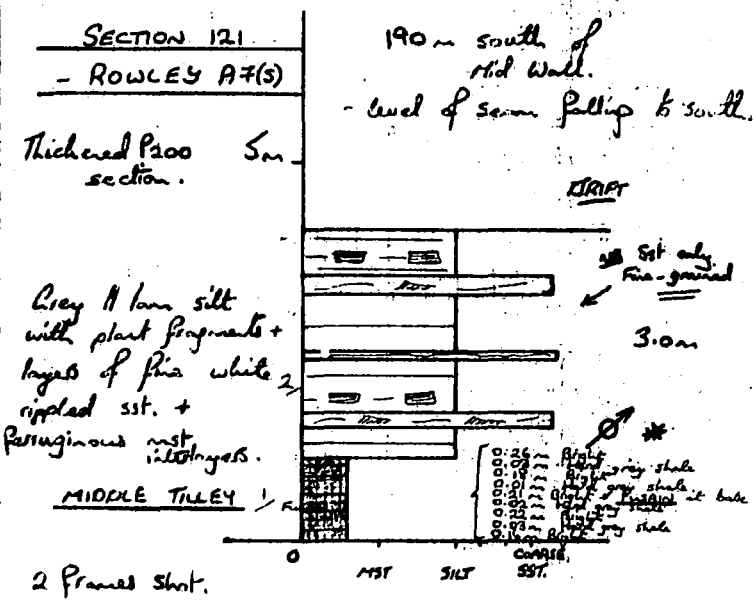
Just to south - centre of partial washout - exposure not good, but in Section 120 leaves 5 & 4 & 3 are lost - leaf 2 is split and largely lost, leaf 1 remains. 6 frames shot + 2 panorama.

By 185m south - washout finished.

SECTION 121 - ROWLEY A7(S)

190m south of Mid Wall.

- level of seam falling to south.



2 Frames Shot.

NB Leaves 3 & 4 merge in places. Leaf 5 dies out to south (15m) - further washout (opposite access road) - same lithologies, but slumping obscures exposure.

Just to north (3m) of 121 - small partial washout (4m wide) - top leaf cut out - sst in washout coarser than elsewhere.

* DIRECTIONAL DATA.

Unit 2 - Ripple x Lamination → 045°

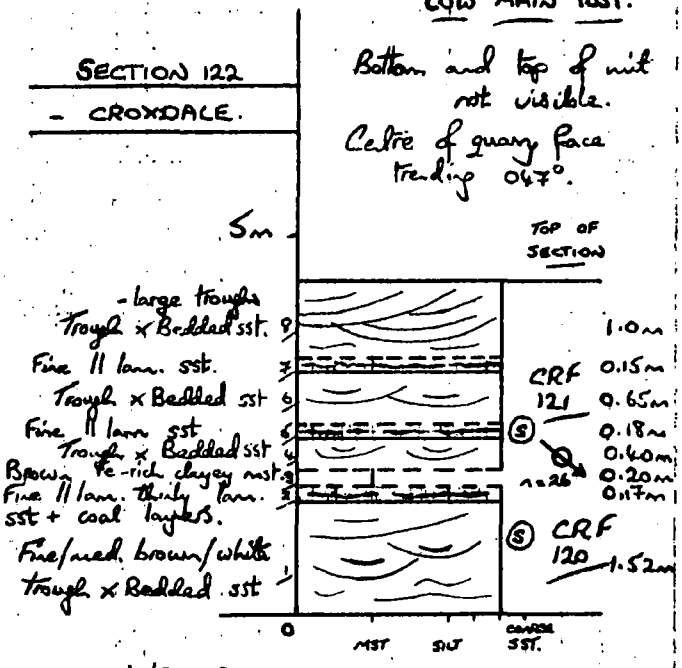
n=1

C.R. FIELDING 12.5.80

LOW MAIN POST.

SECTION 122
- CROXDALE.

Bottom and top of unit not visible.
Centre of quarry face trending 047°.

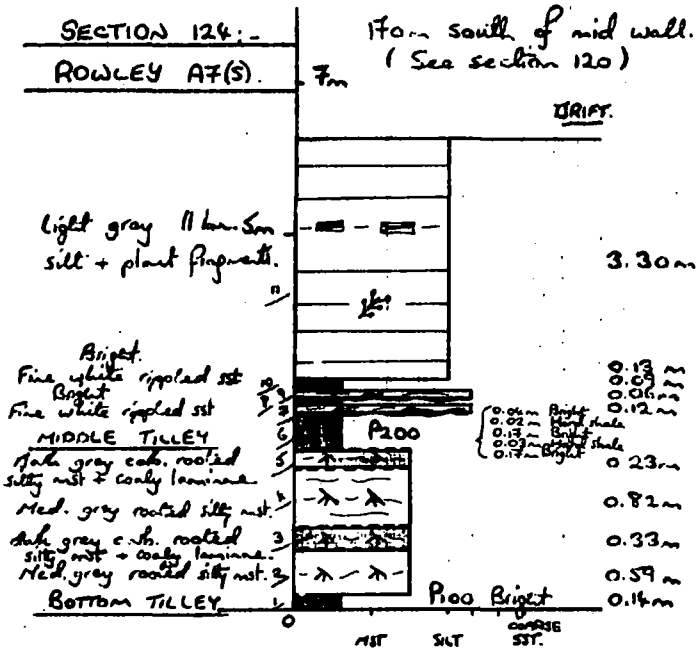


2 photos. 2 samples.
SEE NOTES.

C.R. FIELDING 15.5.80.

SECTION 124:-
ROWLEY A7(S).

17m south of mid wall.
(See section 120)



NB Unit 3 - dies out 10m to north as same lithology - immediately to the south - transforms into bright coal - 0.5m south of Section 126. Unit 3 is represented by 0.30m bright.

CRF. 13.5.80.

SECTION. 123
- HOWDEN GILL

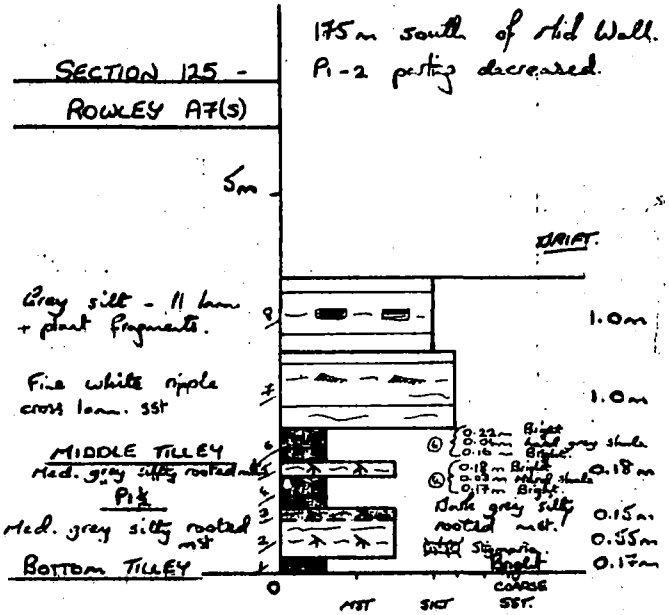
LOW MAIN POST.

Bottom of sst not visible
Howden Gill quarry - by Lanchester.
Fine sst
Silty mst
Fine sst
Silty mst
Fine sst / structureless
Silty mst - dark grey
Fine white sst - Trough
Silt + sandy streak - dark grey - wavy/ripple lam.
Large and small-scale trough x Bedded white/brown med./fine-grained sst. - occasional PCL, near-symmetrical ripples - drifted plant fragments - thin 6cm-10cm units of interbedded finely lam. sst and coal.
1.0m
0.05m
0.65m
0.07m
0.33m
0.15m
0.55m
0.13m
0.26m
5.0m
n=36
9m
GRASS
silty mst.
PCL
CRF 122
0
MST
SILT
COARSE SST.

Section on middle of north wall - face trending 275°.
See Notes. 12 photos and 1 sample.
Thin sst's variable in thickness.

175m south of Mid Wall.
P1-2 parting decreased.

SECTION 125 -
ROWLEY A7(S)



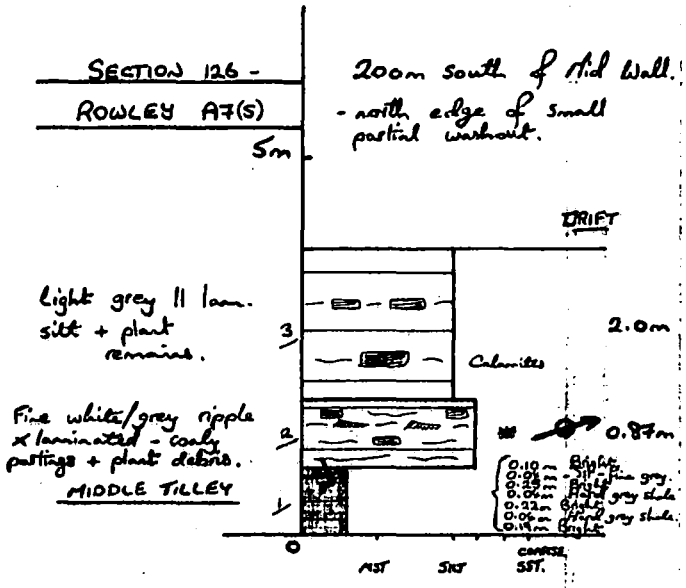
NB Band in P150 dies out to north. By 7m south of section 125, P150 has joined up with main P200 = 182m south of mid wall. P200 - P100 parting = 0.71m.
All leaves retained - 3 from P150 (2nd band develops), 2 (+1 over washout) from P200. Interfingering of sst with P200 occurs by joining of P150 and P200 - as well as at 10m to N & S.

At 200m south of mid wall (5m shaft of access road), thickened P200 outcrops.

C.R. FIELDING 15.5.80

SECTION 126 - ROWLEY A7(S)

200m south of Mid Wall. - north edge of small partial washout.



NB Unit 1e - thinned and amalgamated leaves 3 x ½ from north. Evidence for small synsed. faults where sst loads into top of P200 - SST more or less continuous along face.

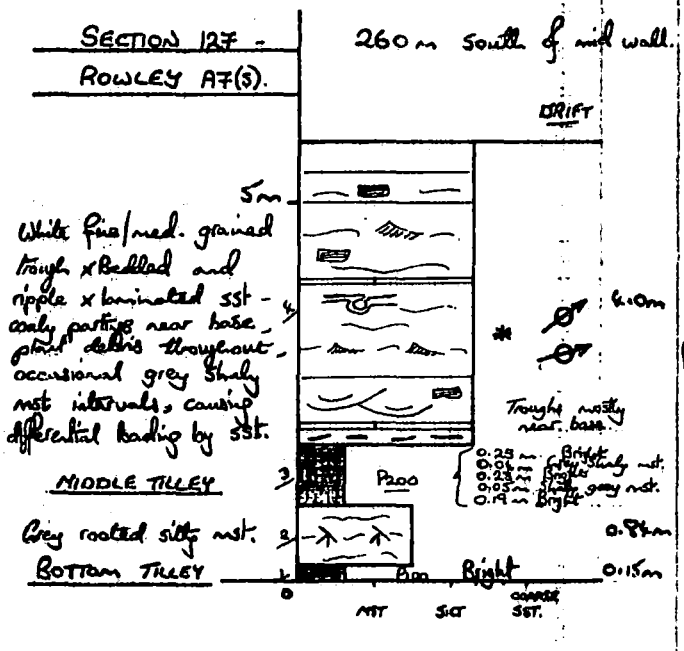
* DIRECTIONAL DATA :- Unit 2 - Drifted plant debris → 1. 035 2. 351° 3. 096° 4. 100° 5. 093° 6. 133° 7. 059° 8. 066°.

θ = 074°/ 77%

At 235m south of Mid Wall_ thinning due to old workings - P200 probably close to original thickness. At 240m _ small (½m displacement ↓S) fault also incoming of large sst body - laterally changes from silt_ with sst below (over P200).

SECTION 127 - ROWLEY A7(S).

260m south of mid wall.



* DIRECTIONAL DATA :- Unit 4

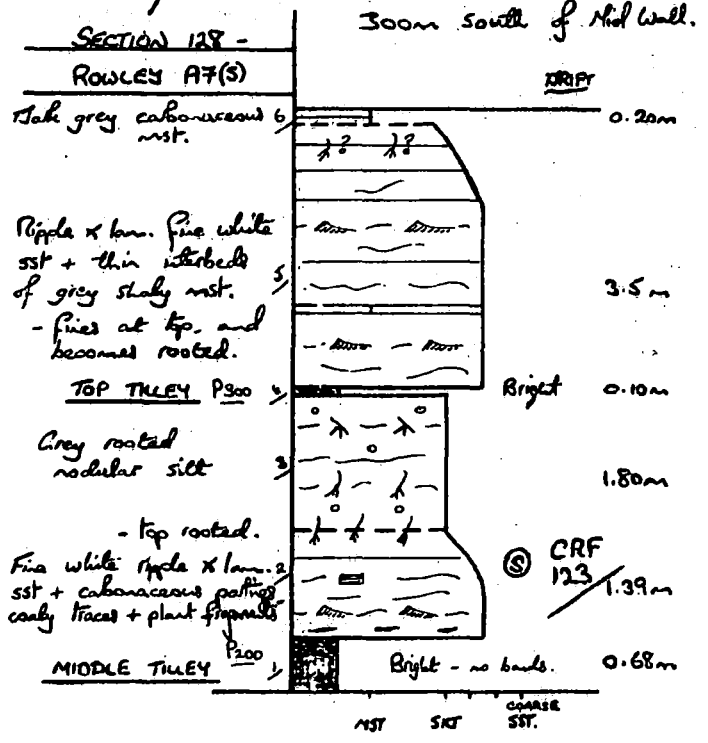
1. Trough x Bedding 0.15m↑ = 1m ea/ 8/ 056° n=1

2. Ripple dip → 073 n=1.

At 270m south of Mid Wall_ P300 appears in top of wall - starts to come down the face to the south. Top Tilley Post above is interbedded sst and shaly mst.

SECTION 128 - ROWLEY A7(S)

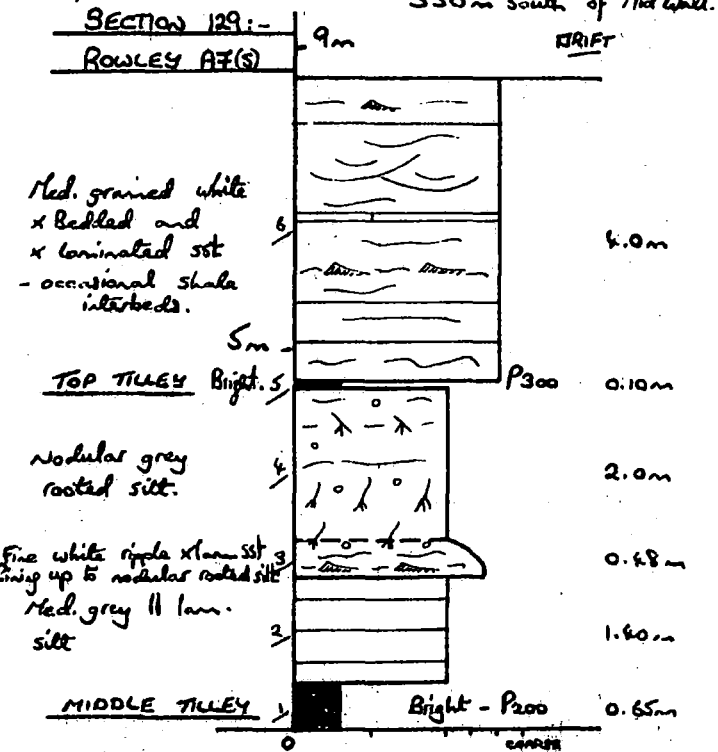
300m south of Mid Wall.



Level of P300 is at lowest - starts to rise again to south. At 315m, sst starts to rise off the roof of P200. At 330m - P300 is 3-3.5m above the top of P200. sst over P200 is rising gently up the face to the south.

330m south of Mid Wall.

SECTION 129:- ROWLEY A7(S)

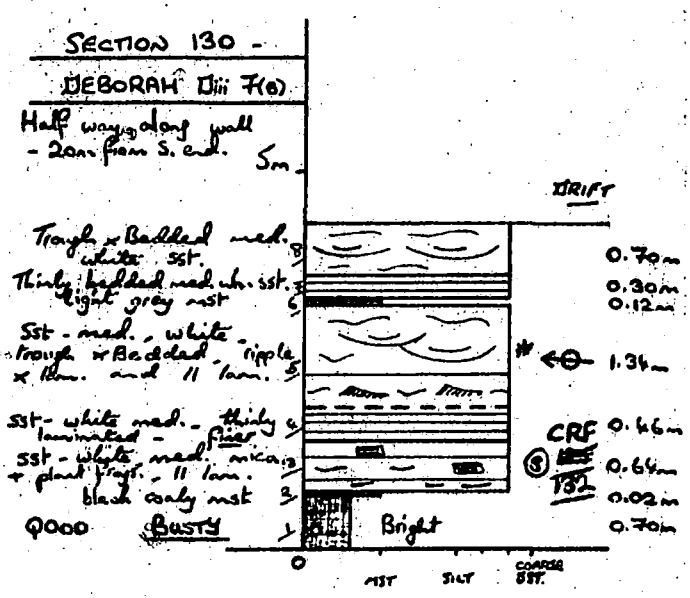


NB Sst thins from section 128 before rising off seam. At 350m thin fine sst bands in silt over P200 come in - continue to end of face. By 370m. P300 is 5m above P200 - sst has reached P300 level. At 360m - sst forms a localised trough feature - thickened locally to 1.5m. Top Tilley really dies away in places. Thin fine sst bands quite common at end of face. Total length of exp - 395m.

C.R. Fielding - 22.5.80.

SECTION 130 - DEBORAH Diii 7(6)

Half way along wall - 20m from S. end.

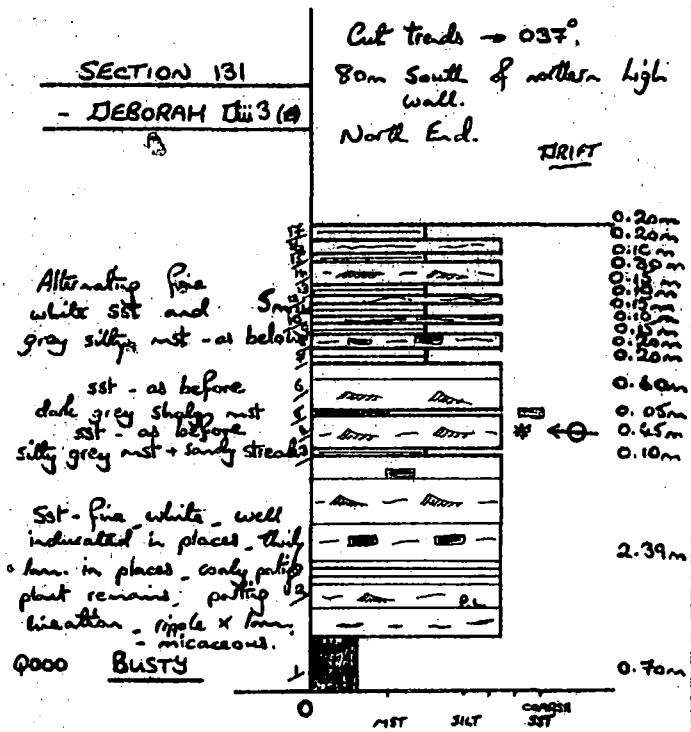


* DIRECTIONAL DATA :-
Unit 5 - Trough x Set - ?/0.5m/277° n = 1
- width unknown.

NB Cut wall trends 223° - Drift cuts down to S. Much less fine material intercalated than in previous cuts. Unit 6 splits to north-east. Sst is laterally variable in character.
Coal QOOO: thins 0.98m → 0.70m to NE over 65m. from back of cut.

SECTION 131 - DEBORAH Diii 3(6)

Cut trends → 037°.
80m South of northern high wall.
North End.



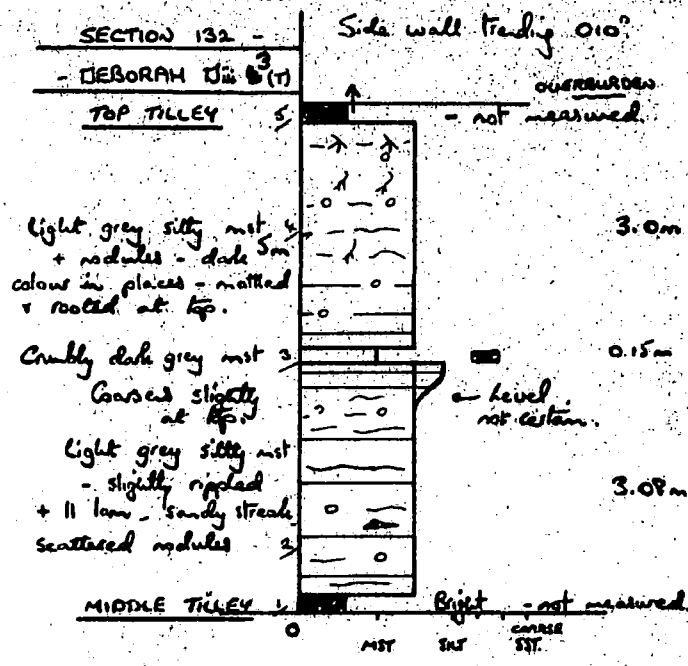
* DIRECTIONAL DATA :- Unit 4
- trough x Set - ?/0.2m/276° - n = 1
2m wide.

NB 2 frames ASA 125 b/w film shot - Film 11 finished. Undulating surfaces picked out by thin silty mst horizon.

Unnamed Bushy no under QOOO dips [illegible]

SECTION 132 - DEBORAH Diii 3(7)

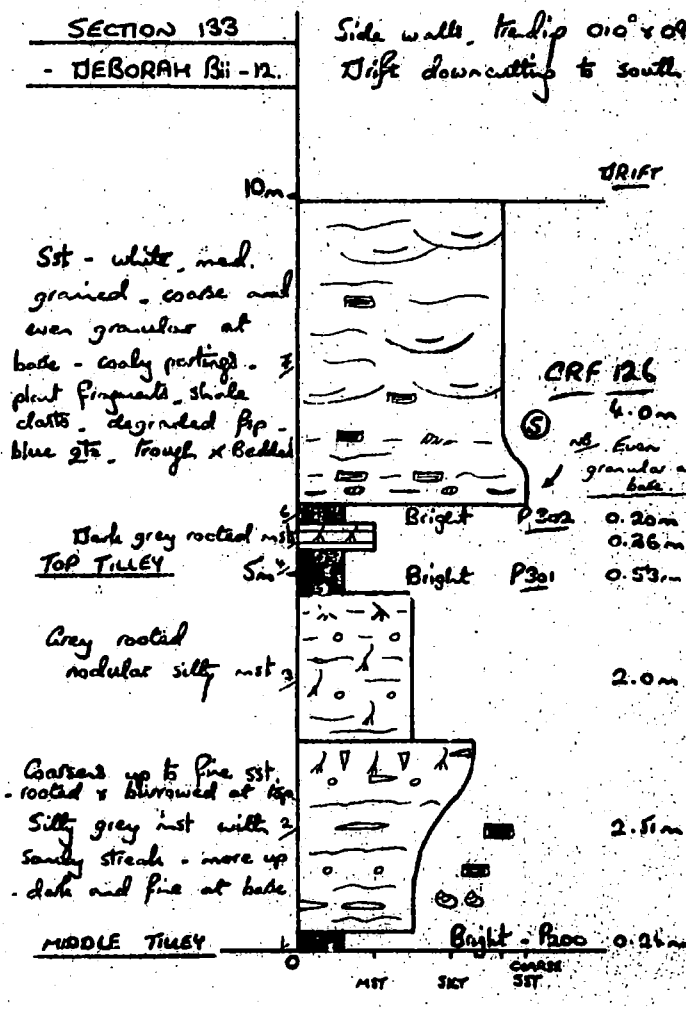
Side wall trending 010°



NB ~~Poo is not present as a coal seam - may be represented by dark mottled layer in mst.~~
Prominent coarsening upward sequence present to the north is largely absent - slightly coarsening occurs near or at top of Unit 2.

SECTION 133 - DEBORAH Bii - 12.

Side walls, tr/dip 010° x 090°.
Drift downcutting to south.

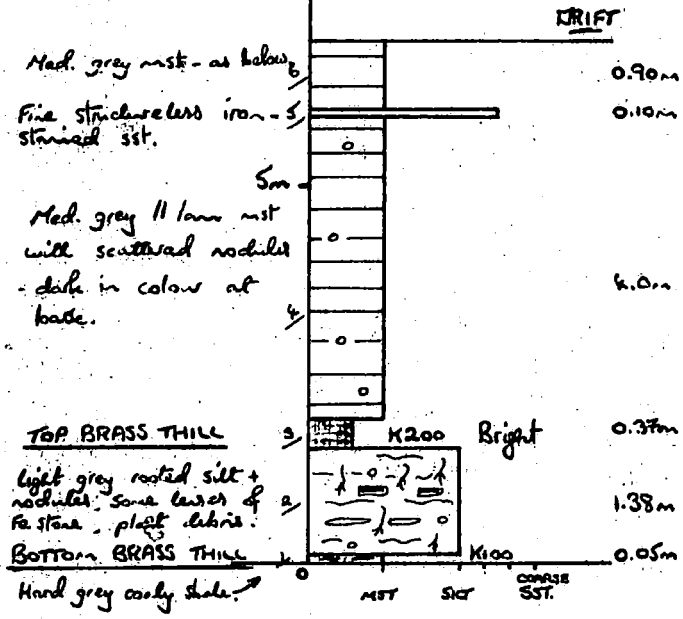


NB In Area A, Top Bushy splits off from Bushy Seam - to north.

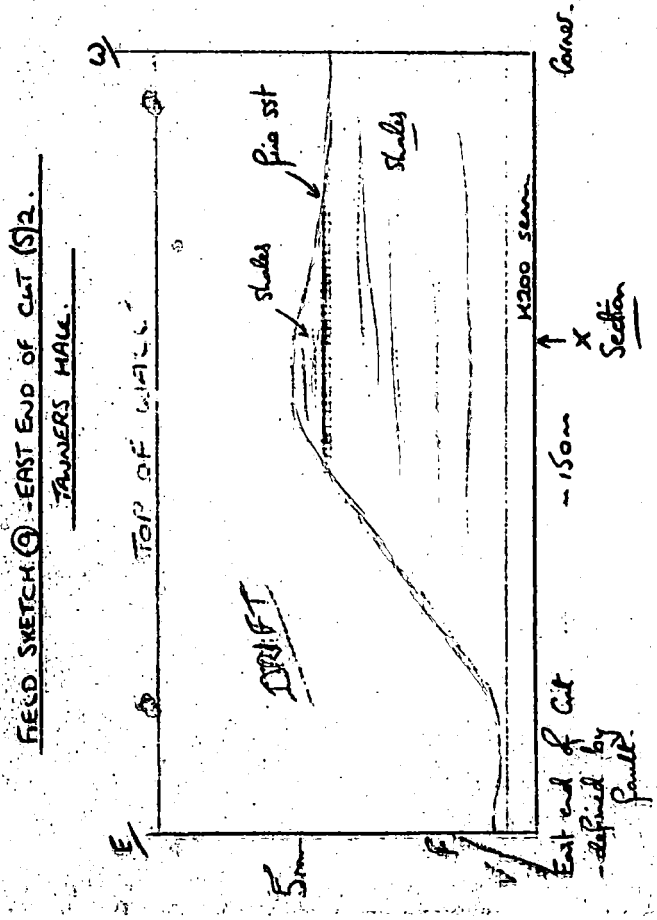
C.R. FIELDING - 29.5.80

Area S - Cut 2.
Composite Log.
Cut Trending 280°

SECTION 134 - TANNERS HALL - 2(S)

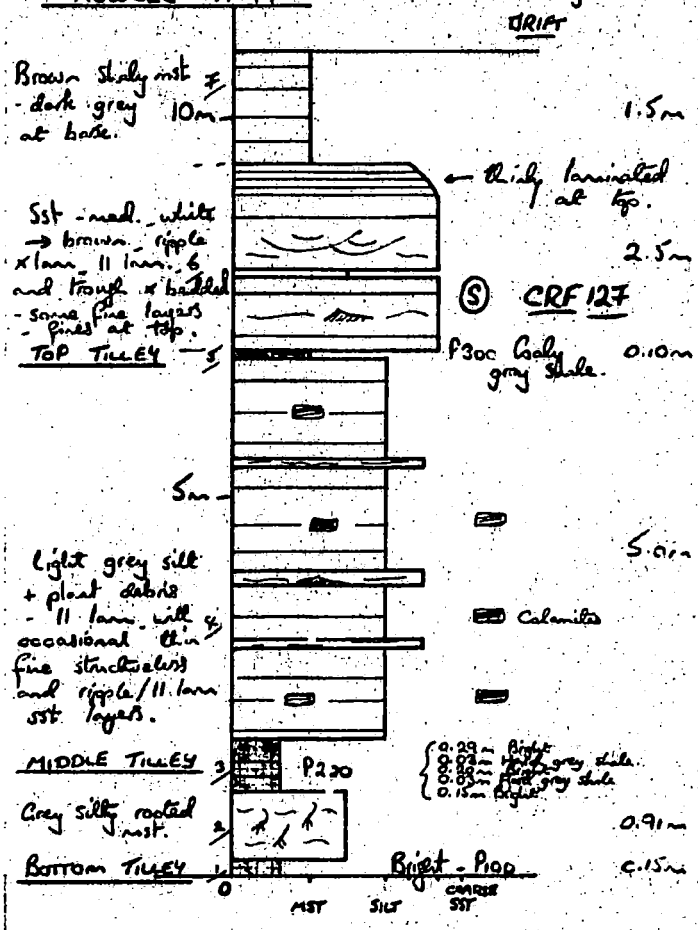


NB Drift cutting down to east - at east end of cut - in 150m from slight corner - drift is just above roof of seam.
At east end - small exposincatal cut exposes level of K100 - hence composite section.
Half way between corner and east end - solid section is ~5m - thin sst occurs - not present further west - due to drift cutout.



C.R. FIELDING - 29.5.80

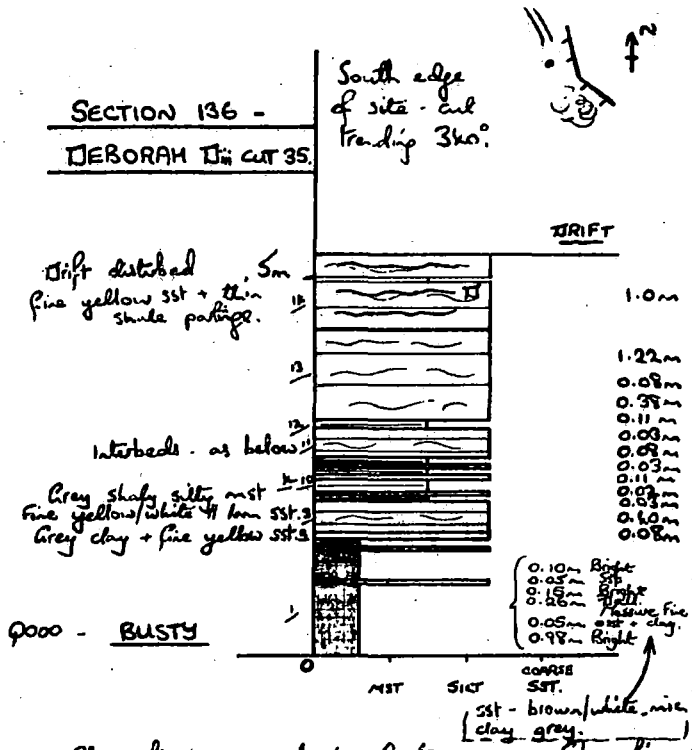
SECTION 135. North end of A8(S) - corner of ROWLEY - A8(S) Mid Wall and Long Wall.



NB One sample - Top Tilley Post.
3 photos - ASA 125 b/w.
In Mid Wall - down cutting relationships in thin is not apparent - probably level bedded.
Working south along high wall - fine unit at top of Top Tilley Post becomes as thick as the main sst (1.25m each) - at 20m south. Then - by 40m south - fine grained unit has disappeared - 2.5m all main sst. - facies otherwise similar to Section 135. Start of slumping due to fault/old workings.
Barren area in P200 approaching.
Along Mid wall - to east - main sst of Top Tilley Post thins down markedly - fine material at top thickens correspondingly.

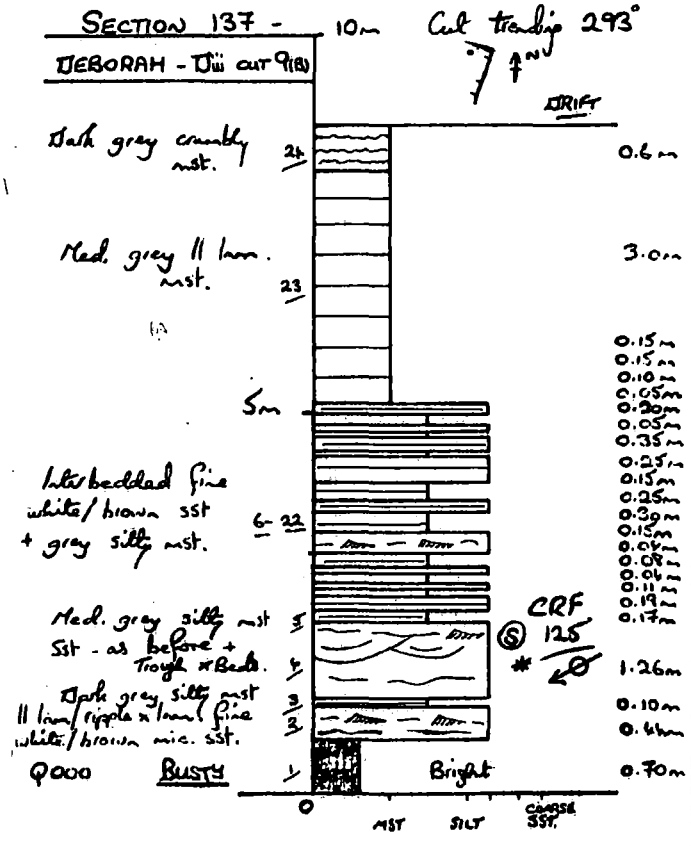
C.R. FIELDING - 5.6.80

SECTION 136 - DEBORAH Dii CUT 35.



Clay diapirs present in Busty seam. Sst partings in Busty increase in thickness from 0 - 0.10m at the south end of the cut. - grey clay predominantly at the top of the bottom parting. Sst layers lies in and out. Some laterally continuous. Unit 13 - lens shaped sst - appears from 0 thickness → 2m at south end of cut. Beds below are also involved with this sst in a downcutting → south. Unit 11 also wedges out 10m to north.

SECTION 137 - DEBORAH - Dii cut 9(B)



DIRECTIONAL DATA:- Unit 4 - Trough x Sets.

1. 0.3m/18/265° 2. 0.8m/16/268°

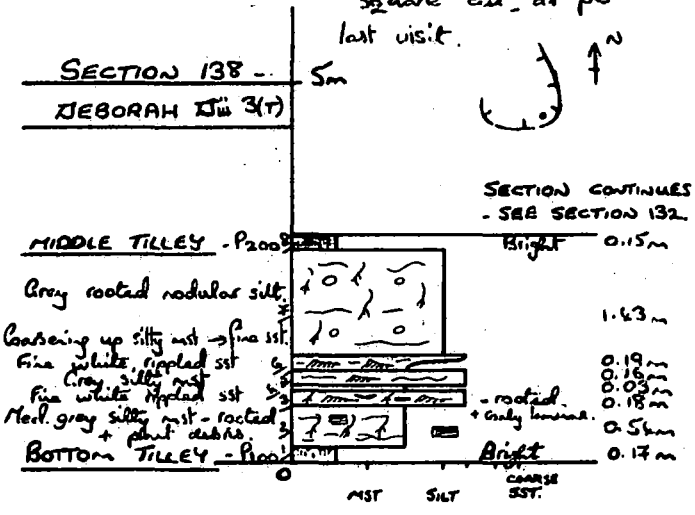
n=2

Again sst layers lens in and out - both E-W and N-S - layers more obviously continuous along N-S face - 1st 3m over Busty is nearly all sst - then sequence of n 0.5m ssts and thin shaly msts. Most beds laterally continuous. Tectonic 10/108.

5 frames ASA 125 b/w shot.

Cut 3 Tilleys - large square cut as per last visit.

SECTION 138 - DEBORAH Dii 3(T)

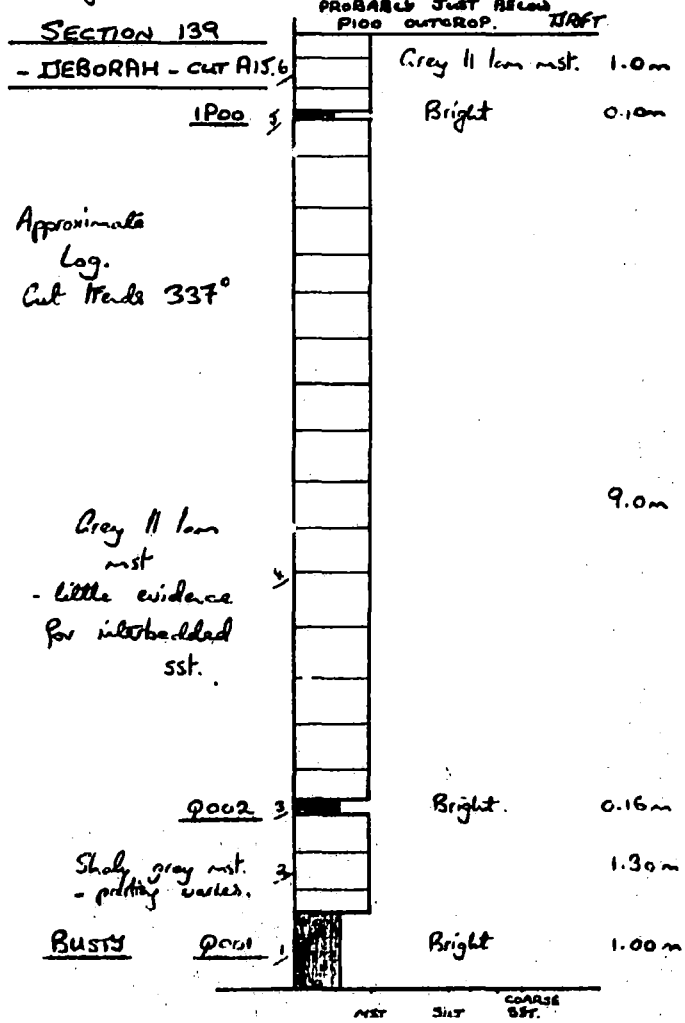


Presently digging down to Busty on Dii x (B) N - 1P00 not present.

Section at SE corner of Cut.

Sst bands die out along the face to the north within 10m. At SW corner 4 sst bands present - roughly same thickness. 5th sst comes in right on corner - units added onto top of section - no splitting. 2 frames shot.

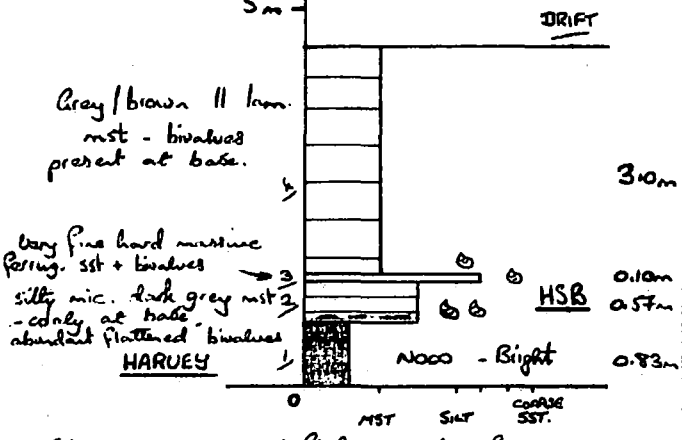
SECTION 139 - DEBORAH - CUT A15.6



C.R. FIELDING - 5.6.80.

East end of A(5) - Cut trending 250°

SECTION 140 - DEBORAH - CUT A5.



Sst preserves decalcified moulds of bivalves.
2 sst units wedge in at extreme east end of cut. - both above shell bed - bottom one ≤ 0.5m. Second one ≤ 0.3m - wedge out to west.

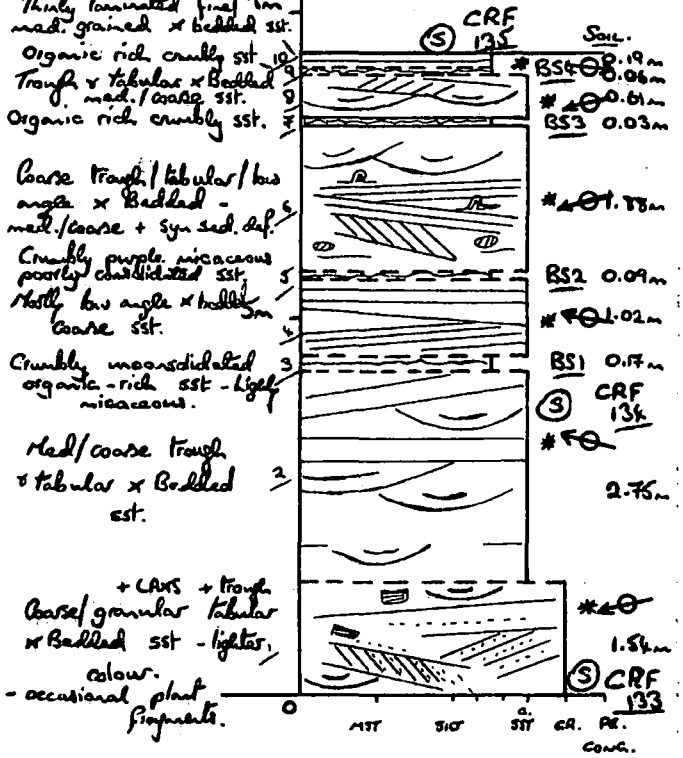
C.R. FIELDING 25.6.80.

SECTION 141 - PARK HEAD BANK

Composite log.

Roadside exposure south of Spennymoor. See also drawings and sheet of notes.

Tectonic Dip 11/347



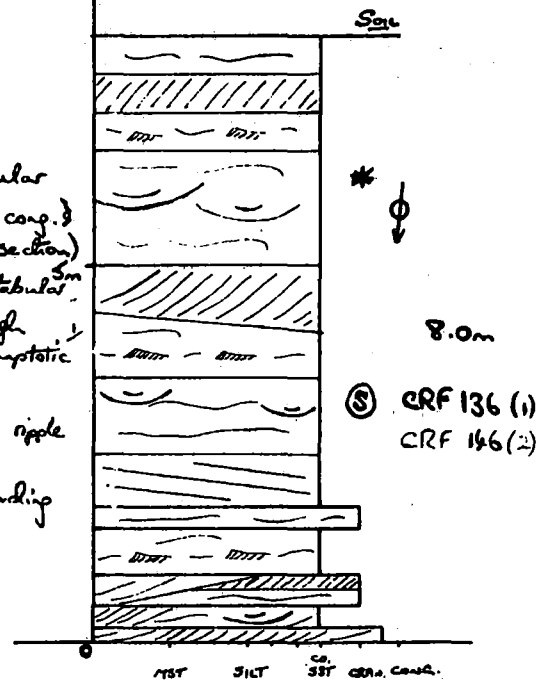
Units laterally variable in thickness.
Entire outcrop red/brown colour - significantly reddened.

* DIRECTIONAL DATA :- See separate sheet.

SECTION 142 - WESTERTON QUARRIES. TO FATHOM POST

Exposure of quarries 1 & 2 probably similar level - sequence repeated by fault.

Composite log from quarries 1, 2 & 3.



NB Some of planar asymptotic sets may be troughs

* DIRECTIONAL DATA :-

See separate sheet - cross-bedding of several types - n = 46

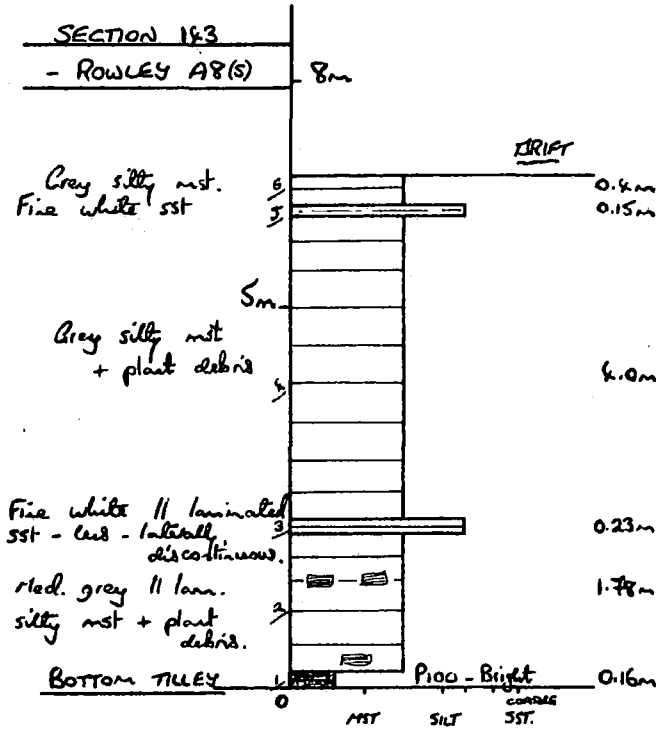
θ = 186.2°
L = 56.0%

For quarry ① θ = 252.1° L = 17.7% n = 19
② θ = 176.8° L = 93.3% n = 26
③ θ = 248.0° n = 1

C.R. FIELDING - 12.6.80

140m south of Mid Wall.

SECTION 143
- ROWLEY A8(S)

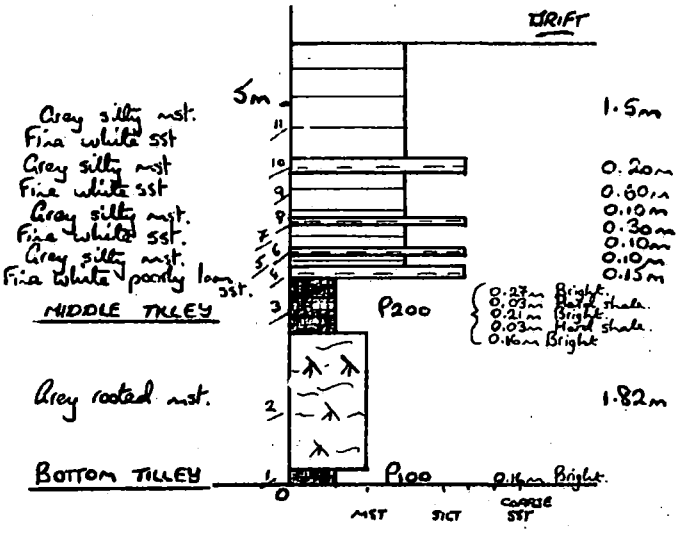


NB 100m south of Mid Wall - facies same as at Mid Wall but P200 missing - taken out by erosion - disappears in first slump 125m - second smaller slump. 180m south of Mid Wall - P200 can be seen to thin laterally → 0 at 173m (→N) and gradually thickens to south. P100 remains intact - so thin seam in barren area to north is P100.

Bottom leaf of P200 continues to thicken to south - top leaf stays ~ constant in thickness. 6m on = 186m south - Bottom leaf proper comes in - P200 now full 3 leaves. Bottom down-cutting sst thins → 0 to south - but overlying units continue - cut down to lie at angle over P200.

192m south of Mid Wall.

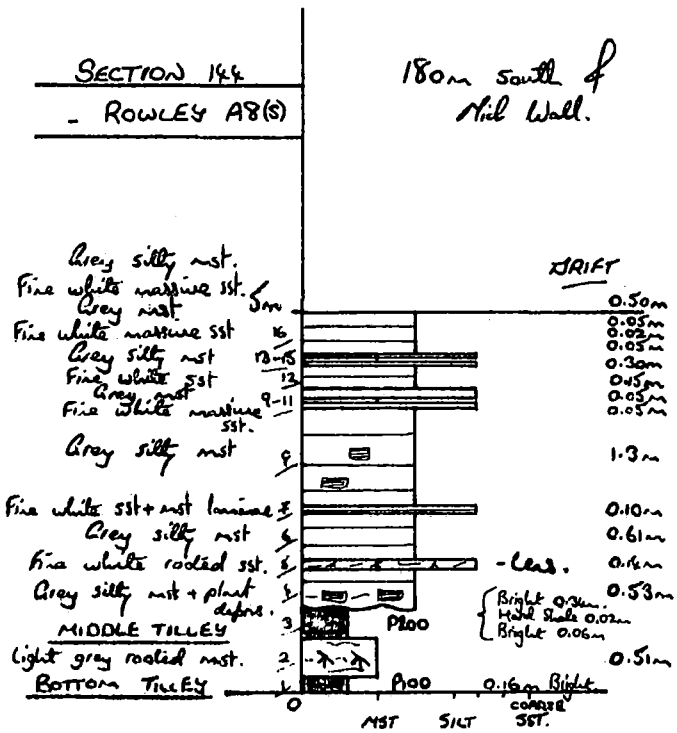
SECTION 145
- ROWLEY A8(S)



NB Unit 4 is equivalent to the second down-cutting sst of Section 144. Beds immediately to south level out - cross-cutting no longer apparent. At 200m south, extra seam P150 comes in - half way up the P1-2 parting. - grades in from coaly mst (to north) toward south. - thickens southward.

180m south of Mid Wall.

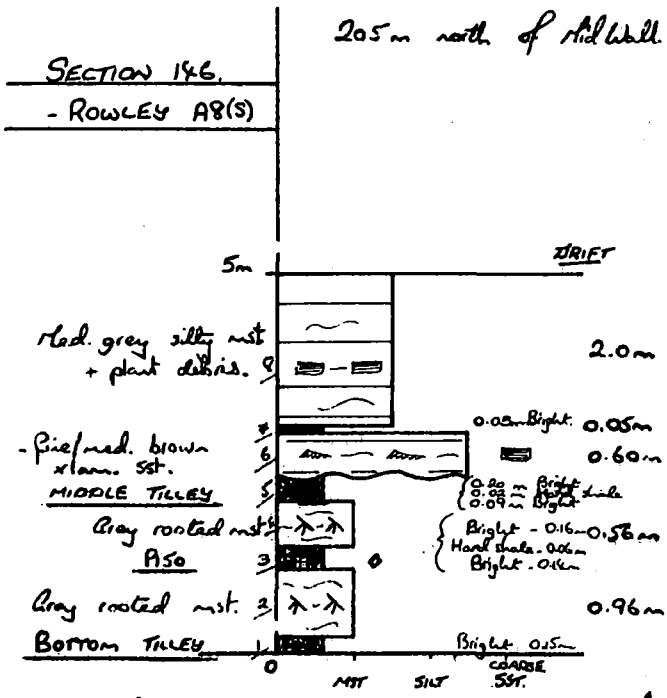
SECTION 144
- ROWLEY A8(S)



NB Bottom leaf of P200 dies out 2m to north. Unit 7 - first bed to cut down to south - beds above cut down - Sst 7 level bedded until 175m - then starts to cut downward.

205m north of Mid Wall.

SECTION 146.
- ROWLEY A8(S)

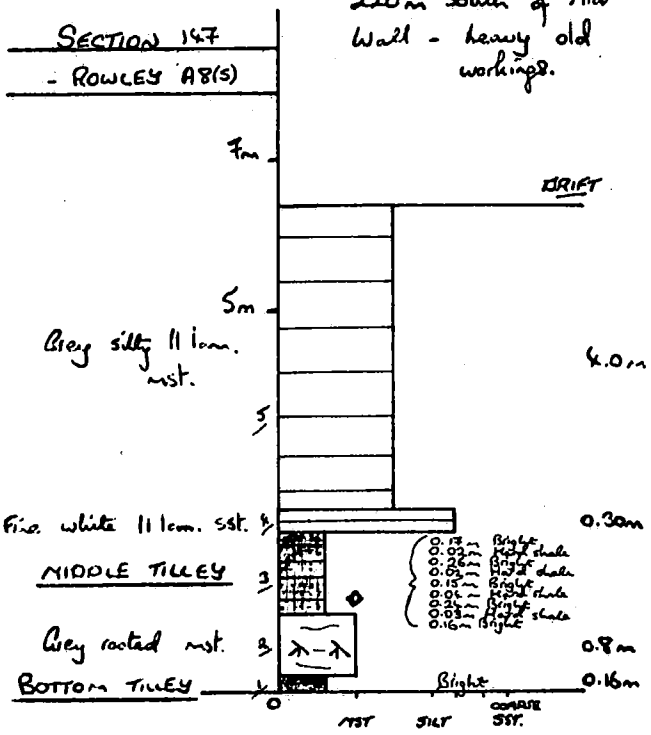


NB Band in Unit 3 appears at 203m - variable in thickness. Unit 6 - partial washout - begins 1m to north - continues for ~5m to south (partly obscured by slumping) - sst arched up - coal rides [illegible]

C.R. FIELDING - 12.6.80.

SECTION 147
- ROWLEY A8(S)

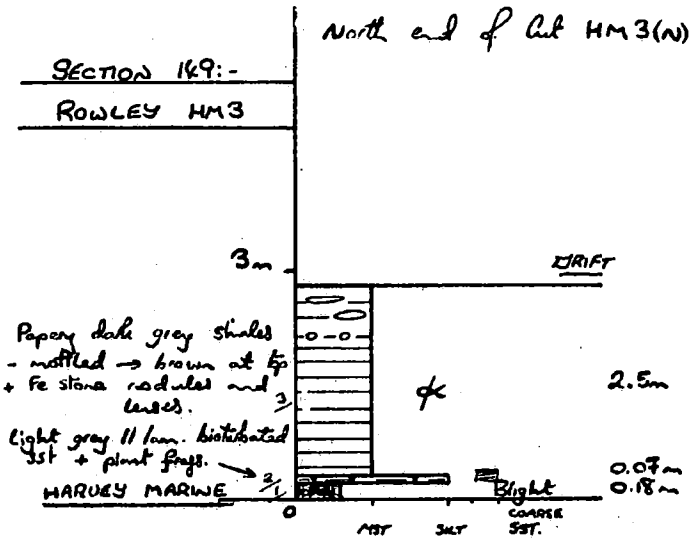
220m south of Mid Wall - heavy old workings.



To south - Top Tilley Post comprises 0.3m sst then 0.5m shaly mst below drift - Top level of large sst over P200 starts to drop to south - bedding dipes over to south. Section badly disturbed by old workings.

SECTION 149:-
ROWLEY HM3

North end of Cut HM3(N)



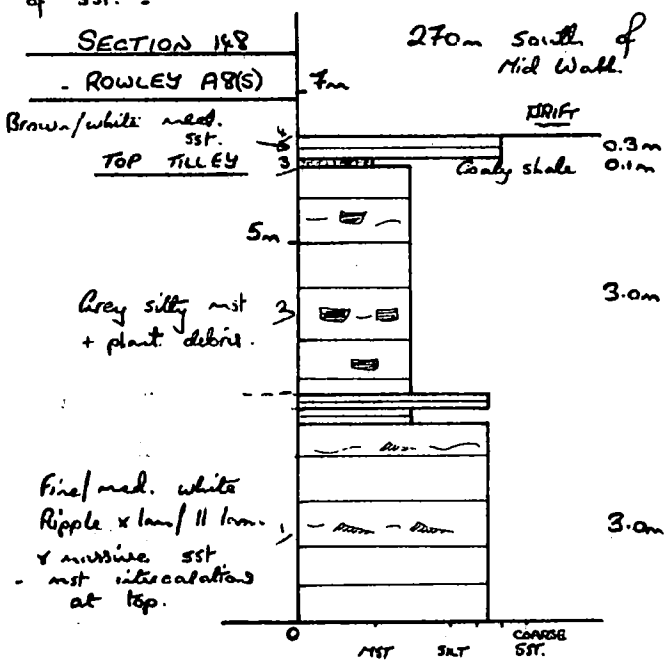
NB Silt band dies out after 210m to south - grades into black carbonaceous mst.
South half of cut - same lithologies - HM3(S). Some ironstones become discrete bands continuous for ~10m along face.

(At 210m - P150 joins onto P200 - thickened seam to south - topographic high for P200 - remnant of dome feature perhaps.)
Section 147 - 5 leaves - reduced to 4 by 5m to south - down to 3 shortly after.
Unit 4 - sst thins → 0 by 5m to south - section all silty mst.
240m - large sst 'is grading in' - P200 obscured by piles of debris - sst starts as two bands ~2m above the floor of P200 - thicken up and more sst grades in to south.
270m - P200 still obscured - measured above new solid sst for 3m - silty mst horizons at top of sst. -

C.R. FIELDING - 19.6.80.

SECTION 148
- ROWLEY A8(S)

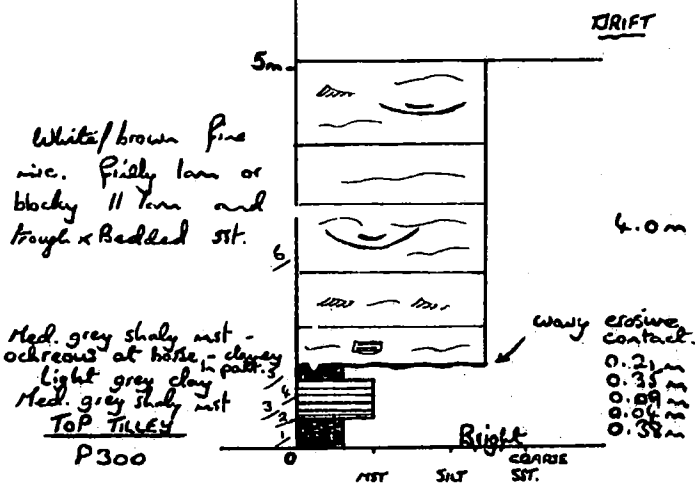
270m south of Mid Wall.



SECTION 150
- DEBORAH Dv CUT 1.

Just south of corner and small fault (↓ to S). Cut trending 331°.

Close to Basset edge.

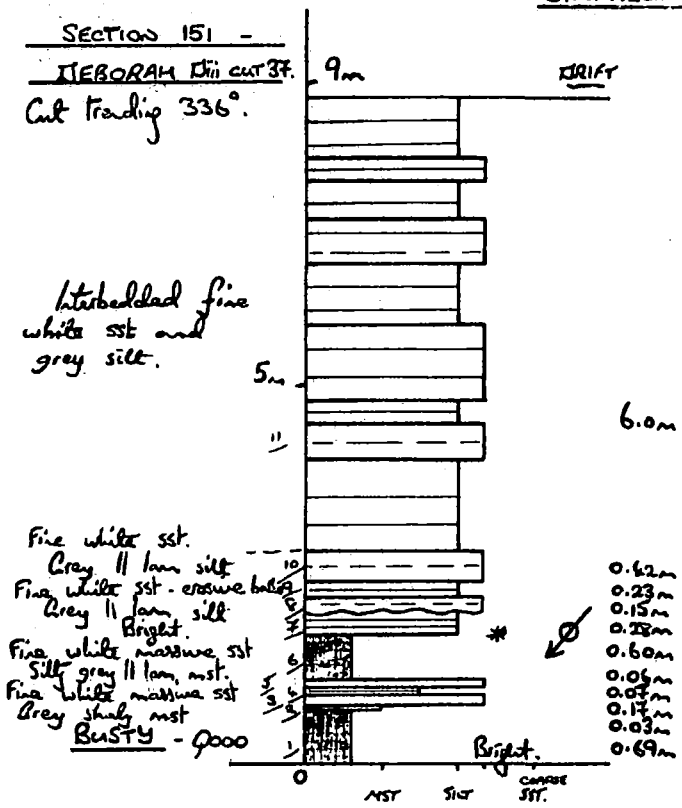


NB Sst interfingers with top of coal at south end of cut.

C.R. FIELDING - 19.6.80.

SECTION 151 - DEBORAH Dii cut 37.

Cut trading 336°.



NB Extra seam above Busty - lenses out at south end of cut. Washout occurs to north - not yet dragged. Extra leaf present as narrow area in previous cut - wedge shaped. Bedding in sst still downcutting along cut to SE. Proportion of sst and thickness of sst units increases to NW. Extra leaves appear to north above 2nd leaf - fingers out to south. Sst and silty mst fill intervals.

In top of 2nd leaf - straight aligned sst - filled gutters. - approaching washout.

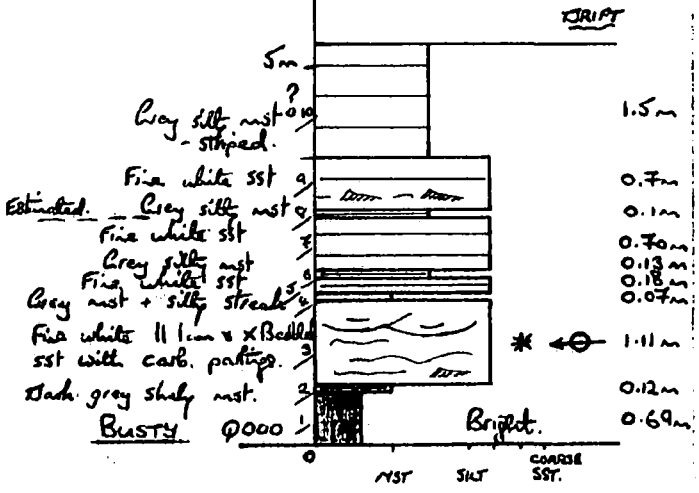
D.D. * 1. 1m wide / 235 2. 1m wide / 232°
3. 0.10m wide / 188°.

Unit 7 - $n = 3$

$\theta = 218.70°$ $\lambda = 93.17\%$

SECTION 152 - DEBORAH Dii 4 W(B)

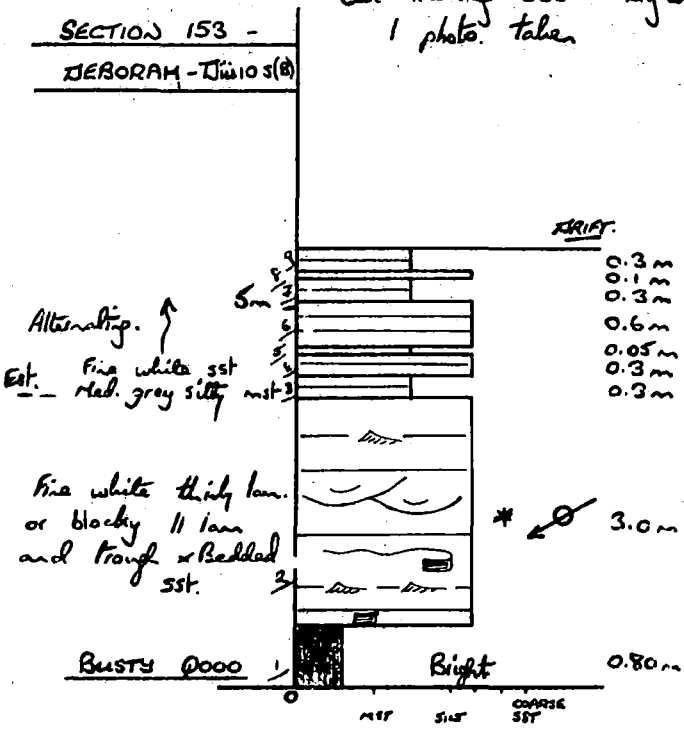
Cut trading 216°.
near south end.
2 photos.
Units laterally persistent.



* DIRECTIONAL DATA :- Low angle x set (Top of unit)

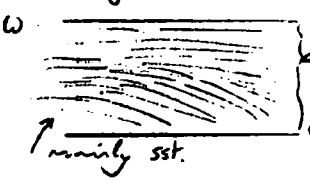
Cut trading 035°. - long wall.
1 photo taken

SECTION 153 - DEBORAH - Dii 10 S(B)



* DIRECTIONAL DATA :- Trough x Sets -
1. 0.5m / 8 / 250 2. 0.5 / ? / 218.
$n = 2$. $\theta = 234°$

NB Draping at north end of cut - E-W wall.



Observations from other areas :-

① Area Dii NE corner - Back wall beneath pylon - ~30m (E) away from power lines Wall → 240° - Top Tilley post sst in interfingering contact with grey mst and fine white ll x ripple x lam sst + mst streak - mst to East, sst to west. Mst continues for 20m to east then slope disturbed by faulting. Disturbance around contact also, but must be sedimentary - lamination in fine member preserved intact. 2 photos.

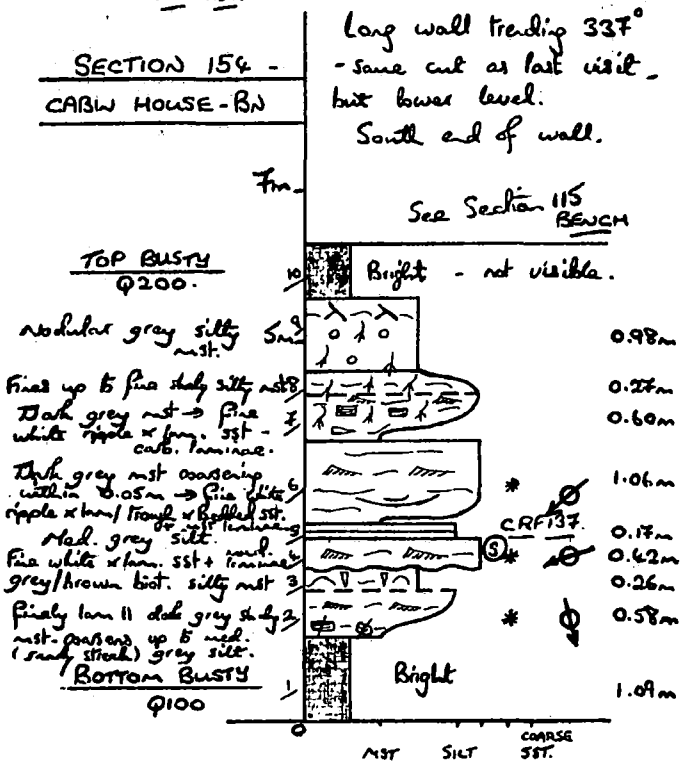
② In Dii 3(T) wall (observed from distance) in P200 - P300 parting - two thin ssts? at north end, only top one at south end - both below crumbly mst 3/3 up parting. Visible as outstanding horizons in section from a distance.

C.R. FIELDING. 23.6.80.

Cut TB2

SECTION 154 -
CABIN HOUSE - BN

Long wall trending 337° - same cut as last visit - but lower level. South end of wall.



* DIRECTIONAL DATA :-

Unit 2 - Ripple x lamination → 164° 150°
$\Theta = 157°$ $\hat{n} = 2$.

Unit 4 - Ripple x lamination → 267° 270°
$\Theta = 259°$ $\hat{n} = 2$.

Unit 6 - Trough? x Set 0.3m/16/241° $\hat{n} = 1$
- Ripple x lamination 258° 241° 197°
$\Theta = 232°$ $\hat{n} = 3$.

Some lateral variation along face to north - mainly in thickness of ssts - nothing systematic.
Sample - fine sst - Unit 4.

Top Busty → Bottom Tilley interval logged on 2.5.80 - Section 115.

Bench with intermittent exposure Top Busty - 5m wide - then rest of wall as for last visit.

Above platform - field excavated down to Bottom Tilley for 85m to east - as far as minor road - north as far as Cabin House - in 150m.

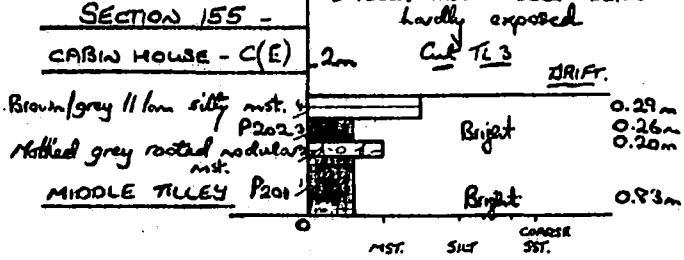
Presently digging down at north end.

Tillays in Area B(S) - same cut as per last visit - land to east as far as road stripped of soil but not yet worked. - south past belt of trees into Area C.

Into area C - east end - box cut to P200 - rocks above and below hardly exposed.

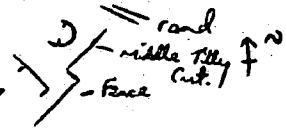
SECTION 155 -
CABIN HOUSE - C(E)

Cut TL3



Possible fault occurrence between this and main Tillay cut to north.

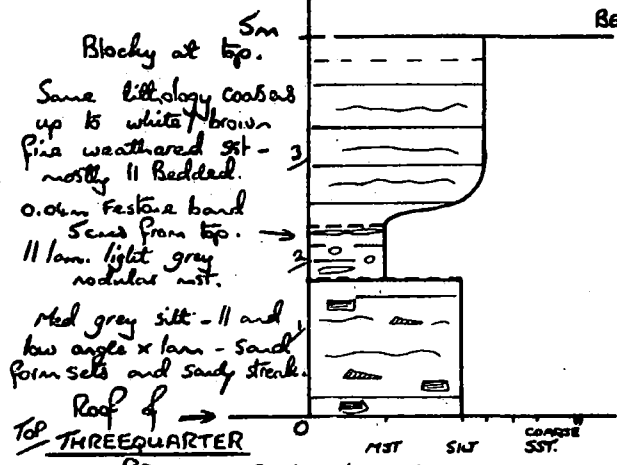
Face working south end of site trends → 037° - then does two 90° turns and continues in same direction toward minor road.



Small abandoned cut to Top Busty.
Face trends 310°.

SECTION 156 -
CABIN HOUSE - C(W)
Cut TP2

Long Threequarter cut - south end of cut. Cut trends 316°. From bench ~0.7m strata before inferred base of Bottom Busty - probably seatearth - coal not exposed.



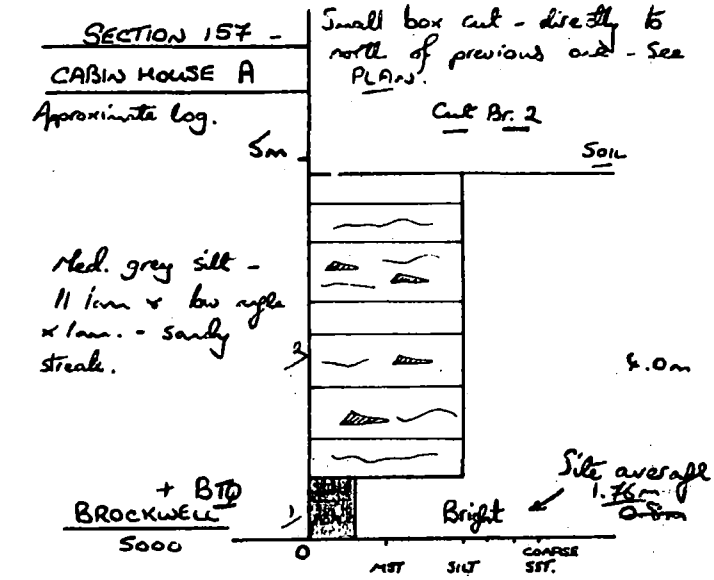
Coal not visible.
0.46m

Presently digging at north end of cut - just to south of belt of trees. Cut ~25m east of previous one.

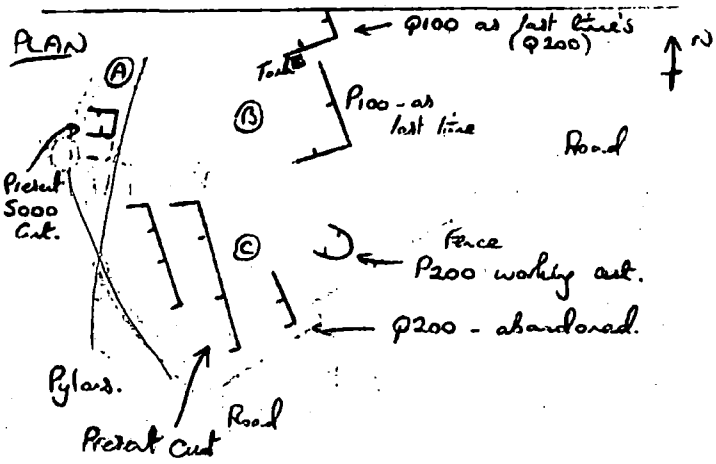
SECTION 157 -
CABIN HOUSE A

Small box cut - directly to north of previous one - See PLANS.

Cut Br. 2



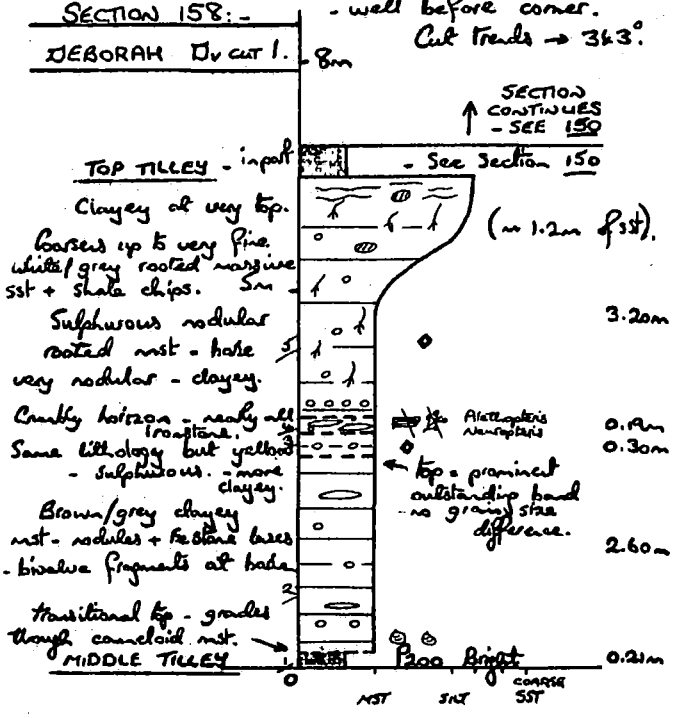
PLAN



C.R. FELDING 26.6.80

SECTION 158:- 30 m north of south end - well before corner. Cut trends → 343°.

DEBORAH Dv cut 1.



Faulting and shearing present at cut corner - close to outcrop.

1 colour photo taken - ASA 100.

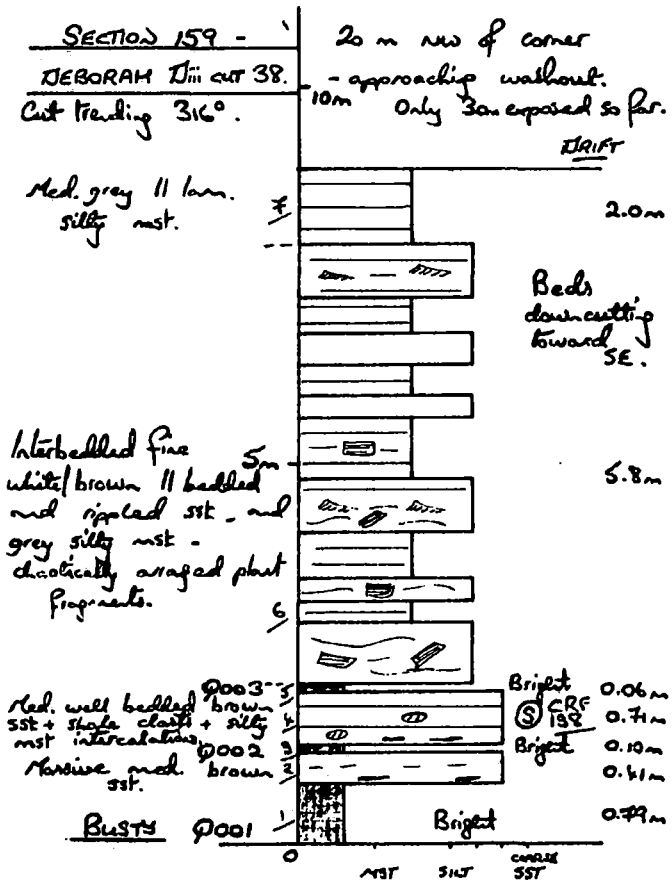
1 photo - panorama.

SECTION 159 - 20 m NW of corner - approaching washout.

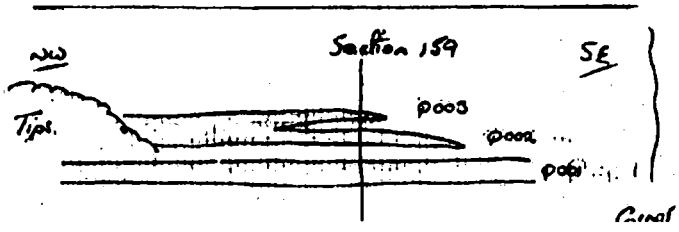
DEBORAH Dii cut 38.

Cut trending 316°.

10m Only 3m exposed so far.



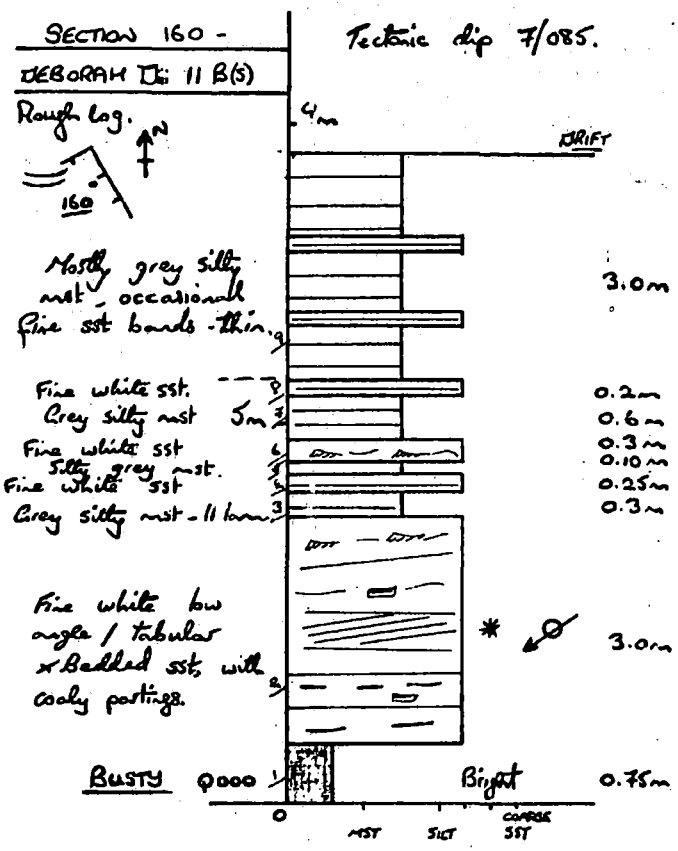
Sample - "washout" sst:-



SECTION 160 - Tectonic dip 7/085.

DEBORAH Dii 11 B(S)

Rough log.



* DIRECTIONAL DATA :- Unit 2 - low angle x Set - tabular form - n = 1. 0.5m / 10 / 235.

Sst layers mostly laterally continuous - less of them and thinner up section. Big continuous sst body now over Busty seam.

GENERAL PROGRESS - End June 1980.

Deborah - on cuts A16, Dii 11 B(S), Dii & B(N), Dii & T, Dv 1, Dii Top Tilly under pylons, Dii 38. Areas Bi, Bii, C complete, E abandoned.

Rowley - on cuts A8(S), A7/8 (N). Areas B & C complete, Harvey complete.

Tanners Hall - work recently started - working Cut 2 (S).

Buckhead - work recently started - not yet visited - Harvey exposed.

Edmondsley - work due to start July 1980.

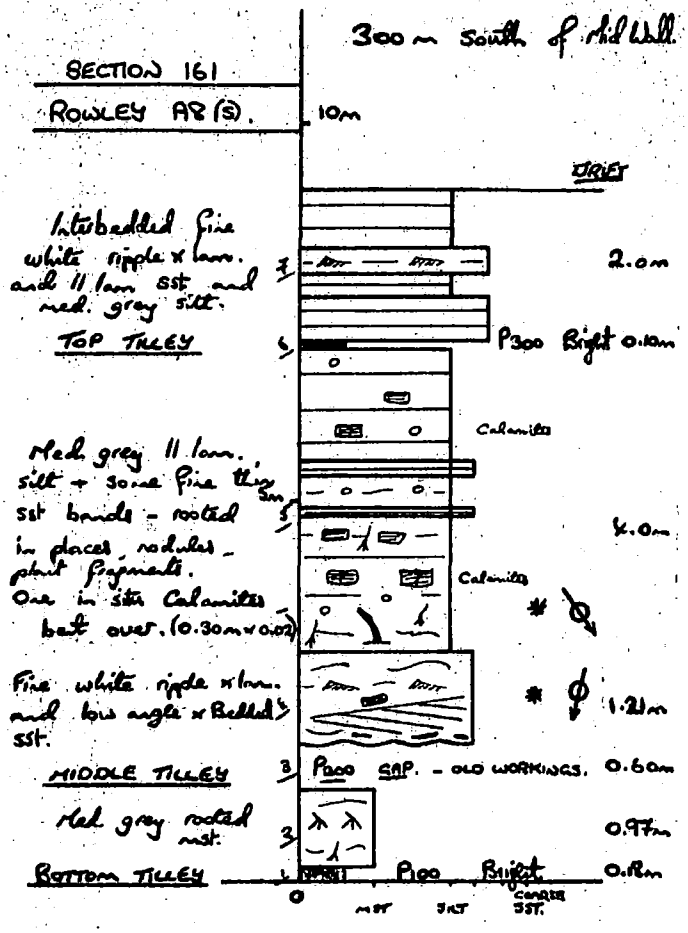
also Private Licence sites

- Cabin House - ½ way
- Mown Meadows - just started.

C.R. FIELDING - 26.6.80

SECTION 161 - ROWLEY A8(S).

300m South of Mid Wall.



* DIRECTIONAL DATA :- Unit 4 - CAMS
→ 1. 199° 2. 195° n = 2
Θ = 197°

Unit 5 - In situ Calamites butt over - (divisions 0.02 x 0.30m) → 169° n = 1

NB Starting at 270m south of Mid Wall - at 270m, major sst over P200 is at greatest level of dev. - ~3m thick and will thin sst units above interbedded with silt unit.

At 300m, P300 level starts to drop down the face. By 310m, sst has thinned down further, but more sst layers above - thickness variable. More butt Calamites

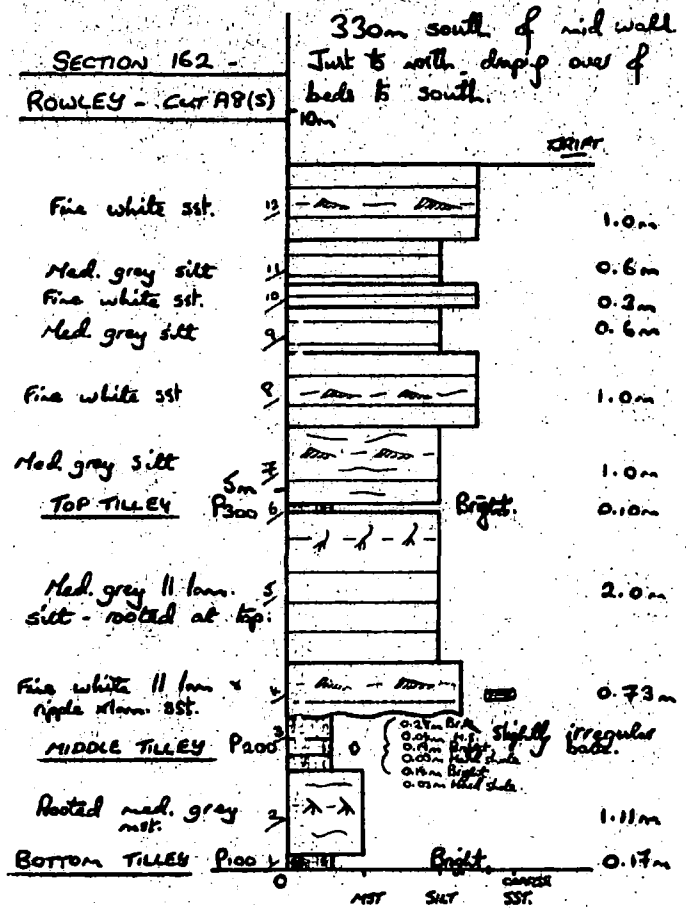
* DIRECTIONAL DATA - 310m - butt Calamites -
1. 162° 2. 150° 3. 205°
Θ = 172° / 92°
- all in silt horizon = Unit 5.

At 322m, beds thickening of sst Unit 4 to 2m.

At 330m, Top Tilley at lowest level in face.

SECTION 162 - ROWLEY - CUT A8(S)

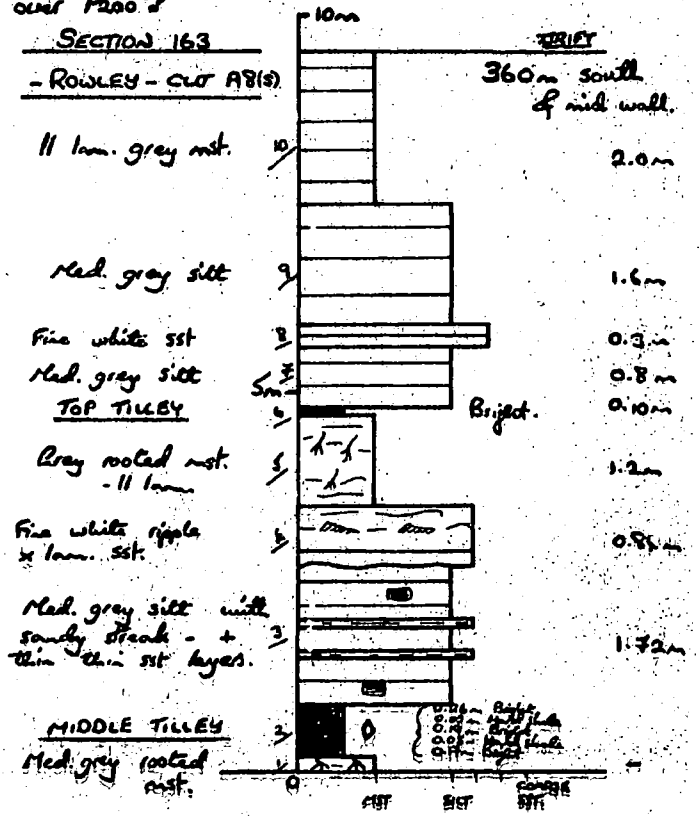
330m south of mid wall. Just to north, dipping over of beds to south.



P300 continues at about the same level for ~15m to south, then starts to rise gently up the face - at 345m. Top Tilley Bst at 345m comprises
DRIFT
2.0m silt
0.4m sst
0.6m silt

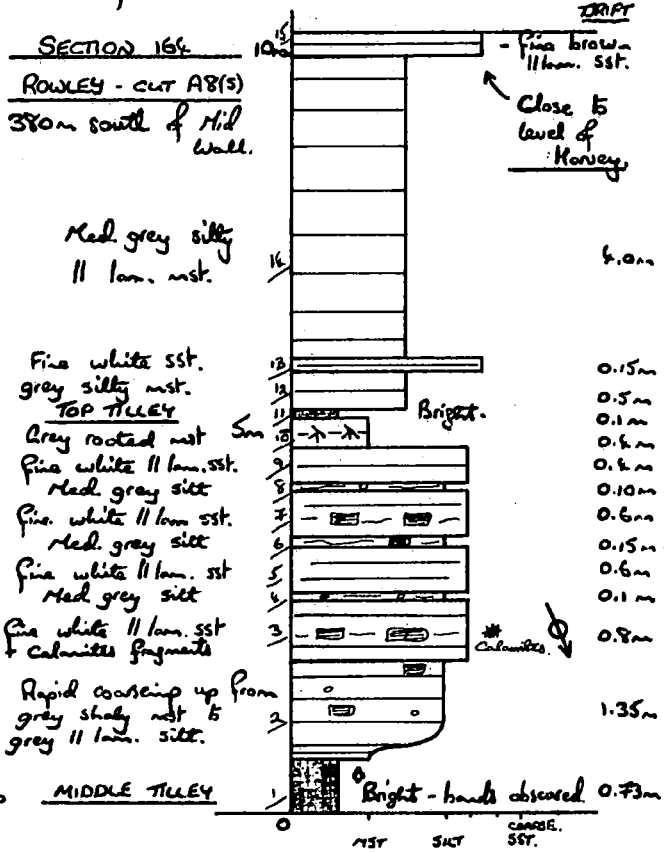
At 360m, thin sst over P200 is lifting - P300 still only rising very gently. Beds under rising sst are draping down toward south - lateral accretion over P200?

SECTION 163 - ROWLEY - CUT A8(S)



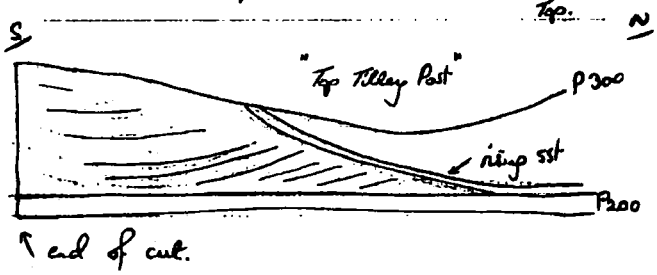
C.R. FIELDING - 26.6.80.

At 369m south of mid wall, upright Calamites - section - 0.03m across - 0.05m ? - in situ - in silt unit below rising sst. At 380m upising sst reaches level of P300, and is planed off. Section below is draping concavely off to south - lot of sst in section.



* DIRECTIONAL DATA :- Large horizontal Calamites stem → 151° n = 1.

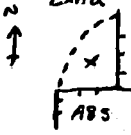
End of cut ~ 400m - beds over P200 in saucer-like shape -



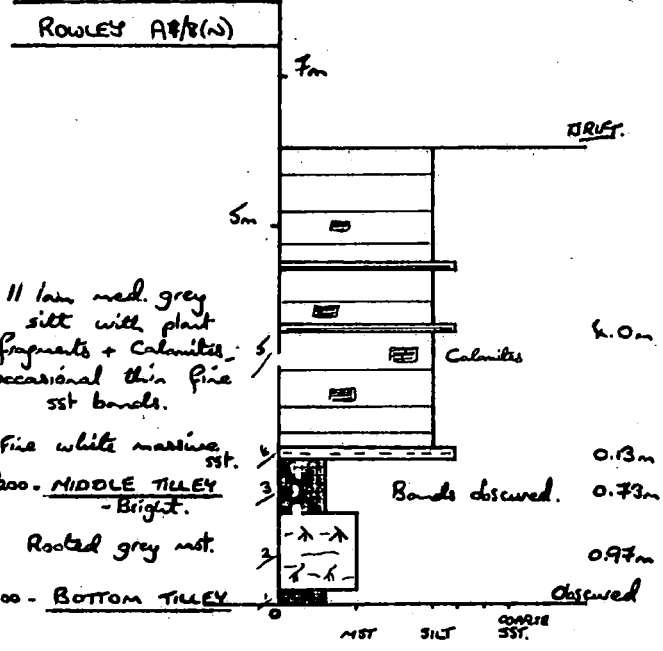
↑ end of cut.

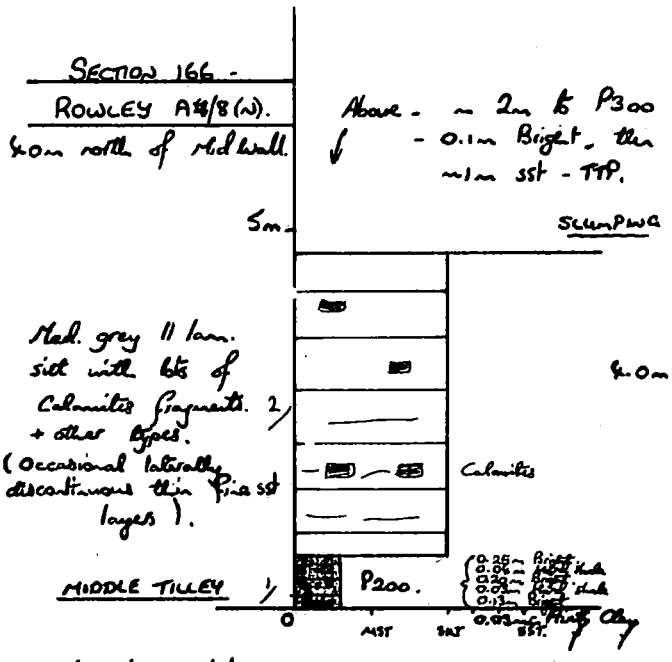
2 colour photos taken + 1 of in situ Calamites.

Extra triangular cut at south end of A(N).



5m north of Mid Wall. Lots of slumping.





1 colour photo.

Entire face to north is badly obscured by slumping. P200 appears to thin slightly to north.

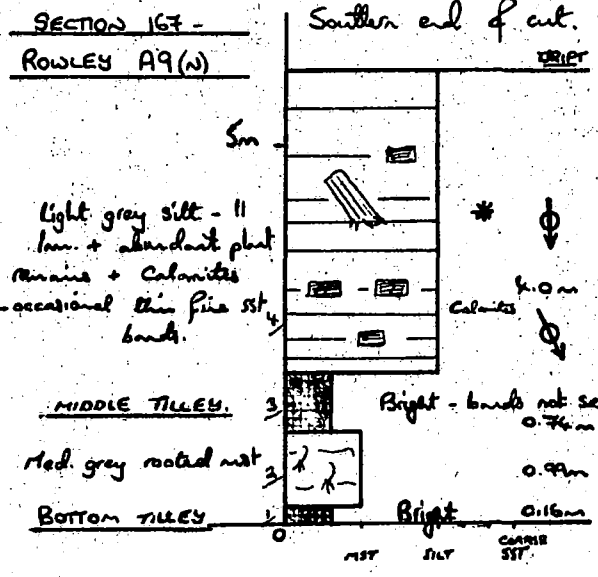
Similar facies for next 100m - dropline presently working ~150m north of Mid Wall.

First section of A7(N) missed.

C.R. FIELDING - 31.7.80.

SECTION 167 - ROWLEY A9(N)

Southern end of cut.



* DIRECTIONAL DATA :- Section of tree - 0.6m thick and 1.5m long - bent over toward 174° - type indeterminable. 174° - n = 1.

Orientated Calamites stalks → 141°, 147° n = 2

θ = 144°

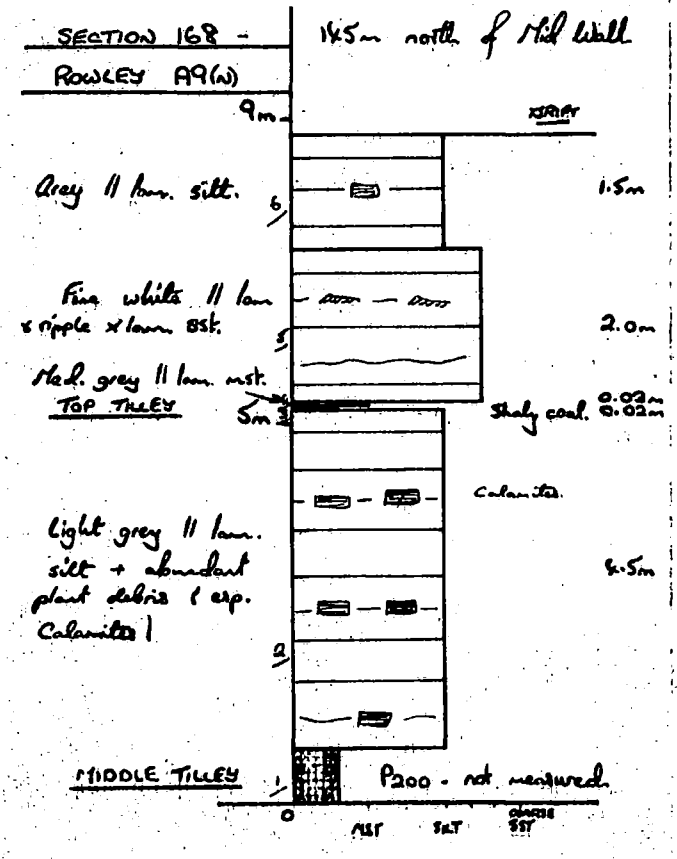
Progressing north, section similar in aspect - obscured in places by slumping. At 50m north, measurement of P200 :-

0.28m	Bright
0.03m	Mud shale
0.20m	Bright
0.03m	Mud shale
0.11m	Bright

At 90m, Top Tilley Post appears in upper part of face. - composed mostly of silt. At 145m, TTP comprises 2m fine white well laminated sst abruptly overlain by light grey silty mst.

SECTION 168 - ROWLEY A9(N)

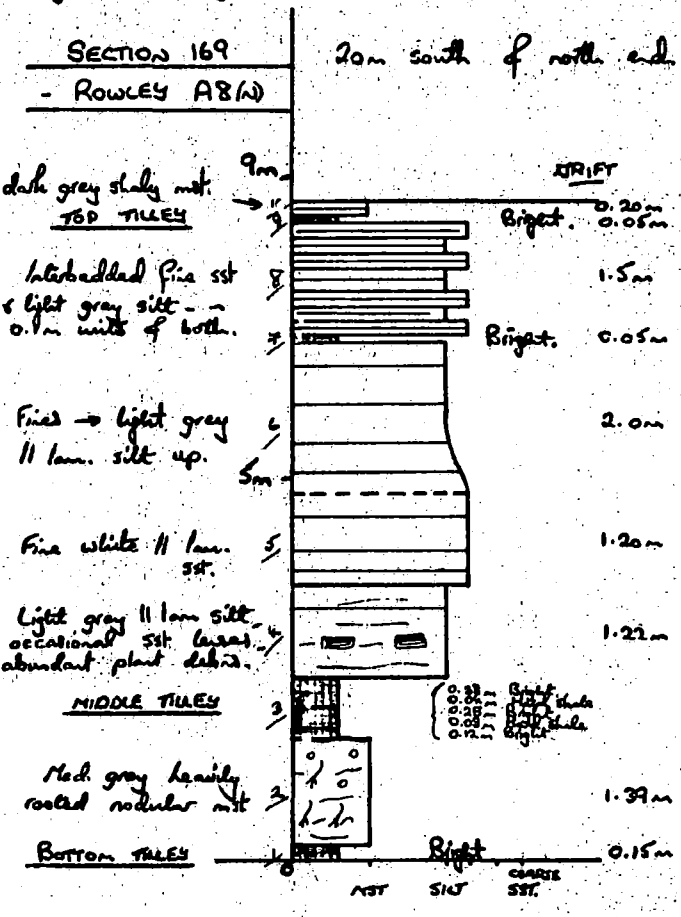
145m north of Mid Wall



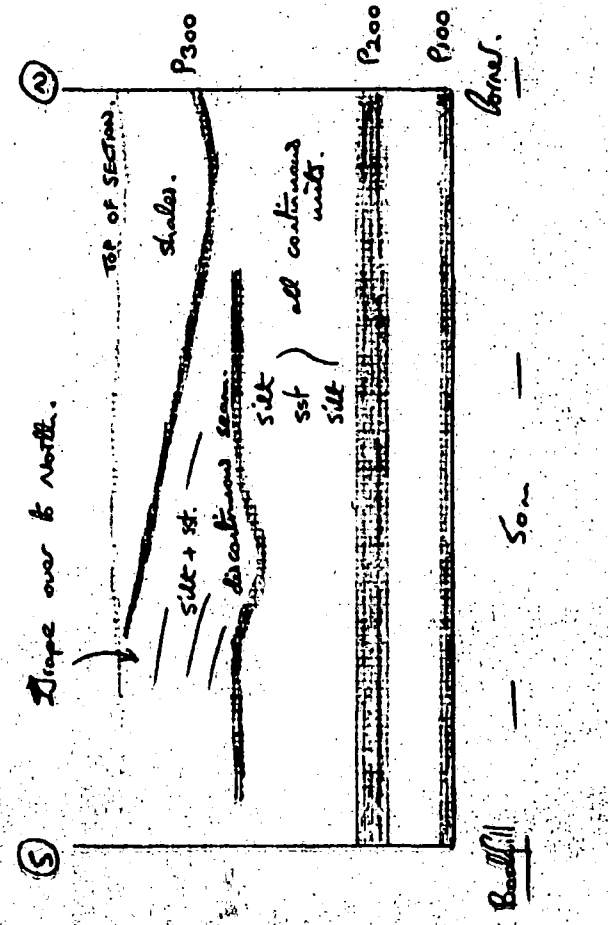
At 182m north of Mid Wall - large pile of debris. - 6 north - thin pilot cut for 50m - then dragline removing A8-9 interval.

SECTION 169 - ROWLEY A8(N)

20m south of north end.



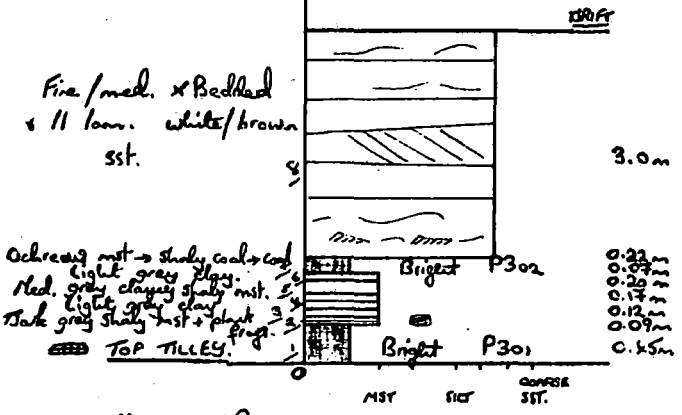
FIELD SKETCH (10) - NORTHERN END OF A8(N).



C.R. FIELDING 31.7.80.

SECTION 170 - DEBORAH DN 3.

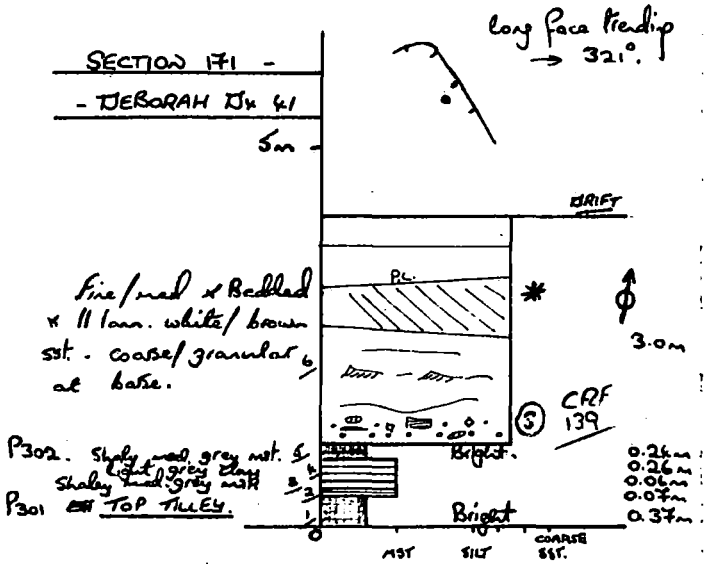
North end by corner - face trending 039°.



Presently backfilling Cut 2

SECTION 171 - DEBORAH DN 41

Long face trending → 321°.



NB Coarse base to T.T.P. contains coalified plant remains, shale clasts, areas of pyritised clay, granular horizons with 2mm detrital garnets.

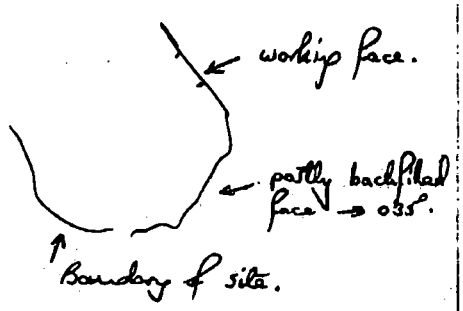
* DIRECTIONAL DATA :-

Planar asymptotic x Set - 10°/1.2m/ 010°. n=1
Parting lineation also present.

Drift cuts down to SE - lies over coal at S. end of cut.

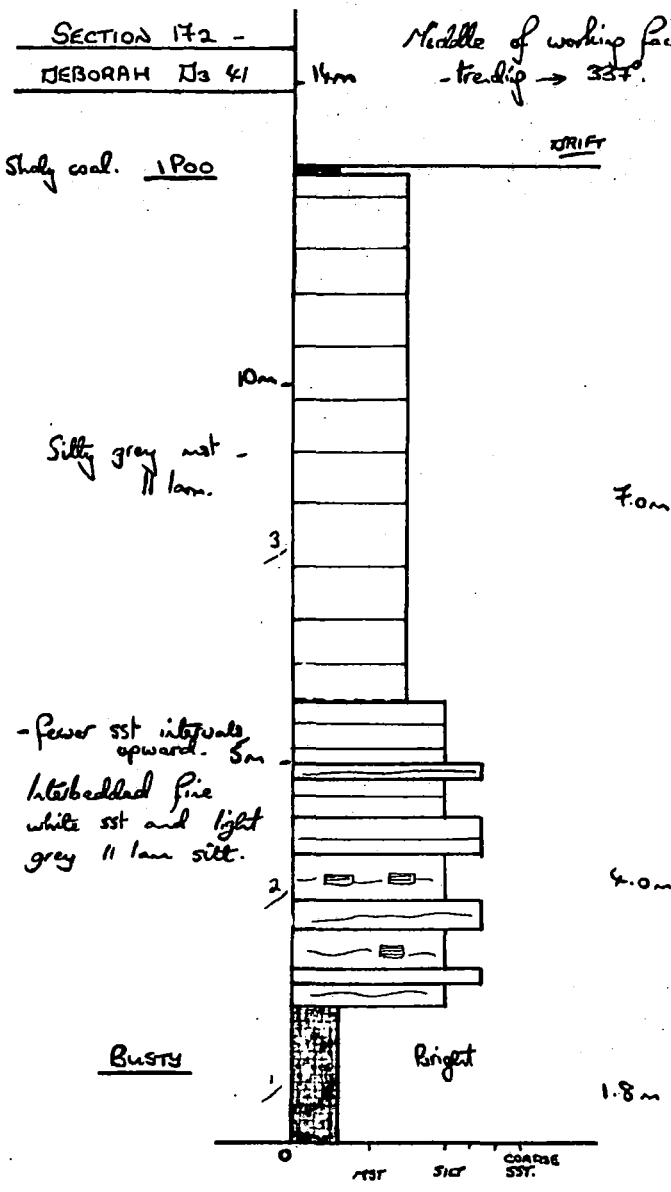
Cut 38? - long face exposing Top Tilley post trending → 311°. - cross bedding not very apparent.

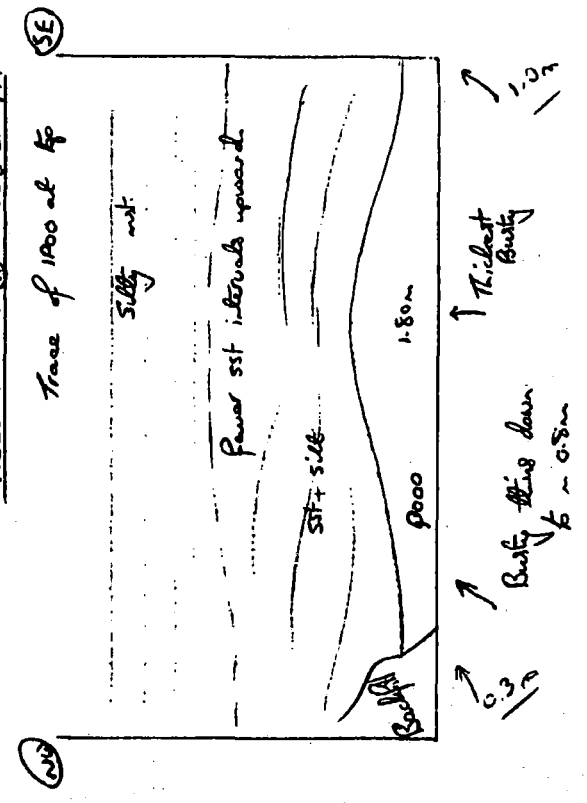
Area DN3 cut 41 - cut trends → 337°.



SECTION 172 - DEBORAH DN3 41

Middle of working face - trending → 337°.



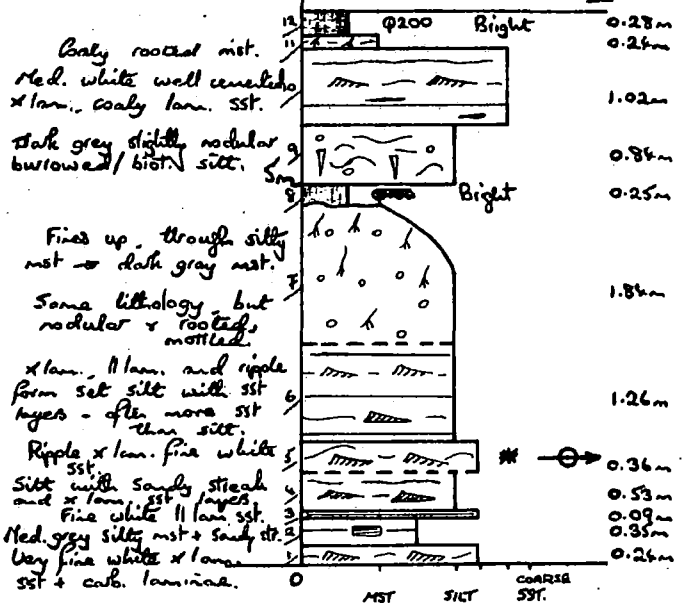


Cut DN3 14 B (3) - as previous cuts - 0.8m Busty overlain by ~ 8m silts and fine interbedded ssts - [illegible]

C.R. FIELDING - 1.8.80.

SECTION 173:- CABIN HOUSE - B(N)

Hole at north end of long Top Busty cut - just to south of cabin house. Cut TB5



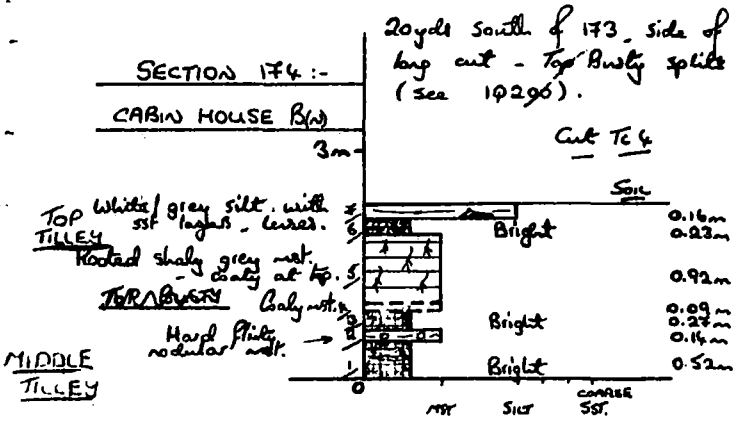
* DIRECTIONAL DATA :- Ripple x lamination → 116°, 068° $\hat{\theta} = 09^{\circ}$ $\hat{=} 2$

NB Units are laterally continuous within range of exposure. Bottom of cut not seen - filled in - ~ 3m to Bottom Busty Top.

SECTION 174 :- CABIN HOUSE B(N)

20yds south of 173, side of long cut - Top Busty split (see 1P296).

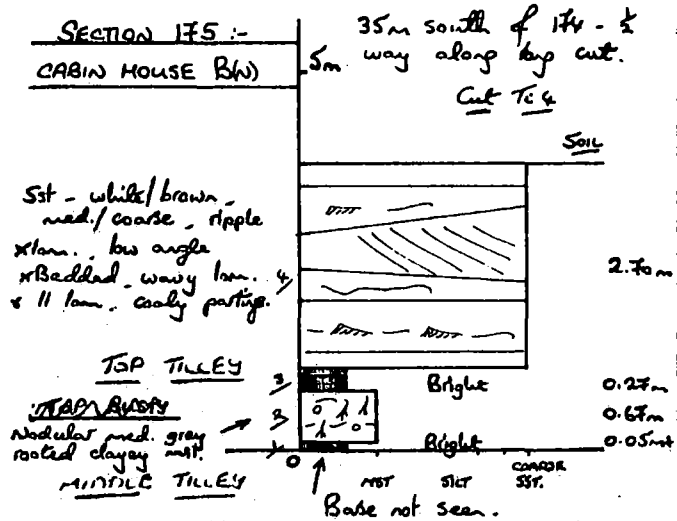
Cut TC4



SECTION 175 :- CABIN HOUSE B(N)

35m south of 174 - ½ way along long cut.

Cut TC4



Base not seen.

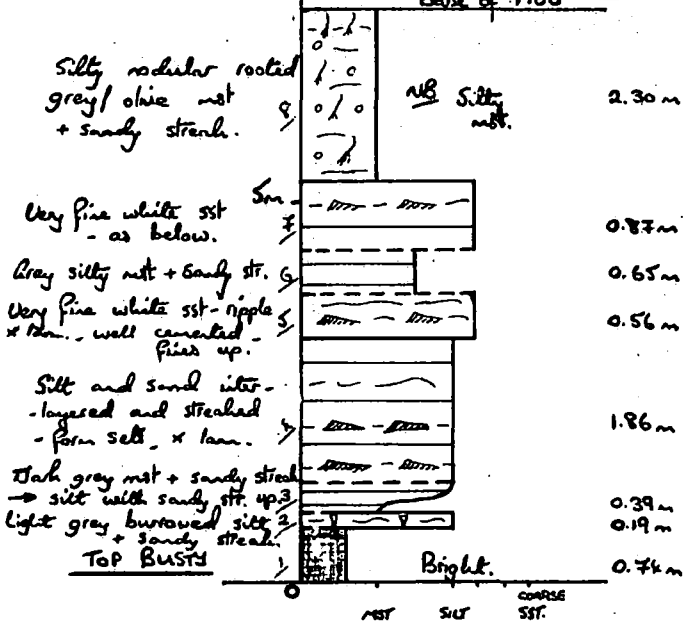
Large sst nodules in fissile silt & wavy between

SECTION 176 - CABIN HOUSE B(S)

South end of long cut to Top Busty.

Cut TB4 8m

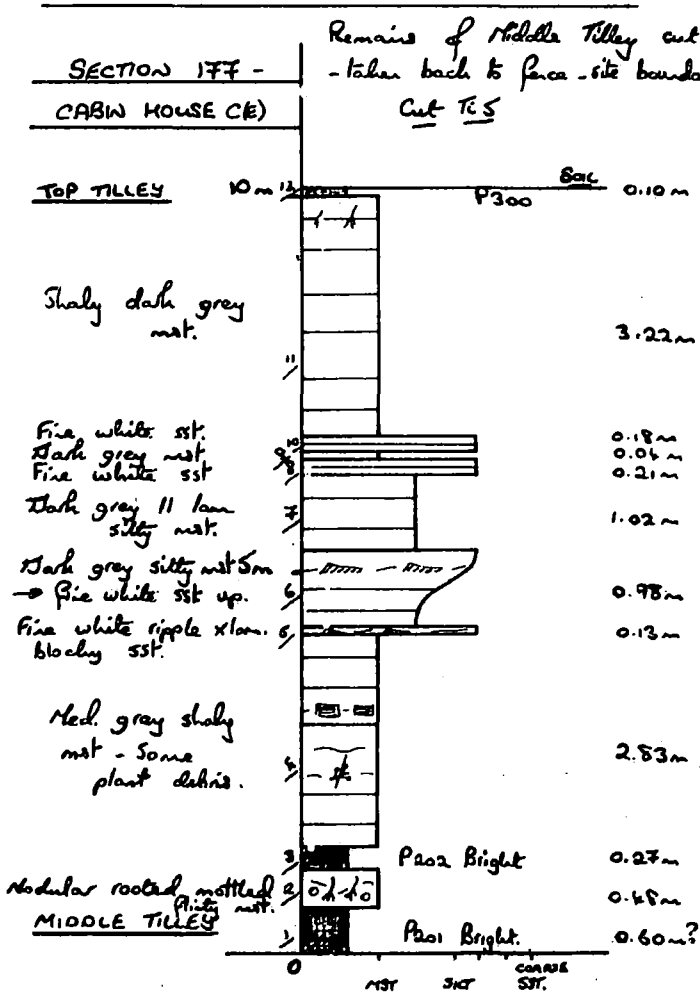
Base of P100 BENCH



SECTION 177 - CABIN HOUSE C(E)

Remains of Middle Tilley cut - taken back to Fence-site boundary.

Cut TC5

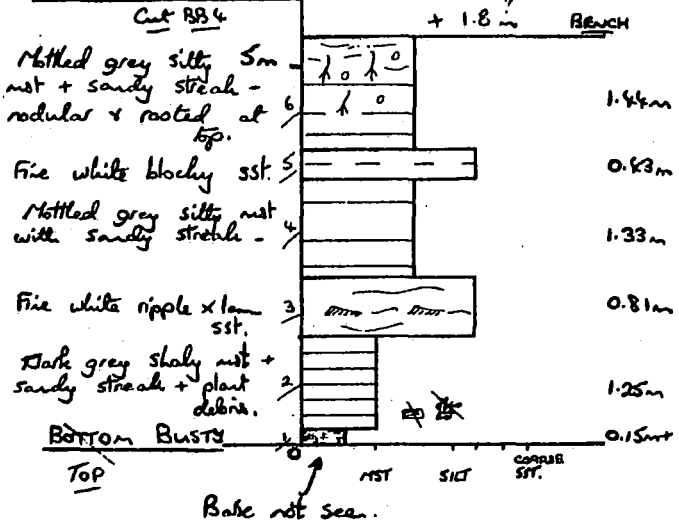


C.R. FIELDING - 1.8.80.

SECTION 178 - CABIN HOUSE C(W)

Cut BB4

Long cut to Bottom Busty - south end little lateral variation.



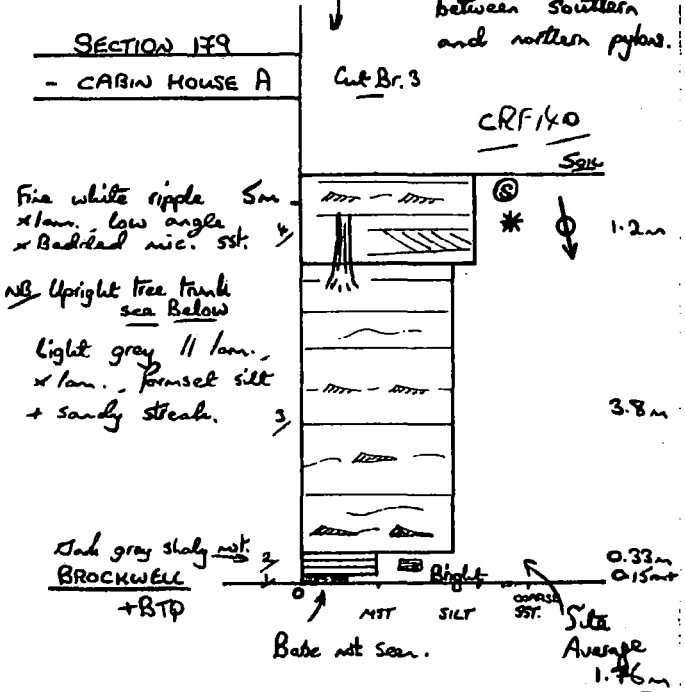
Area C (W) - long Threequarter cut from previous visit is cooled out and partly backfilled - To east just before small abandoned Top Busty cut - long cut to Bottom Busty - See 178. Scrapers presently removing interval to Threequarter

Area A - Brockwell workings - one cut further north than previous visit - back face trends → 340°. ⅔ of distance between southern and northern pylons.

SECTION 179 - CABIN HOUSE A

Cut Br. 3

CRF140

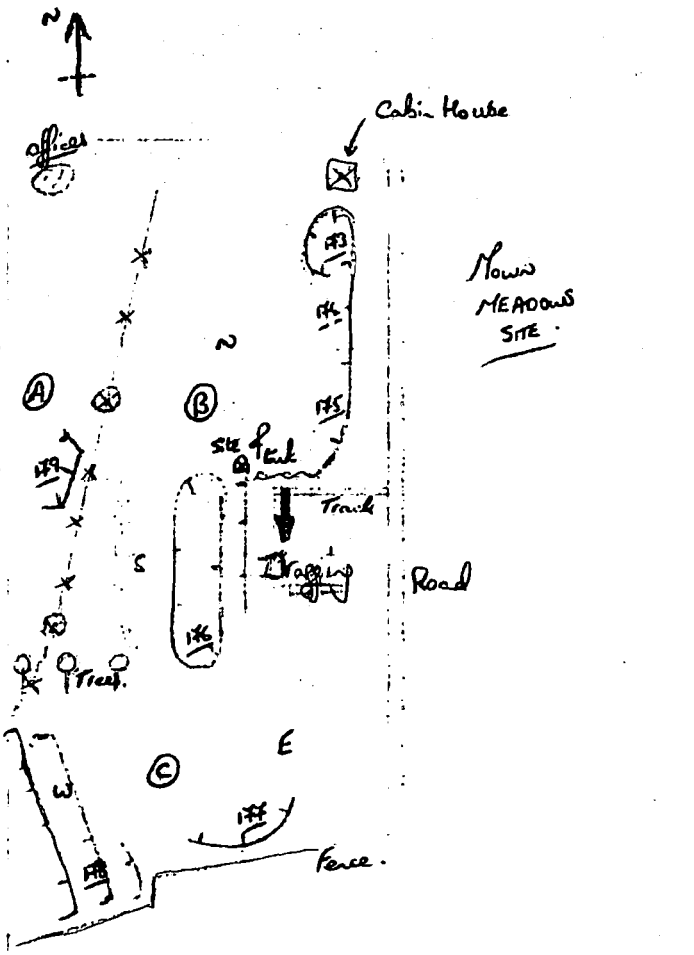


* DIRECTIONAL DATA :- low angle x Bedding - 0.2m/10°/156° n = 1

Sample - Unit 4 - Fine white sst.

Upright tree - in silt - roots visible - not bent over - in top 0.3m of silt unit, and first 1m of sst. - 0.25m thick - type indeterminable. Top evidently chopped off by sst flooding.

PLAN OF CABIN HOUSE - showing workings at 1.8.80.



Developments since last visit:-

1. long cut to Top Busty in area B (N), with hole at north end down to Bottom Busty.
2. Area under former Tilley (P100) cut dropped away down to Top Busty (176). B (S)
3. Dragline presently taking next cut to P100 and Busty east of 176. B (S)
4. Previous small cut to Middle Tilley in B(S) expanded, and worked out back to boundary fence.
5. Long Threequarter cut from previous visit in area C(W) - worked out and partly backfilled. Presently scraping for next cut.
6. new long cut to Bottom Busty in area C(W) - cooled out.
7. New cut to Brockwell in area A - further north from that exposed in previous visit.

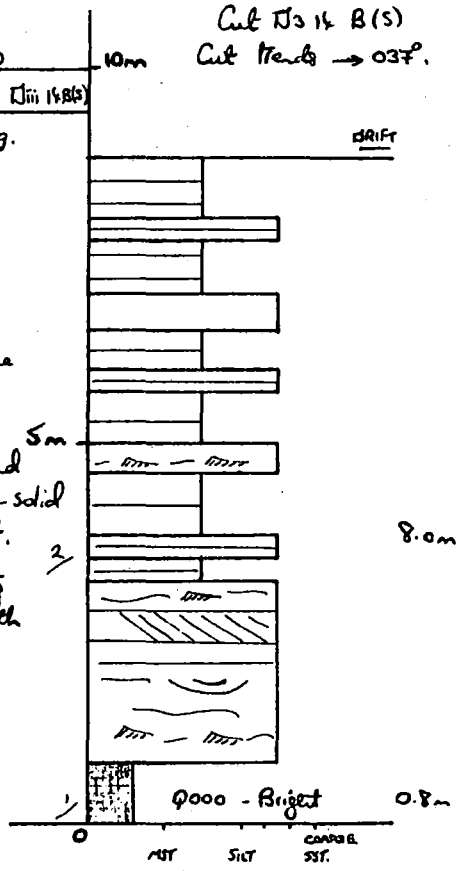
C.R. FIELDING - 31.7.80.

Cut N3 14 B(S)

Cut trends → 037°.

SECTION 180 - DEBORAH N111 1481(S)

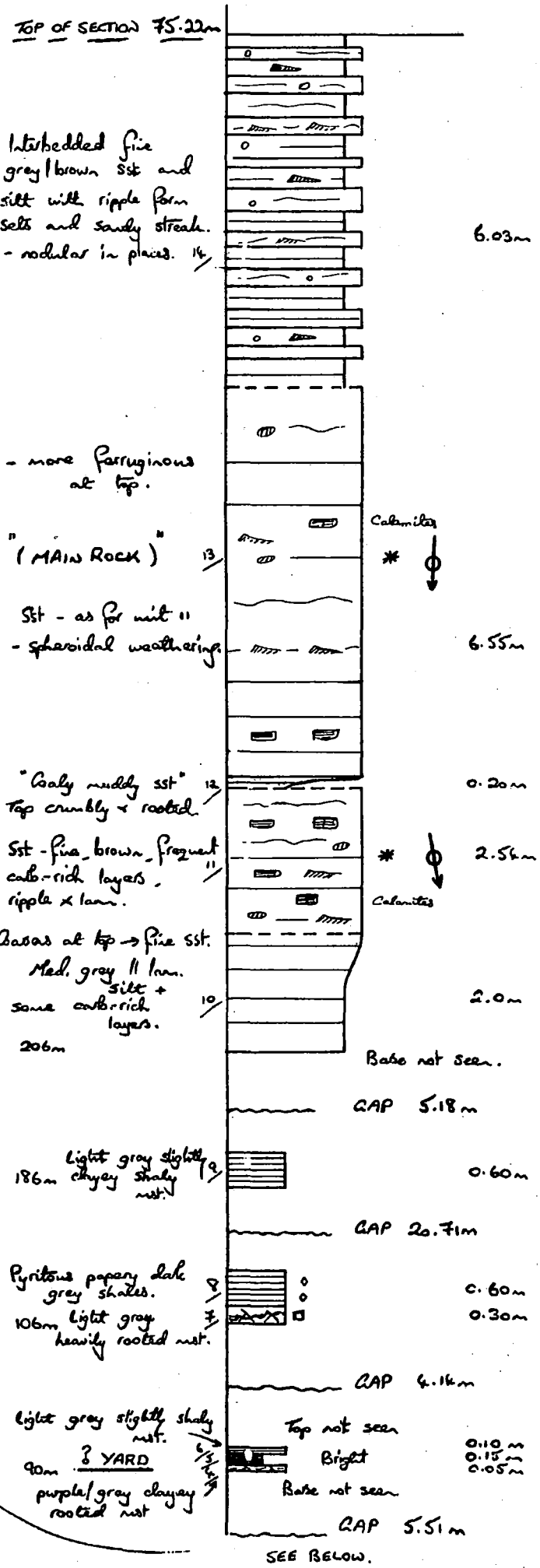
Approximate log.



C.R. FIELDING - 5.8.80.

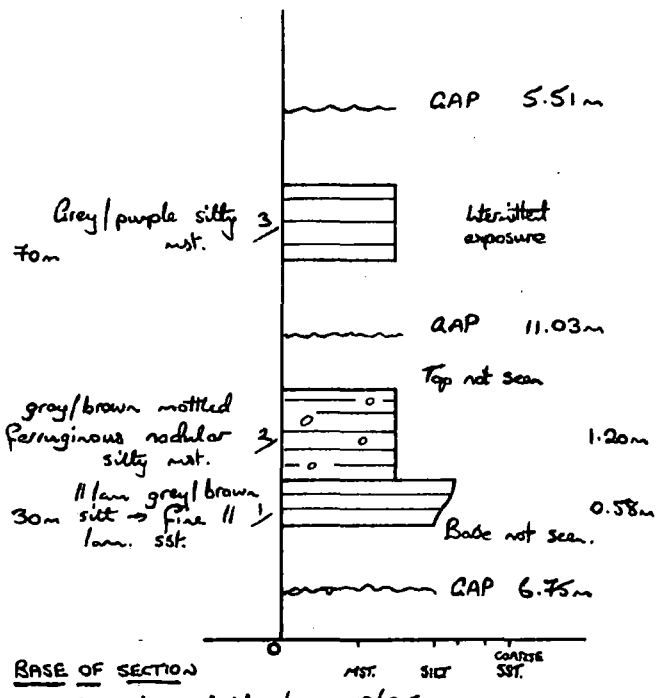
SECTION 181 - BENHOW BECK, WHITEHAVEN.

G.R. 978169.. NX



BENHOW BECK - Lower Part.

CONTINUED OVER



BASE OF SECTION

NB Dip - Units 1/2 = 13/251.
Dip - Units 4-6 = 16/253.
Dip - Units 10-14 = 15/199
Progression up stream from Reservoir - Units 1 → 14.

* DIRECTIONAL DATA :-

Unit 13 - R x L → 193_181° ~ = 2
θ = 187°

Unit 11 - R x L → 165° ~ = 1

C.R. FIELDING - 5.8.80.

C.R. 977 152.

SECTION 182.

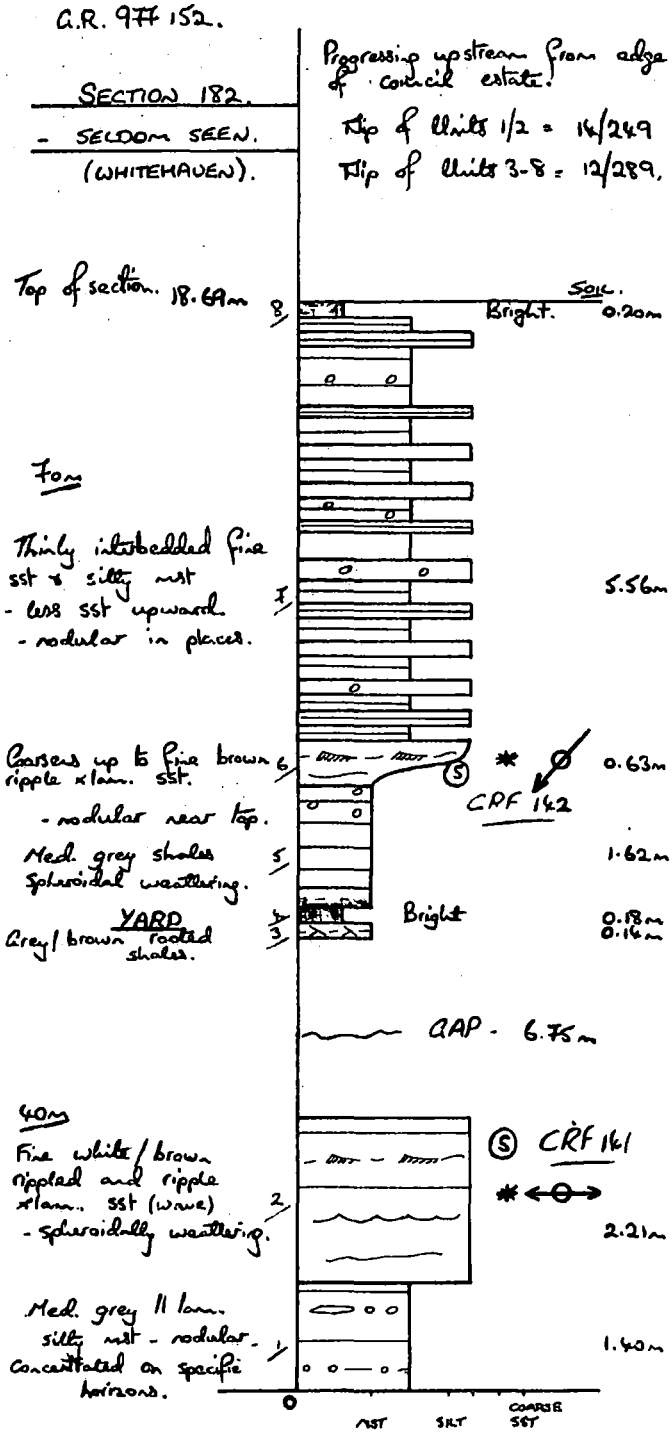
- SELDOM SEEN.

(WHITEHAVEN).

Progressing upstream from edge of council estate.

Dip of Units 1/2 = 14/249

Dip of Units 3-8 = 12/289.



* DIRECTIONAL DATA :-

Unit 6 - ripple x lamination → 221°.
n = 1.

Unit 2 - ripple crests - fairly straight - sharp topped - 0.01m ↑ - average 0.04m ↔ - symmetrical

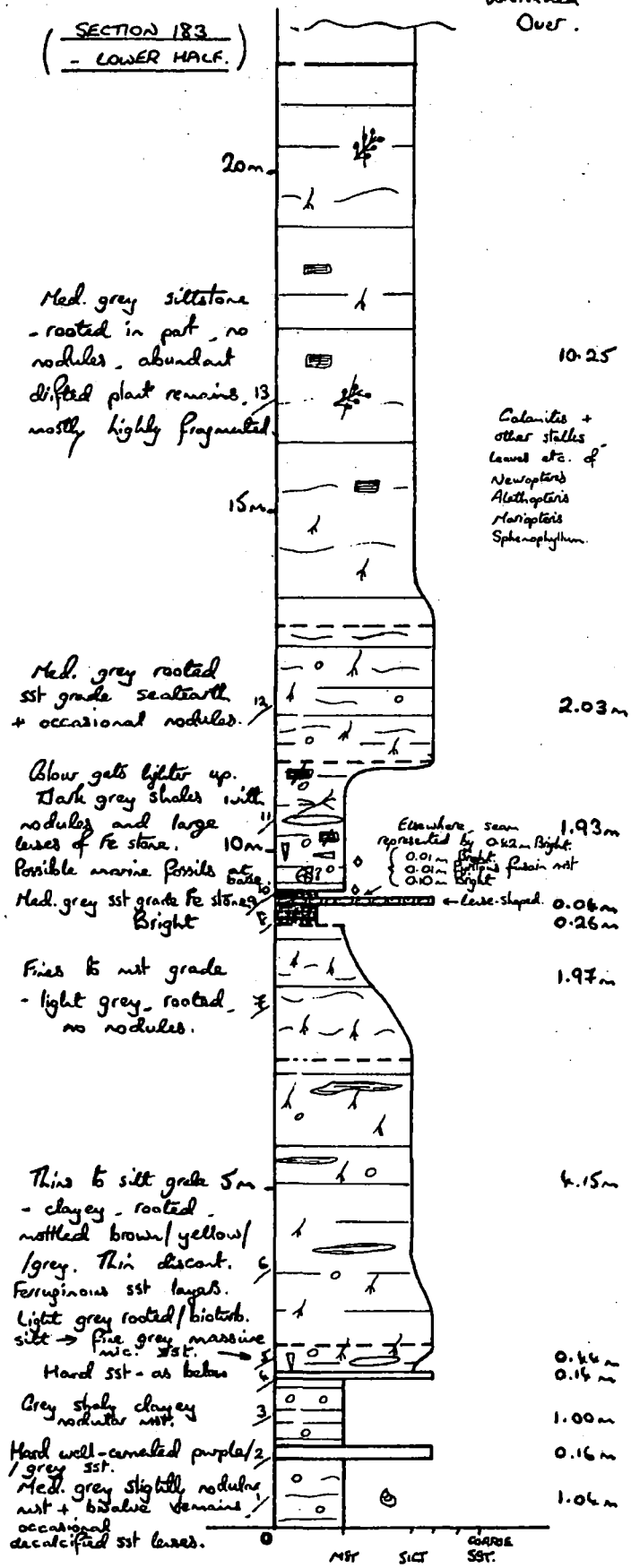
- strikes → 321°
  271°
  248
  240

flow → θ = 089/268°.
(86%)

C.R. FIELDING - 6.8.80.

Continued Over.

(SECTION 183 - LOWER HALF.)



Dip 19/262

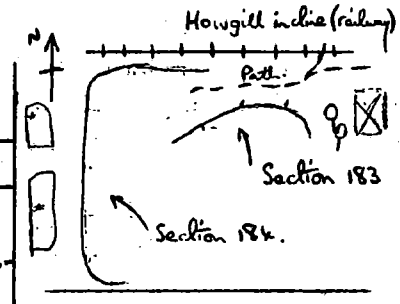
Notes Selected clay pits for Whitehaven Brickworks

Rocks in quarry wall appear laterally persistent and only slightly variable in thickness along face.

See photos.

Slumping at top of section obscures highest units - repeating of units - see notebook.

C.R. FIELDING - 6.8.80.



C.R. 972166

SECTION 183
- HOWGILL CLAY PIT.
(WHITEHAVEN)

(Top Half.)

45m

Slumping

Dark grey shaly mst + bivalve shells + burrows.	29	1.01m
Bright.	28	0.26m
Med. grey heavily rooted mst.	27	1.24m
40m		
Cap in exposed section. - See Section 184. CAP		3.52m
Dark grey papery shales + fragmented plant debris.	26	0.30m
Bright	25	0.10m
Dark grey heavily rooted mst.	24	0.24m
Bright	23	0.36m
Light grey silt grade seatearth - heavily rooted, occasional sandy ironstone lenses. 35m	22	2.73m
Transition through coaly shale → dark grey rooted mst.	21	0.25m
Bright	20	BASE OF SECTION 184. 0.61m
Top 0.3m light cream colour. As below, but rooted & mottled.	19	1.86m
Dark grey shaly mst.	18	0.35m
Bright	17	0.30m
30m		
As below, but rooted, mottled brown - nodular in places.	16	3.40m
Med. grey 11 lam. silt - as before 25m	15	3.00m
Hard grey ironstone - laterally discont.	14	0.43m
See previous sheet.	13	10.25m in total

SECTION 184
- HOWGILL CLAY PIT
- BOTTOM HALF

Continued over.

20m

Fine white/grey rooted sst.	21	1.22m
Silty mst - large nodules present.	20	1.94m
very fine sst	19	0.48m
silty mst	18	0.11m
very fine sst	17	0.20m
silty mst	16	0.20m
Very fine grey sst	15	0.28m
light grey silty mst + Fe stone nodules & lenses.	14	0.41m
Coarsens up → very fine light grey 11 lam sst.	13	1.27m — Some soft sediment - loading.
Coarsens up → light grey silt with sandy streak.	12	3.55m
10m		
Light grey shaly mst + nodules, Fe stone lenses.	11	2.46m
		TOP OF SECTION 183.
Bright.	10	0.27m
Light grey/ mottled nodular rooted mst - occasional thin sst lenses.	9	3.28m
5m		
Med. grey shaly mst	8	0.49m
Bright	7	0.08m
Grey rooted shaly mst	6	0.16m
Bright	5	0.42m
Med. grey rooted nodular silty mst.	4	2.18m
Grey massive calc. sst.	3	0.06m — Laterally discontinuous
Med. grey shaly mst.	2	0.32m
Bright - base not seen. 0	1	0.55m+

MST SLST CGSE SST.

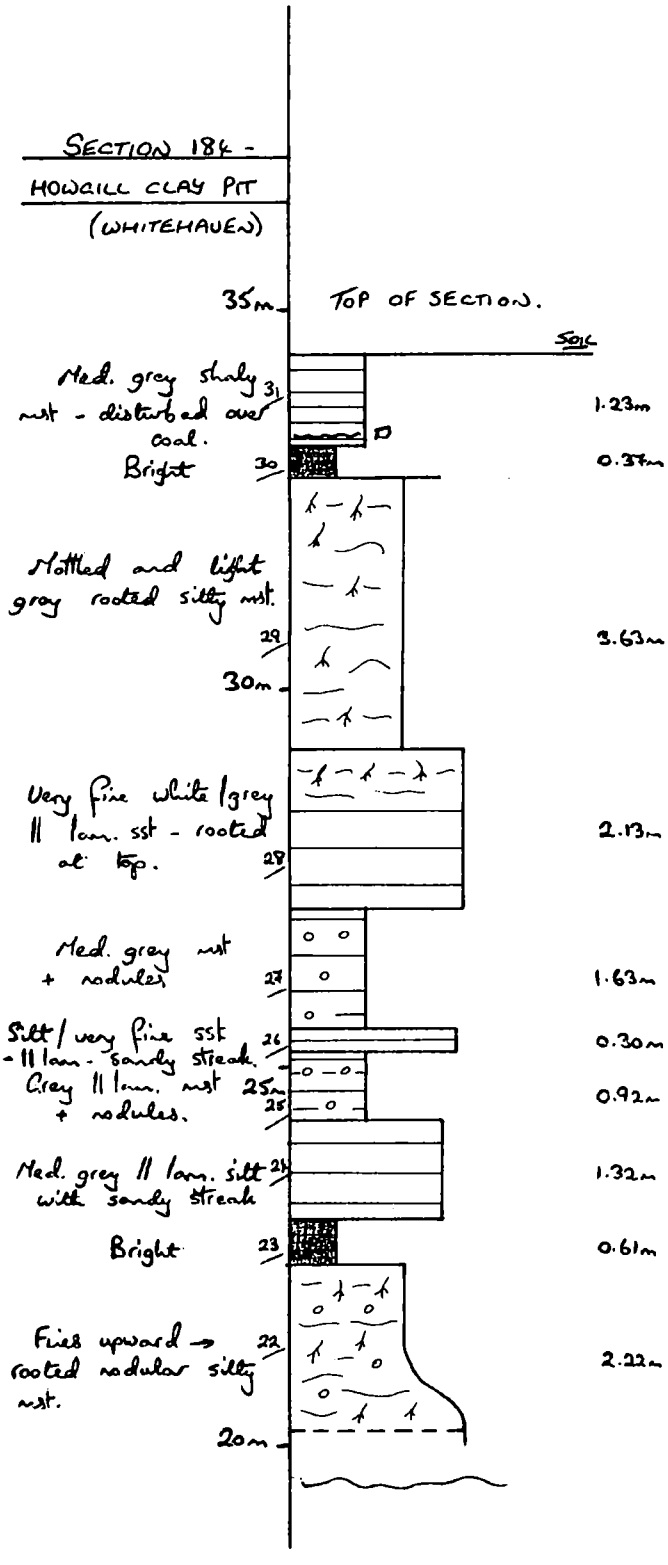
Dip = 20/239°.
Base of section 184 duplicates top of Section 183 - incl. slip gap in section.

Some slumping apparent.
CR 972166.

C.R. FIELDING. 6.8.80.

West Face of main quarry - composite section. Units laterally very persistent and uniform. Units 8/9 possibly replaced by sst at south end.

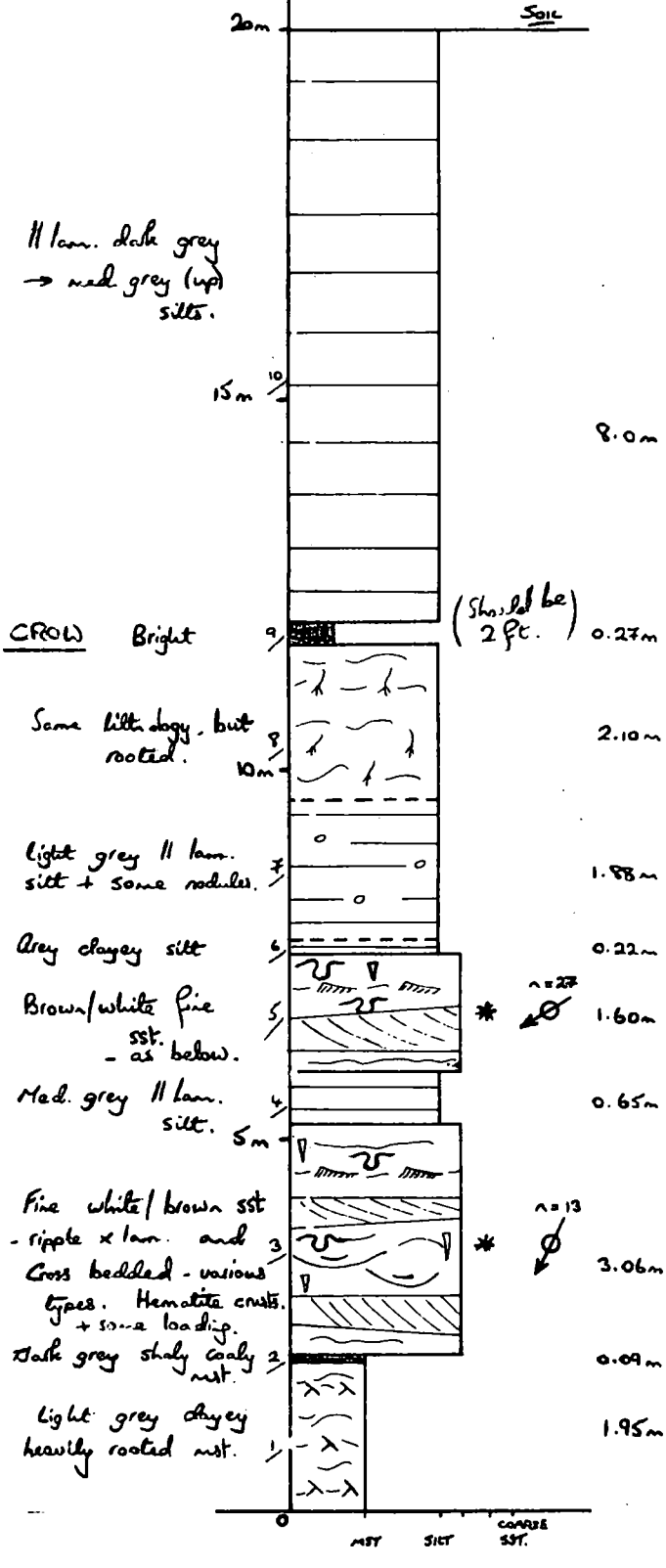
SECTION 184 - HOWAILL CLAY PIT (WHITEHAVEN)



C.R. FIELDING - 7.8.80.

Composite. - From first 500m of section south from Tom Hurd Rock

SECTION 185 - WHITEHAVEN BEACH (SOUTH)



Dip 13/244.

Little lateral variation in lithology or thickness.

C.R. FIELDING - 8.8.80.

SECTION 186 - WHITEHAVEN BEACH (SOUTH)

41.20m — SOIL

At 107 m south of Tom Hurd Rock - small gully.

Start of exposure 1 m above slope foot.

NB At least 2m more purple sst under base of exposure at top of gully.

Purple stained coarse grained cross-bedded sst - conglomeratic in places - full description - see Sheets.

S CRF 1kg

12.0m

n=116

"W.S.S."

GAP - ~~15 cm~~ 12.0m

- as for Unit 5. — 7 — 0.94m

Some lithology - but hard - flinty. — 6 — 0.45m

Light grey silty mst - rooted and heavily bioturbated - some Fe staining. — 5 — 2.69m

Olive brown / grey silty mst - occasional nodules, horizontal burrows.

Spheroidal weathering. — 6.74m

4

Med. grey shaly mst + nodules - plant fragments. — 3 — 1.16m

Bright — 2 — ? CROW — 0.61m

Light grey / cream mottled red mst - grade seatearth. — 1 — S CRF 1kg — 2.01m

Base not seen

0 — MST — SILT — COARSE SST.

SECTION 187 - WHITEHAVEN BEACH (SOUTH)

? 20.0m "W.S.S."

25m

Slightly purple/white med./coarse x Bedded sst — 11

Similar lithology - but heavily rooted - iron stained at top. — 10 — 2.32m

20m

Blue/dark grey shaly silty mst - slightly rooted and nodular in places. — 7.00m

9

? Coal 1ft 3 ins.

15m

Hard fine white/yellow sst - burrowed - heavily rooted at top. — 8 — 2.31m

Blue/grey mst grade seatearth. — 7 — 1.38m

10m

Light grey shaly silty mst + nodules.

6 — 5.80m

CROW Coal - "2 feet"

5m

Light grey silty mst - rooted. — 5 — 3.09m

As below, but rooted — 4 — 0.27m

Fine light grey ll lam. burrowed sst. (coarser up) — 3 — 0.78m

Dark grey shaly mst. — 2 — 0.72m

Fine/very fine light grey ll lam, burrowed and slightly rooted sst — 1 — 0.32m

0 — MST — SILT — COARSE SST.

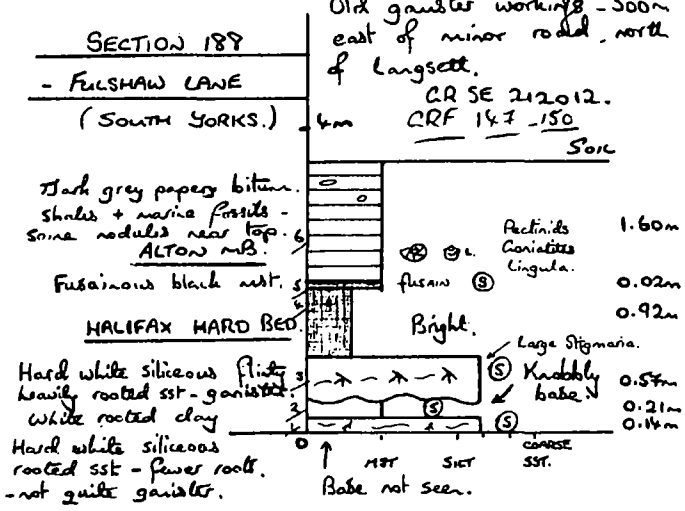
Base not seen.

... at 153.5m south of

C.R. FIELDING - 19.8.80.

SECTION 188
- FULSHAW LANE
(SOUTH YORKS.)

Old gaister workings - 300m east of minor road, north of Langsett.
GR SE 212012.
CRF 147 - 150



= Sheffield Blue Canister.

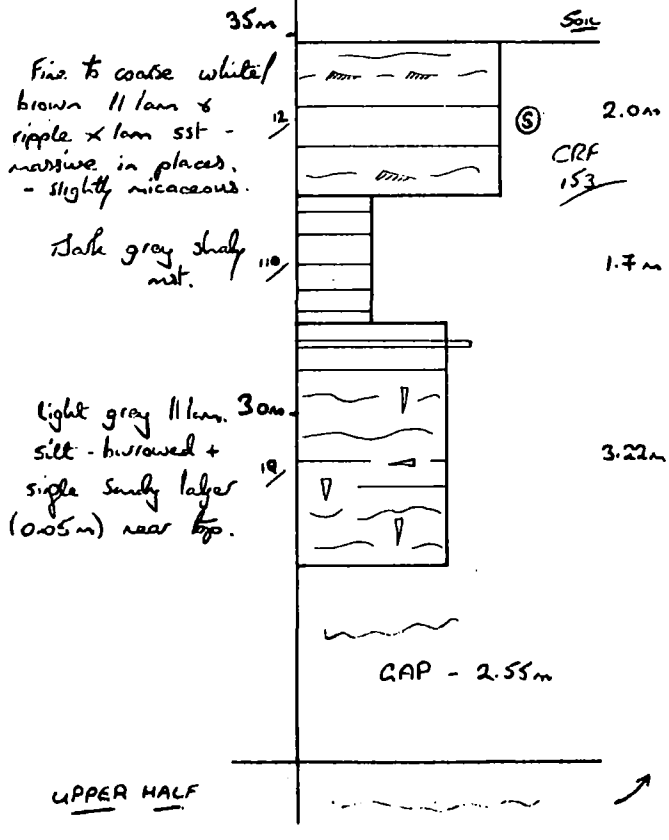
Main gaister unit varies laterally in thickness - very prominent uneven knobbly base.

Tectonic dip 9/080.

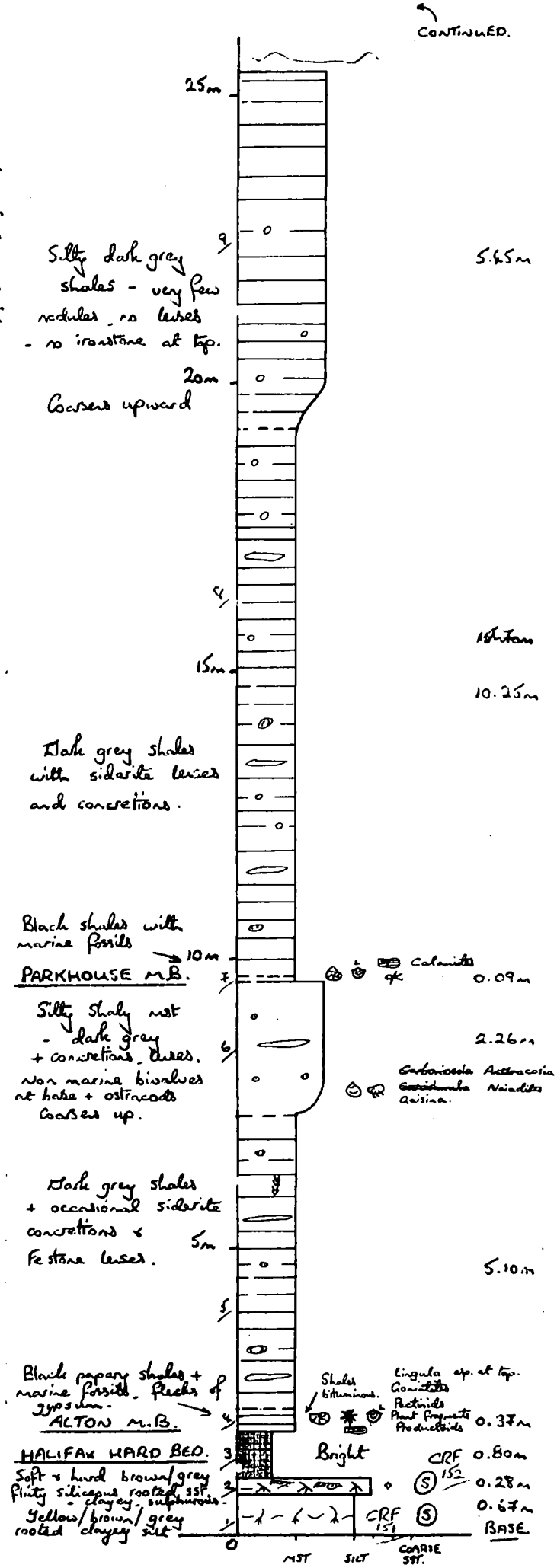
Section 189. - NB. At a small exposure, a thin (0.02m) pyritous fusain mst separates the Coal from the Alton marine shales. - not present in main face. Dispersed siderite present throughout the section. Fossils all flattened impressions on bedding planes. Concretions early-stage formation - displace strata and contain unfractured goniatites. Cone-in-cone calcite occasionally occurs.

SECTION 189 -
MIDDLECLIFFE QUARRY.
(SOUTH YORKS.)

Working quarry for Hepworth Iron Co. - G.R. SE 202041
Composite section.
Main face trends → 307°.



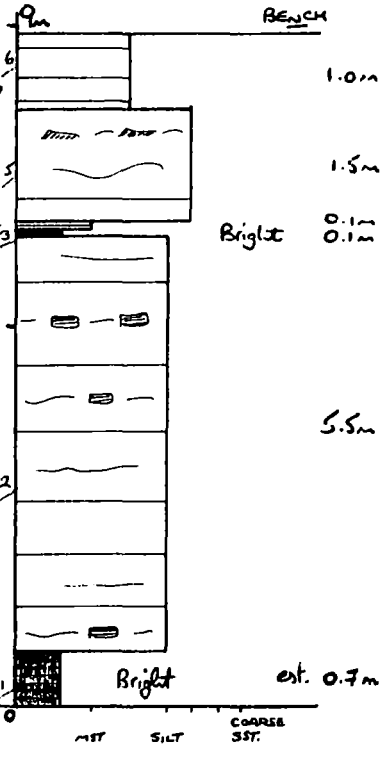
CONTINUED.



C.R. FIELDING - 21.8.80.

SECTION 190 - 180m north of Mid Wall.

ROWLEY A9(N)



Middle Tilley not visible due to slumping.

NB Top Tilley Post present all along out.

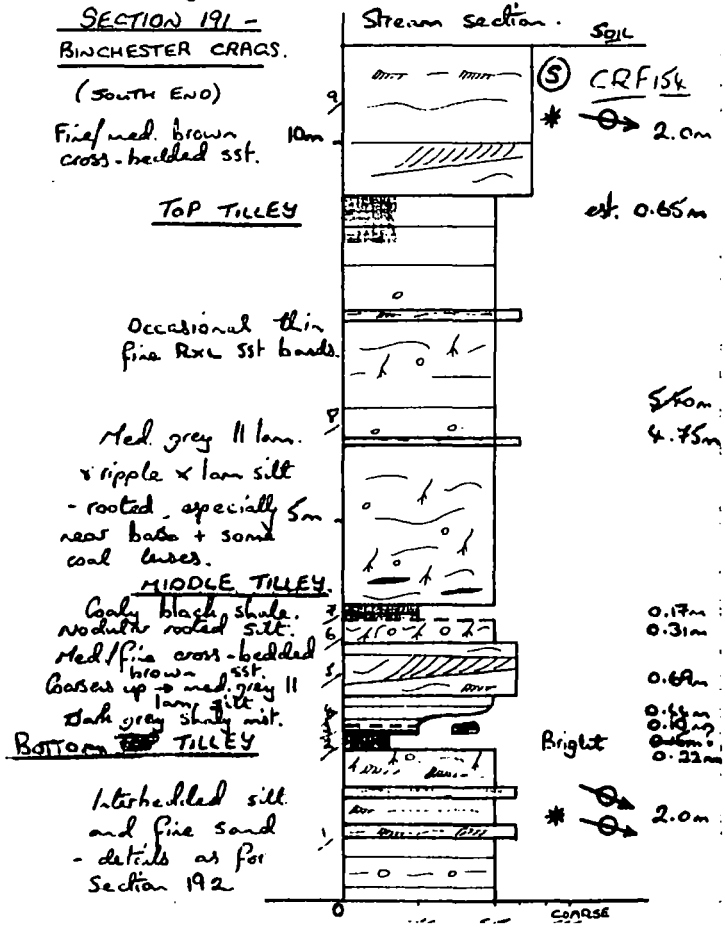
At 190m TTP sst down to 1m thick - then increases to 2m+ to north. Junction between sst and overlying silty mst is sharp - a little interfingering occurs in places - thin layers of mst at top of sst.

Above bench - more mst - becomes brown, mottled and ∂ rooted after 2m from top of sst - total 4m mst, then trace of coal - ? Harvey - just below soil level.

SECTION 191 -

BINCHESTER CRAGS.

(SOUTH END)

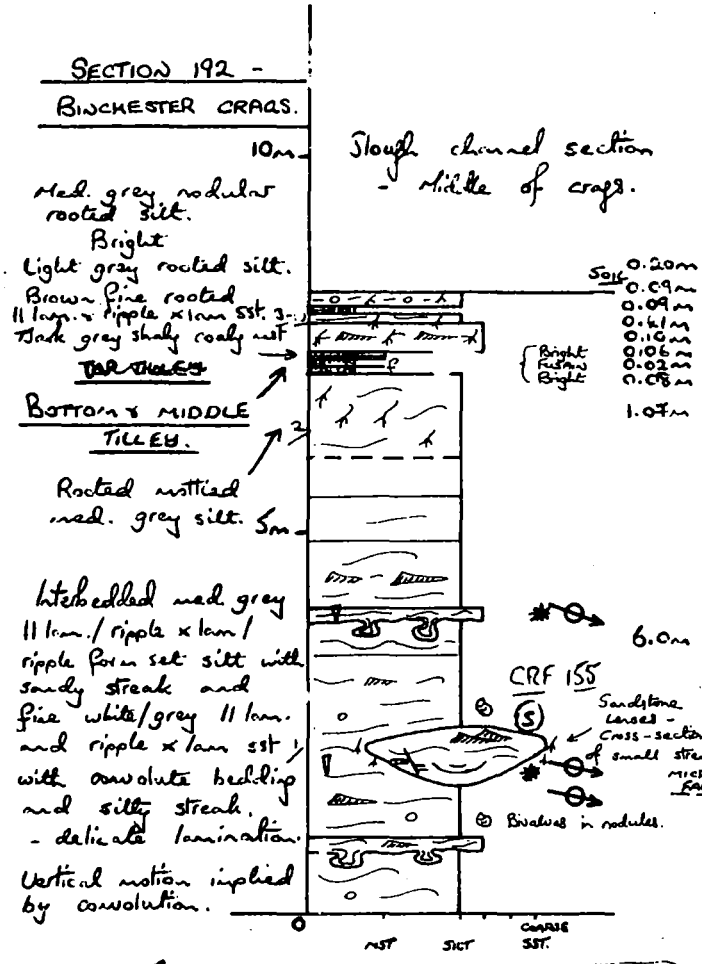


C.R. FIELDING 22.8.80.

SECTION 192 -

BINCHESTER CRAGS.

Slough channel section - Middle of crags.



* DIRECTIONAL DATA :-

OVERALL - Θ = 118°, ι = 94%, ∧ = 25

Unit 1 - Sandstone lenses - oblique cross-sections in small streams - ∧ = 5 Θ = 113.5°

elongate → 045°, 100°, 095°, 125°. ι = 96.0%

Unit 1 - Ripple x lam. in fine sst. & silt

→ 136°, 111°, 135°, 110°, 129°, 121°, 130°, 122°, 164°, 089° ∧ = 10. Θ = 124.6° ι = 88.6% Θ = 113.6° ι = 94.5%

Unit 1 - Ripple x lam. in sst lenses -

→ 140°, 157°, 089°, 117°, 107°, 109°, 099°, 110°, 105°, 125°, 095° ∧ = 11.

Also - AXL in silt at Loc → 037° - 31.1.81.

Overall - Θ = 109.0° ι = 60.1% ∧ = 32.

Unit 9 -

Tabular x Sets Θ = 127.5° ι = 77.0% ∧ = 6.

Planar asymptotic x sets Θ = 102.6° ι = 59.1% ∧ = 23

Low angle x Sets Θ = 227° ∧ = 1

Trough x Sets Θ = 088° ∧ = 1

Near symmetrical ripples Θ = 080 ∧ = 1

* DIRECTIONAL DATA :-

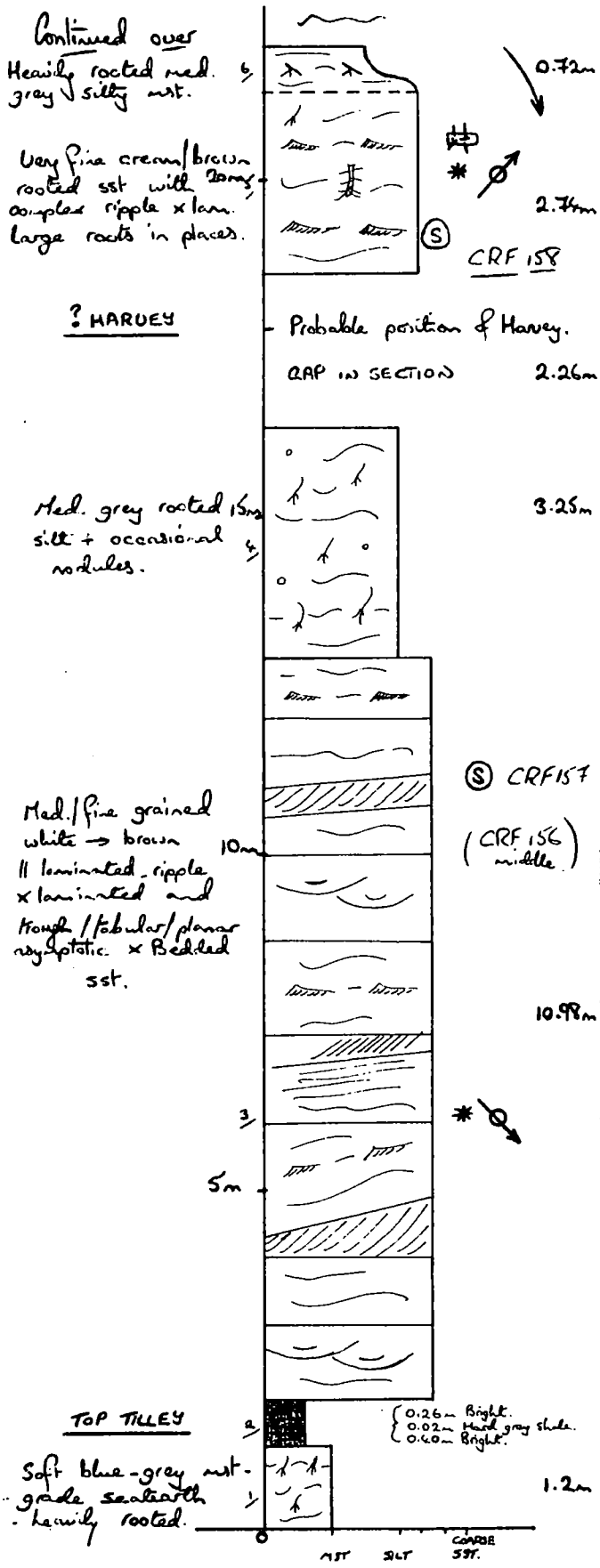
Unit 1 - rib & furrow x lamination → 123° ∧ = 1.

Unit 1 - rippled surface - 0.01m↑, 0.05m λ, sinuous crested, round topped, near symmetrical, striking → 193°. ∧ = 1. (⇒ flow 103°)

Tectonic dip 14°/123°.

Only top 0.05m of Bottom Tilley measured - base not exposed - thickness inferred

C.R. FIELDING - 25.8.80.

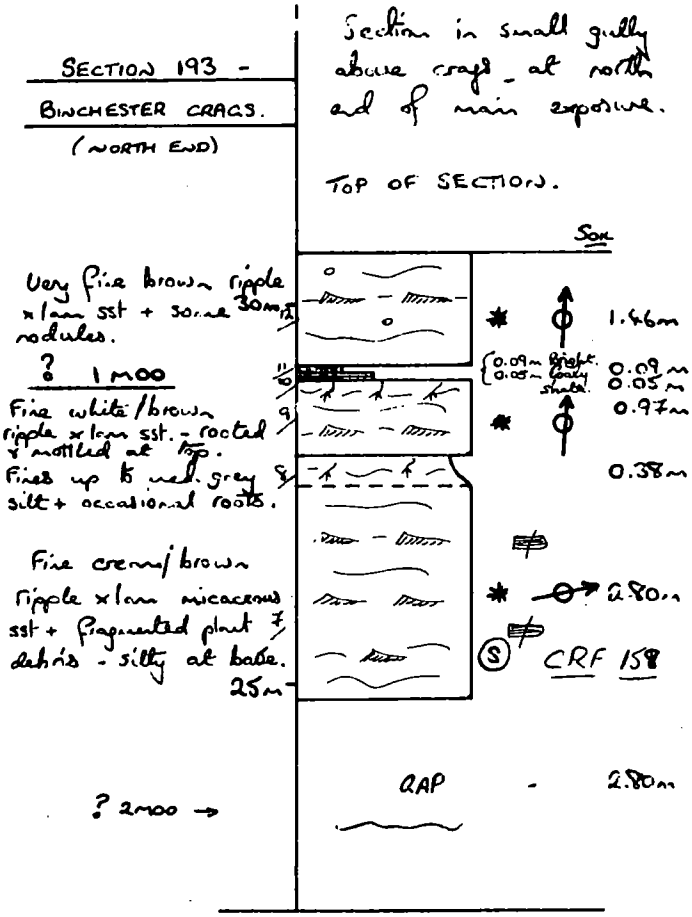


BASE OF SECTION

SECTION 193 -
BINCHESTER CRAGS.
(NORTH END)

Section in small gully above crags at north end of main exposure.

TOP OF SECTION.



* DIRECTIONAL DATA :-

Unit 12 - Ripple x lam → 356°, 014° $\curvearrowright = 2$.
$\Theta = 005°$.

Unit 9 - Ripple x lam → 015°, 355°, 009°, 013°.
$\curvearrowright = 4$. $\Theta = 008.0°$ $\ell = 98.95\%$ $\curvearrowright = 4$

Unit 7 - Ripple x lam → 070°, 074°. $\curvearrowright = 2$.
$\Theta = 072°$

Unit 5 - Ripple x lam → 081°, 041°, 084°, 055°, 065°, 006°, 337°. $\curvearrowright = 7$.
$\Theta = 046.1°$ $\ell = 80.9\%$ $\curvearrowright = 7$

Unit 3 -
Tabular x Sets $\Theta = 142.8°$ $\ell = 71.0\%$ $\curvearrowright = 10$
Planar asymptotic x Sets $\Theta = 136.7°$ $\ell = 80.4\%$ $\curvearrowright = 48$
Trough x Sets $\Theta = 166°$ $\curvearrowright = 1$
Ripples Θ 360° $\curvearrowright = 1$

Overall - $\Theta = 137.4°$
$\ell = 76.55\%$
$\curvearrowright = 60$

C.R. FIELDING - 27.8.80.

SEE SITE PLAN

FAULT-DISTURBED IN MIDDLE PART.

Cut BBS/TB6

High wall at south end of narrow cut to Bottom Busty - Area B(N)

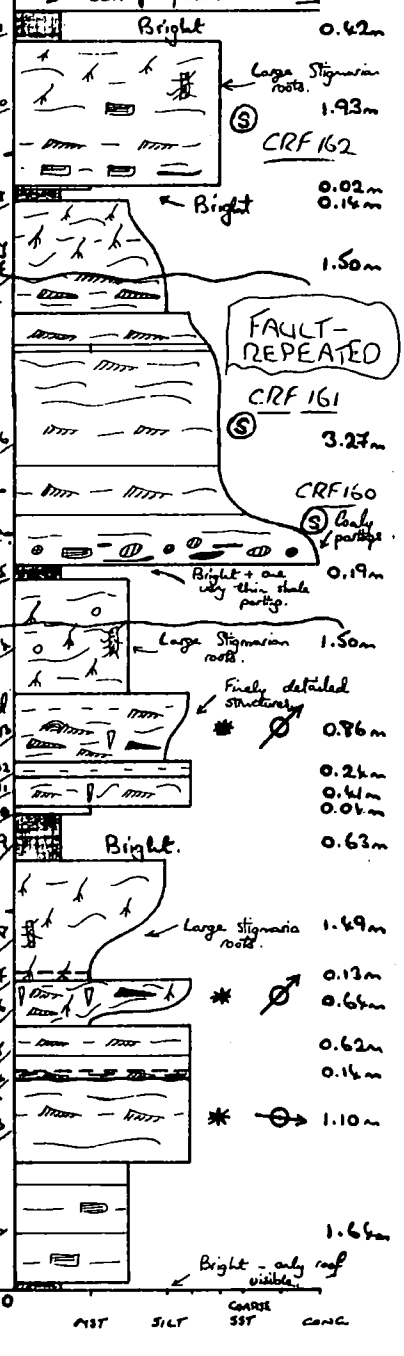
SECTION 194 -

CABIN HOUSE B(N)

18m

Flat wide platform.

May not be top of seam - disturbed by soil profile.



* DIRECTIONAL DATA :-

Unit 13. Ripple x lamination → 052° n = 1
+ backflow ripples.

Unit 6. Ripple x lamination → 051° n = 1

Unit 3. Ripple x lamination → 112°, 100°.
n = 2.
Θ = 106°

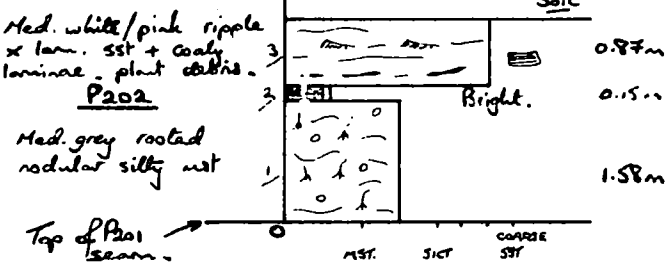
SECTION 195 -

CABIN HOUSE B(S)

Half way along wide long platform - worked to Middle Tilley.

Cut TL7

3m



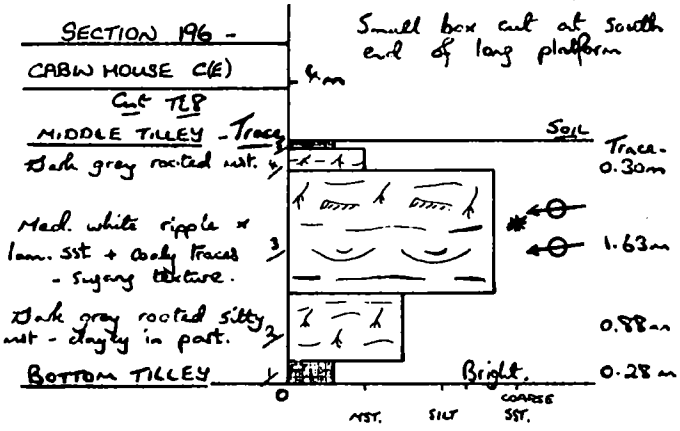
SECTION 196 -

CABIN HOUSE C(E)

Cut TL8

Small box cut at south end of long platform

4m



*

DIRECTIONAL DATA :-

Unit 3 - ripple x lamination → 1. 289° 2. 266°
3. 231° 4. 257° 5. 253°. n = 5.
Θ = 259° ℓ = 95%.

Unit 3 - trough x set - 0.2m/22/263°.
n = 1.

Cut TL9

SECTION 197 -

CABIN HOUSE C(E)

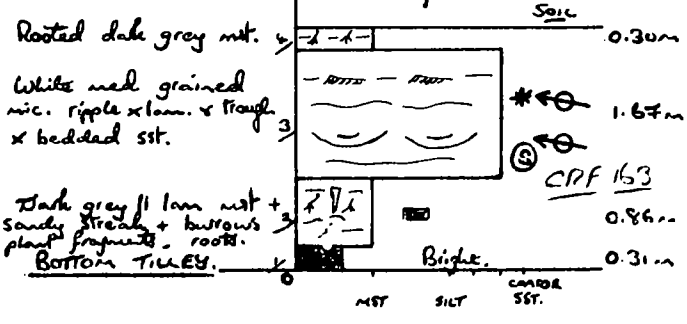
North end of long cut to Bottom Tilley - trending 115°

5m

ends at boundary fence.

Section on west side of access road - facies laterally consistent - especially sst bands.

Dipping gently to East.



* DIRECTIONAL DATA :-

Unit 3 - Ripple x lamination → 293°, 302°, 284°, 293°, 284° n = 5.

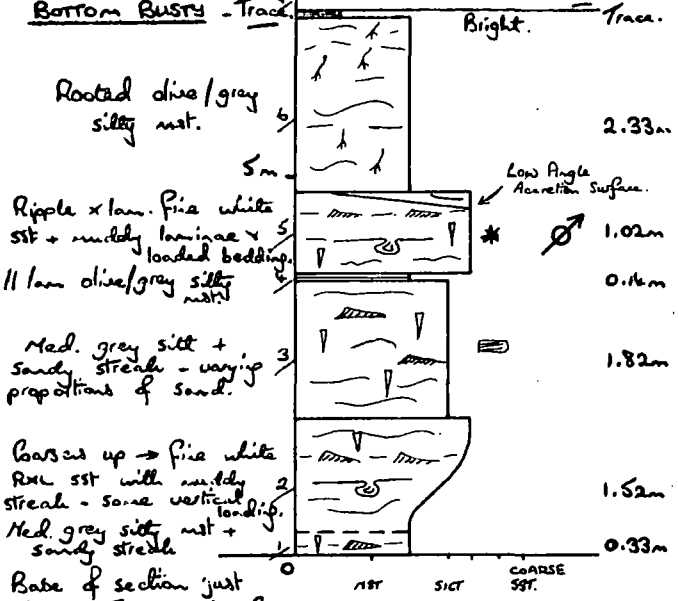
Unit 3 - Trough x Sets → 1. 0.3m/12/285°
n = 2 Θ = 291° 2. 0.15m/17/297°

Low angle accretion surfaces visible also. Face -

C.R. FIELDING - 27.8.80.

SECTION 198 -
CABIN HOUSE C(W)
Cut TB4

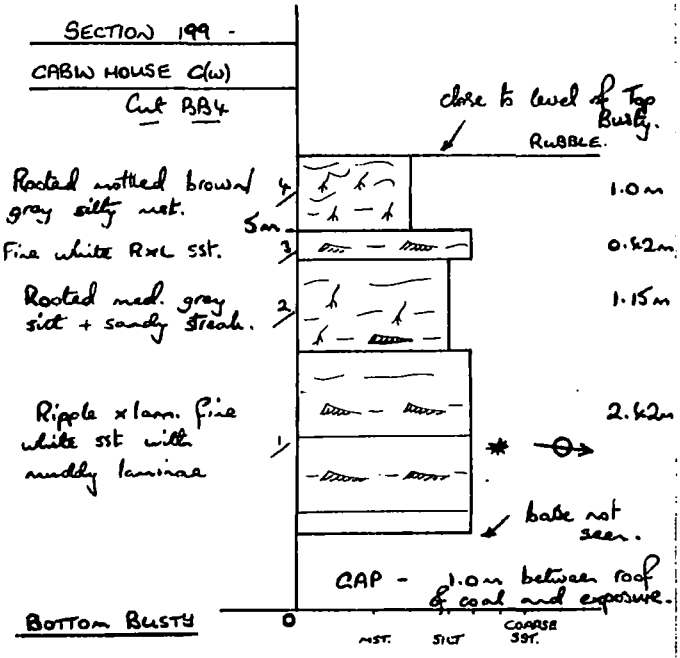
Small threequarter cut - NE end of area C(W) - nearly level with top of line of trees.
Dip 3/054.



Base of section just above Threequarter Seam.

Top
* DIRECTIONAL DATA :-
Unit 5 - Large low-angle x surface
→ 046° - n = 1

SECTION 199 -
CABIN HOUSE C(W)
Cut BB4

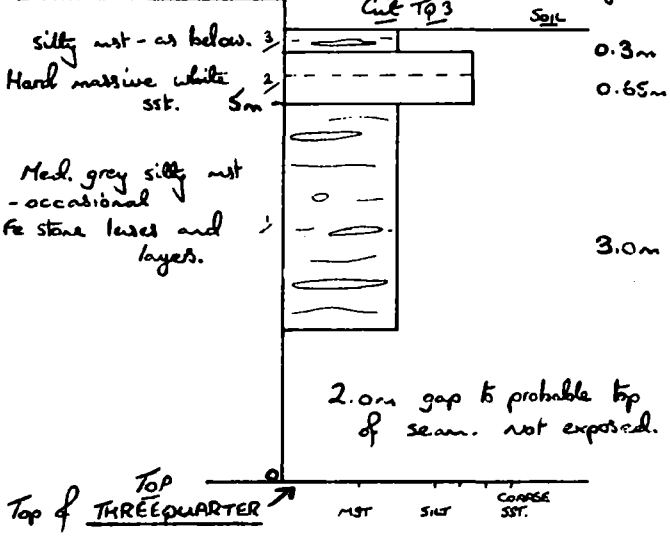


* DIRECTIONAL DATA :- Unit 1 -
Ripple x lamination → 099°. n = 1.

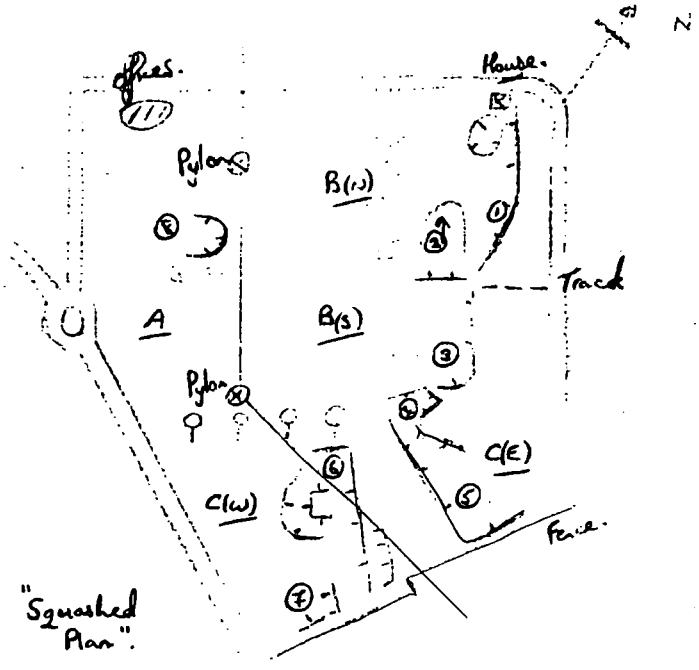
Section at north end of long cut - same as last visit. - wall continues to southern site boundary trending 154° - to south facies remain similar to Section 199 - but sst of Unit 3 thins to 0.2m and dies out completely after 5m. Cut ends just below small abandoned cut to Top Busty.

SECTION 200 -
CABIN HOUSE C(W)

Small box cut to Threequarter at south end of Area C(W).
(Extension of previous long cut).
Cut TB3



PLAN OF WORKINGS AT CABIN HOUSE SITE - 27.8.80.



1. Long cut to Top Busty extended and worked out - cut trends 300°, then 350° at south end.
2. Dragline standing on Top Busty platform, dragging narrow cut to Bottom Busty - 20m back so far. Back wall exposes 2.0m to Bottom Busty roof.
3. Large flat platform - Middle Tilly cooled out - cut which was dragging on last visit. Long wall trends → 170°. Cut is 20m wide. 30m to road to east. Back of cut in line with line of trees. 50.
4. Small box cut to Bottom Tilly
5. Large cut to Bottom Tilly - working Middle Tilly on last visit.
6. Threequarter and Busty workings at top of line of trees. Long cut to Q100, smaller one to R000.
7. Small box cut to Threequarter.
8. Box cut to Brockwell - one further than last

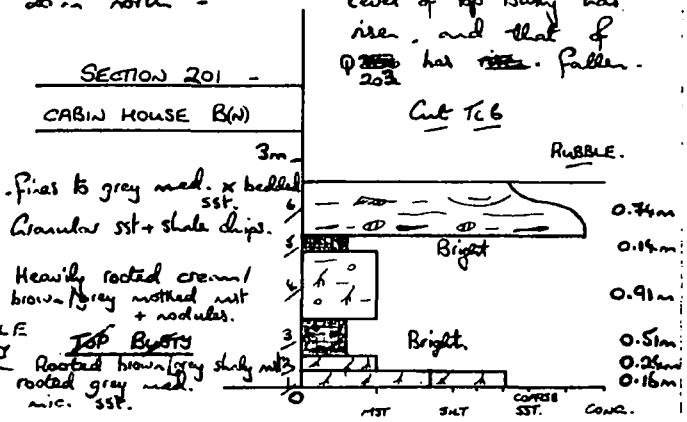
Top
BTB

C.R. FIELDING 28.8.80.

Working along long face in Area B(N).
South end - see Section 194 - single Q200 + 1P00 or (Q203) ~ 3m above. P100 ~ 5m above that. Facing north from south end - Base lie at back wall. 1P00 in wall 2m above Q200 bench.

20m north - level of top Busty has risen, and that of Q203 has fallen.

SECTION 201 - CABIN HOUSE B(N)



Some of rise in level of Q200 accommodated in dip.

27m along - still 1.00m parting between two seams - 0.18m discontinuous Fe stone layer developed half way up the parting. Facies otherwise similar. However - Top Busty only 0.30m thick - underlain by hard dark grey rooted shale - seam must have split below.

42m along - top leaf 0.22m - overlain by 2m coarse white/brown sst - conglomeratic base in places - underlain by 0.69m med. grey mst grade shaly seatearth - then bench - seam? - underlain by seatearth - then white sst fining down to silty dark grey mst. Total ~2m.

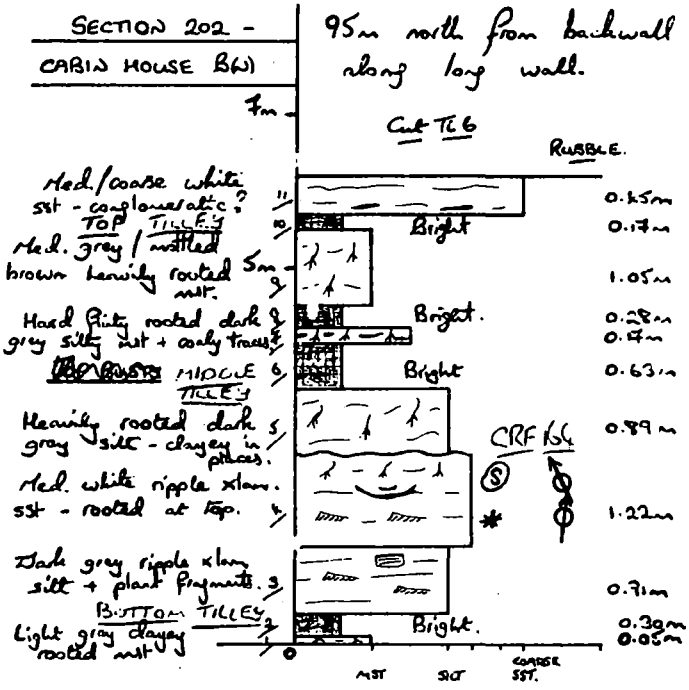
72m along - by corner - wall now 5m high. To north - large hole by cabin house is being infilled.

Facies continue north for 35m - to remains of large hole. See Sections.
1P20 of Section 173 is equivalent to bottom of seam in section 202.

Back to southern backwall - "1P20" has graded into dark grey shaly mst - Unit 6 (base) of Section 194.

SECTION 202 - CABIN HOUSE B(N)

95m north from backwall along long wall.



DIRECTIONAL DATA:-

Unit 4 - Ripple xlamination → 326° n=1.

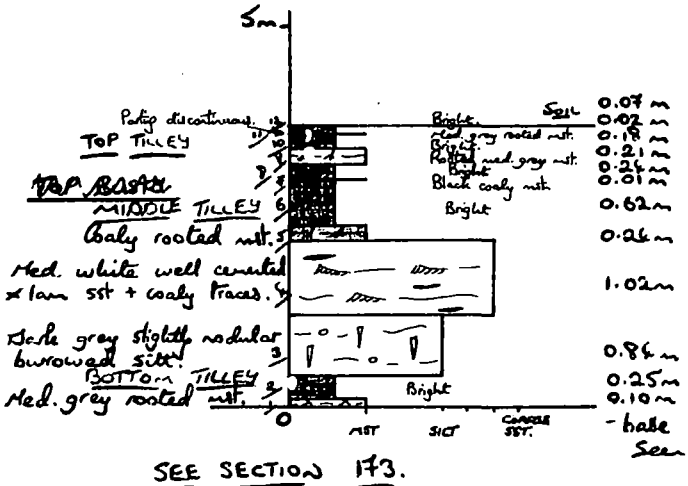
Unit 4 - Trough x Set - 0.2m/21/012°. n=1

NB Leaves 2 & 3 appear to join just to north. Drastic slumping in places.

1100m along long wall (to north) - over remains of large hole.

SECTION 203 - CABIN HOUSE B(N)

Cut TL6

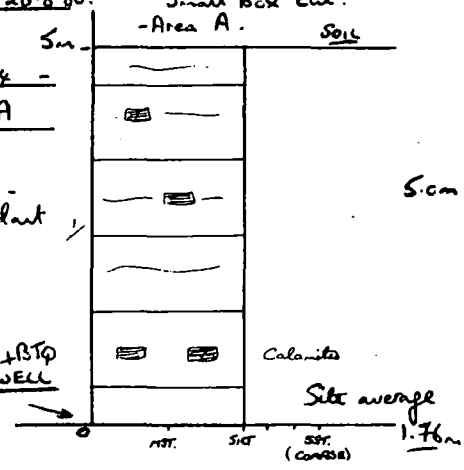


SEE SECTION 173.

NB Leaves 2 & 3 have amalgamated - leaf 4 has grown slightly - leaf 1 has shrunk. - Leaf 1 is "1P20" of Section 173.

C.R. FIELDING - 28.8.80. Small box cut. - Area A.

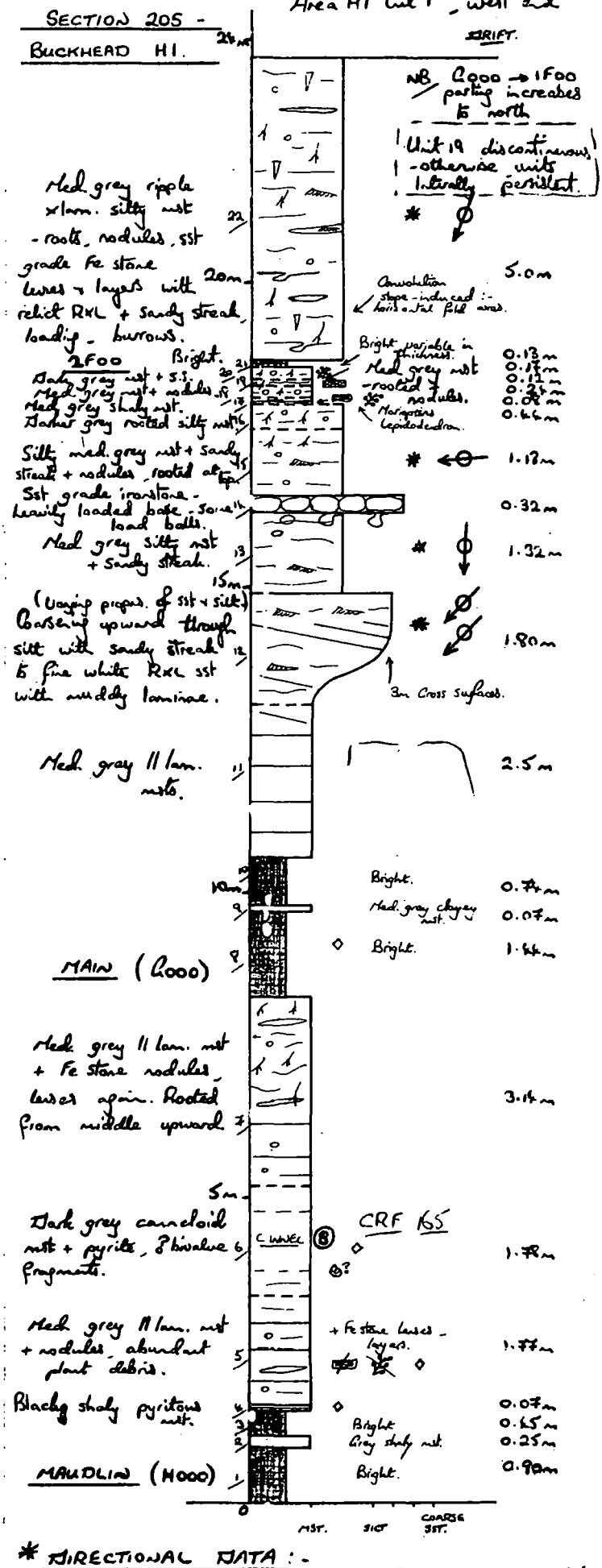
SECTION 204 - CABIN HOUSE A



C.R. FIELDING 29.8.80

Area H1 Cut 1 _ west end

SECTION 205 - BUCKHEAD H1.



* DIRECTIONAL DATA :-

Unit 22 - RxL → 177°, 232°, 220°. n = 3. θ = 210° (92°)

Unit 15 - RxL → 215°, 313° n = 2. θ = 265°

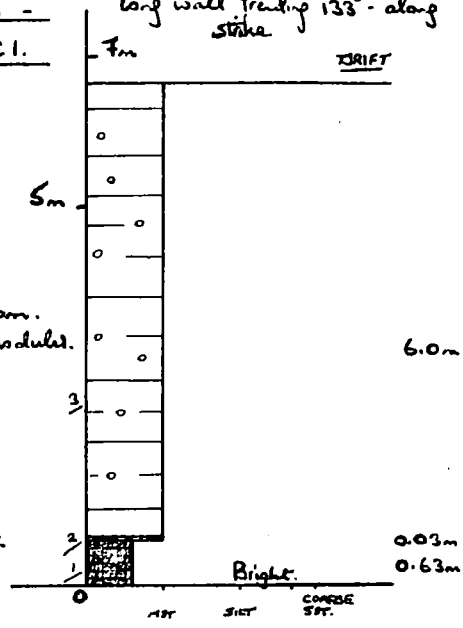
Unit 13 - RxL → 197°, 192° n = 2. θ = 195°

Unit 12 - RxL → 270°, 233°, 277°, 175°, 179°, 280° θ = 6. n = 235°

C.R. FIELDING - 29.8.80.

SECTION 206 - BUCKHEAD - C1.

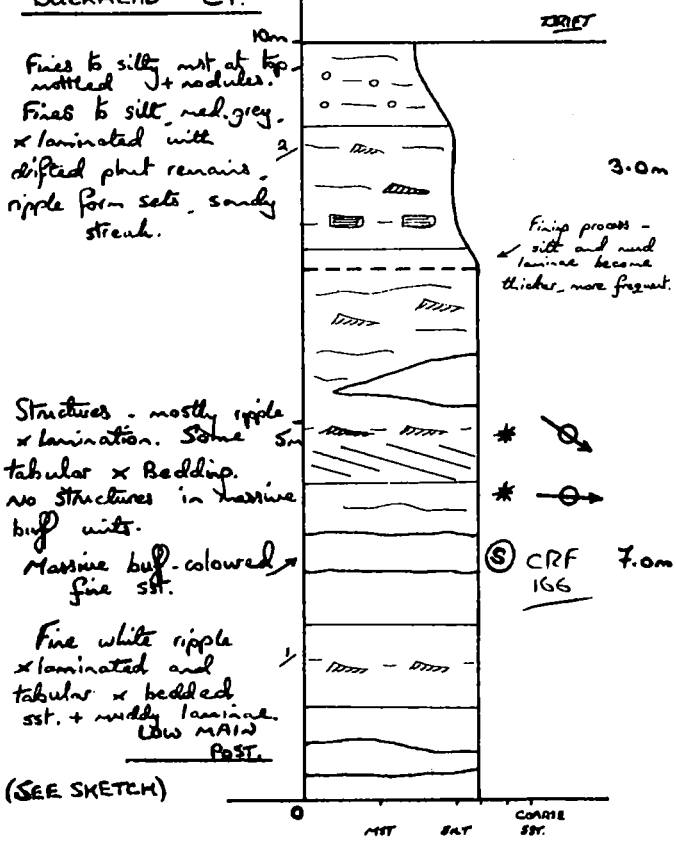
N.E. Edge of site.
long wall heading 133° - along strike



NB Coal logged at 0.50 m in borehole.
To north - fault brings down Low Main coal and Low Main Post - coal not yet reached - ground level still in sst.

SECTION 207 - BUCKHEAD - C1.

North of fault.

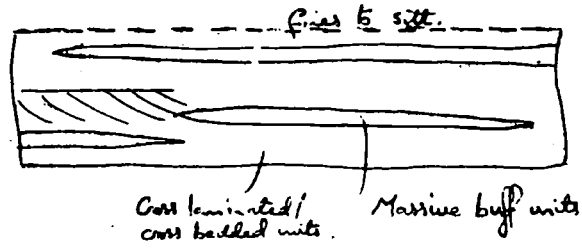


* DIRECTIONAL DATA. :-

Unit 1 :- Ripple + Lamination → 119°, 133°, 155°, 162°, 123°, 152°, 089°, 143°, 115°, 135°, 133°, 123, 155°, 111°, 146°, 085°, 122°, 144°, 140°. n = 19.
Θ = 131° C = 9k%

Unit 1 - Tabular + set
1.2m / 16 / 097°.

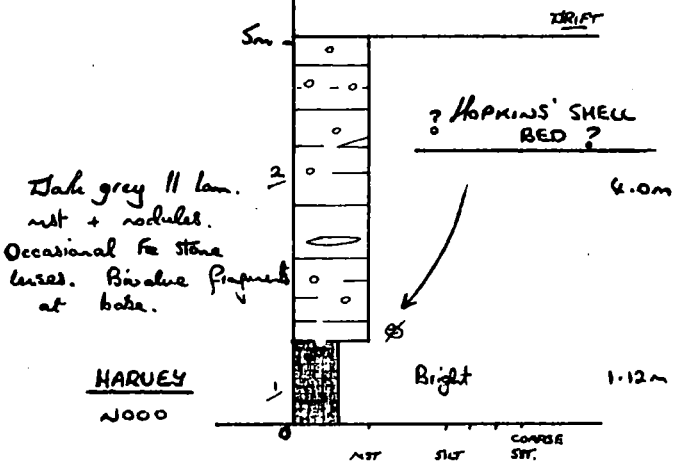
FIELD SKETCH OF BUCKHEAD C-1 WALL - SEE SECTION 207.



Lenses of buff coloured sst ≤ 100 m long - 1.5m thick - some seen to pinch out very rapidly.
NB Comparatively little cross bedding in low Main Post.

SECTION 208 - BUCKHEAD - A1.

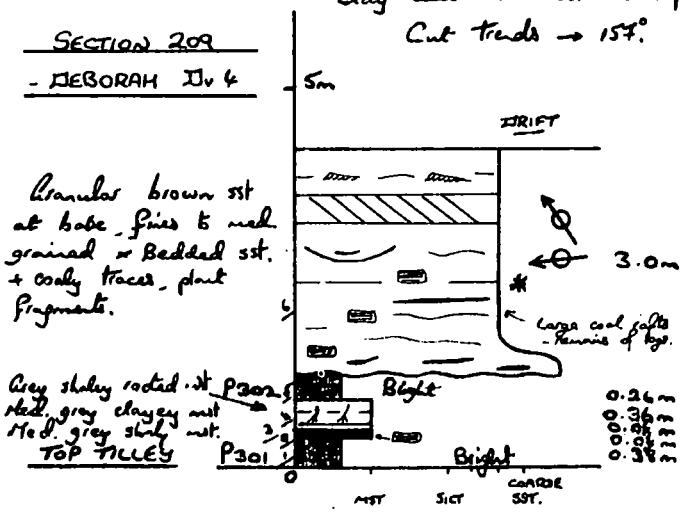
East end of cut 1.



NB Variable thickness over coal due to drift cutout. Small fault exposed. Coal heavily pillared.
At west end of cut - seam 1.50 m thick - with a thin discontinuous clay band near the base.

SECTION 209 - DEBORAH Dv 4

North end of cut Dv 4. Clay unit not well - developed. Cut trends → 157°.



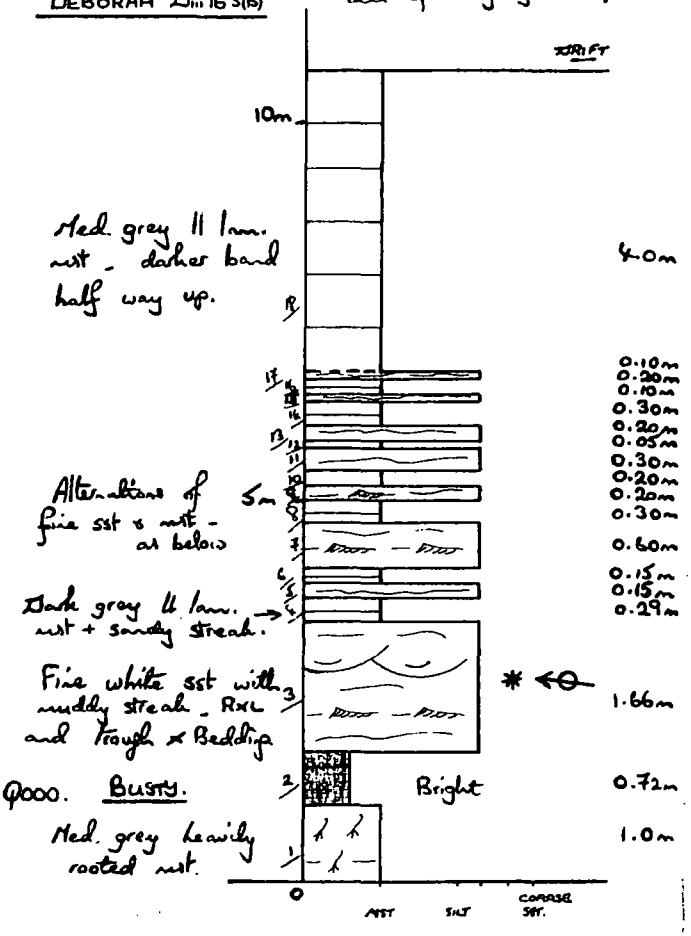
* DIRECTIONAL DATA :-

Unit 6 Cross bedding
Tabular 0.2/16/323° n=1
Trough 0.3/?/258 n=1.

C.R. FIELDING - 29.8.80.

SECTION 210 - DEBORAH Diii 16 S(B)

Cut trending 130° - northern end of "dogleg" cut.



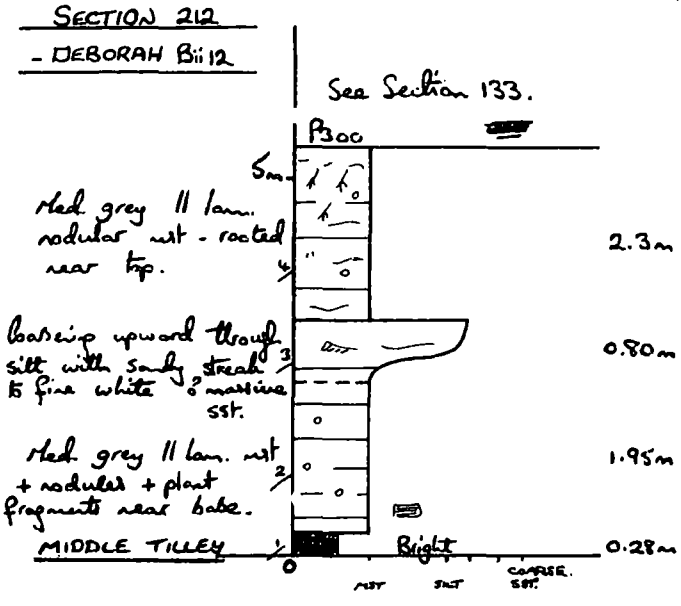
* DIRECTIONAL DATA :-

Unit 3 - Trough x Bedding :- 0.15m/11/277
0.2m/10/290
$\theta = 28\frac{1}{2}°$
$n = 2$.

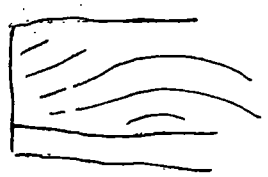
NB P100 not visible - apparently still present.

SECTION 212 - DEBORAH Bii 12

See Section 133.

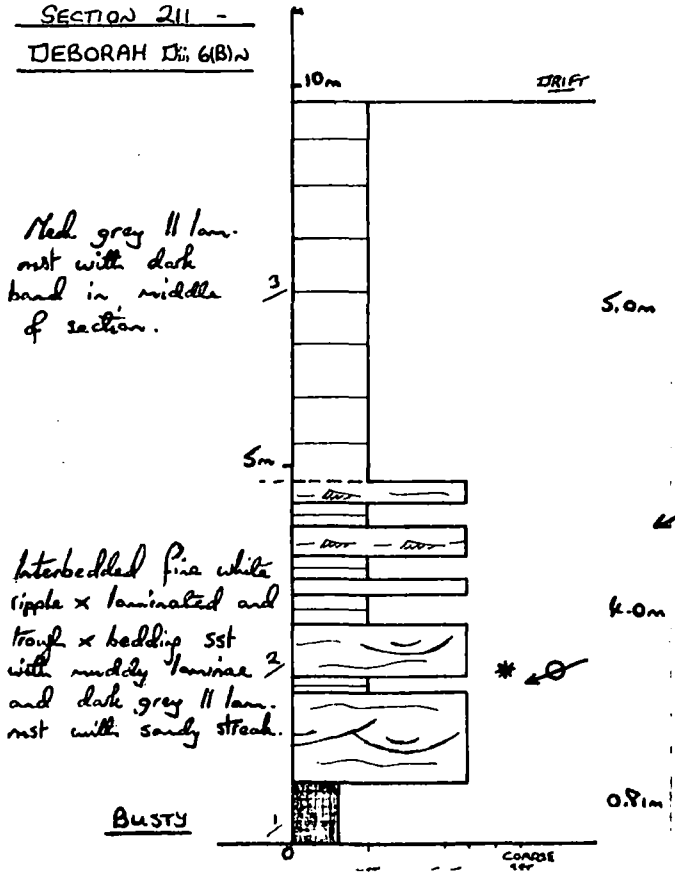


NB Area Diii Cut 43 - Busty exposed - ~1.8m thick in SE. end of wall → 0.7m at N.W. end - thinning toward washout - undulating sst bands - at extreme NW end ssts dip toward coal



* *

SECTION 211 - DEBORAH Diii 6(B)N



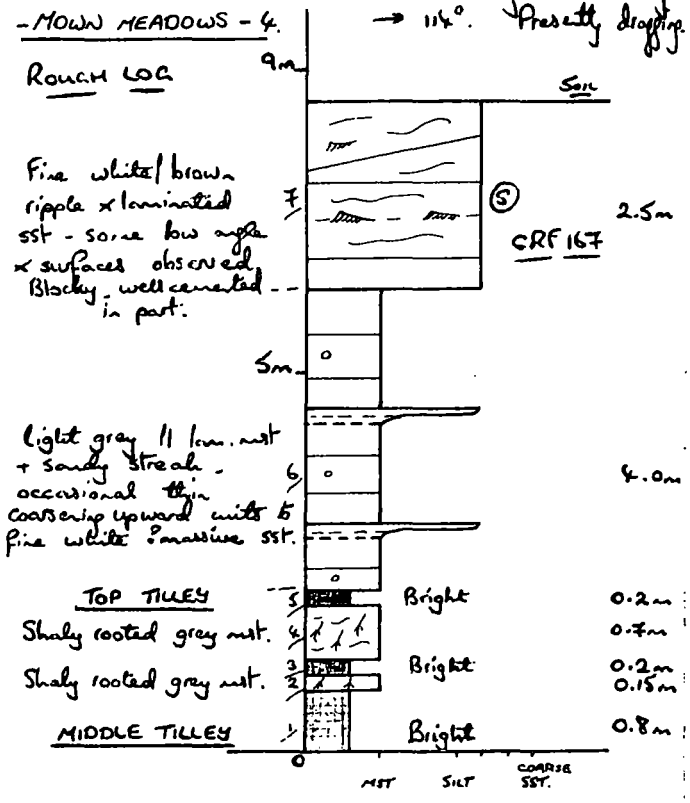
* DIRECTIONAL DATA

Unit 2 :- Trough x Bedding
0.3m/10/265
0.3m/7/233
0.2m/10/215.
$n = 3$.
$\theta = 238°$ $C = 94\%$

C.R. FIELDING - 2.9.80.

SECTION 213 - MOWN MEADOWS - 4.

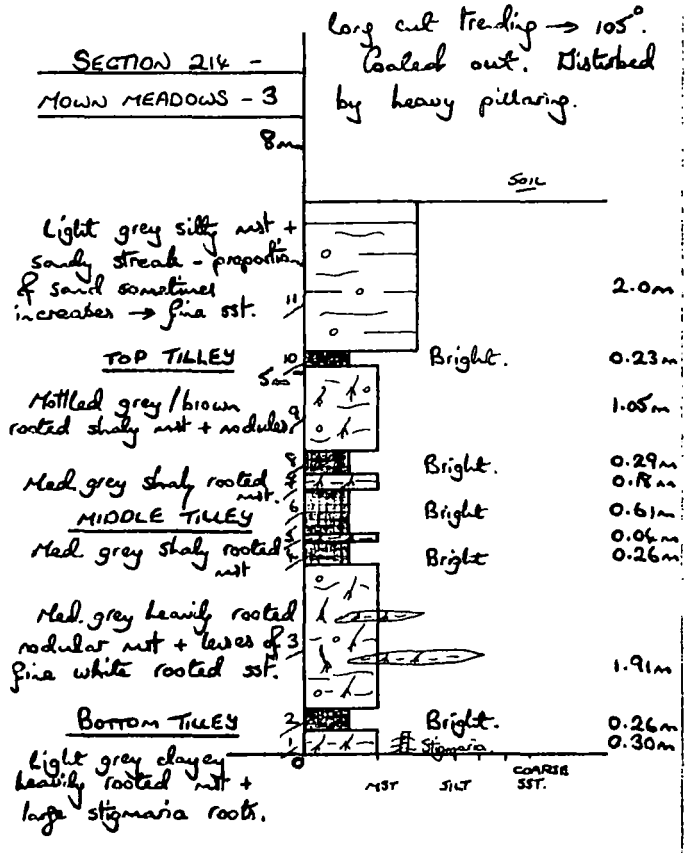
Cut 4 - long cut trending → 114°. Presently dragging.



Units traceable along the face fairly consistent in thickness. 2 photos taken.

SECTION 214 - MOWN MEADOWS - 3

Long cut trending → 105°. Caved out. Disturbed by heavy pillaring.

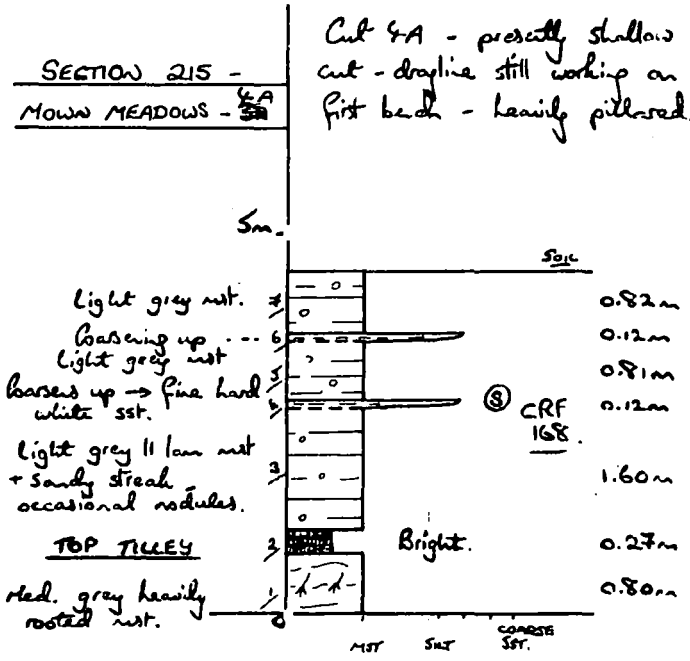


4 photos taken. Partings appear fairly consistent along the face. Height of wall increases to east - base of major sst visible at east end above ~ 3.5 m mark.

Units of mst + fine sst traceable over ~20m - max. distance between pillars. Cut trends → 180°. 2 photos.

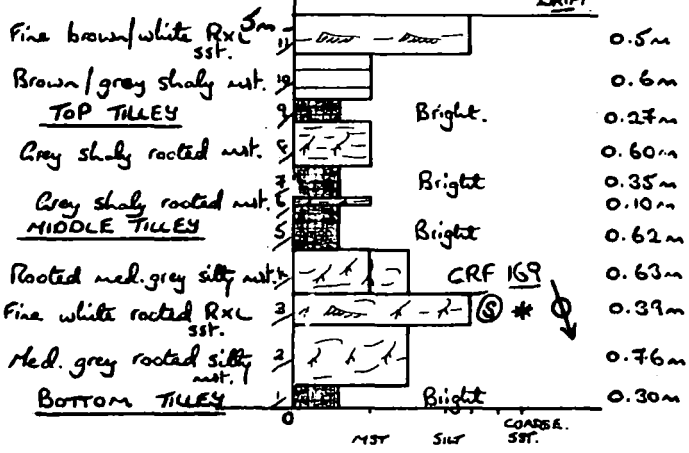
SECTION 215 - MOWN MEADOWS - 4A

Cut 4A - presently shallow cut - dragline still working on first bench - heavily pillared.



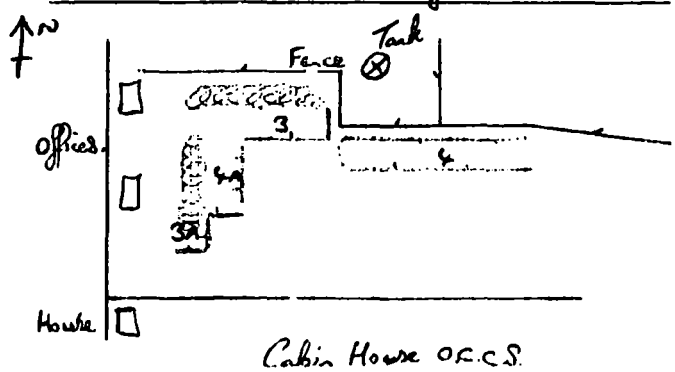
SECTION 216 - MOWN MEADOWS 3A

Previous cut backwall - trending → 127°. Lateral correlation difficult - heavy old workings and infilling



* DIRECTIONAL DATA:-
Unit 3 - Ripple x lamination → 154°. n = 1.

MOWN MEADOWS - Workings as at 2.9.80.



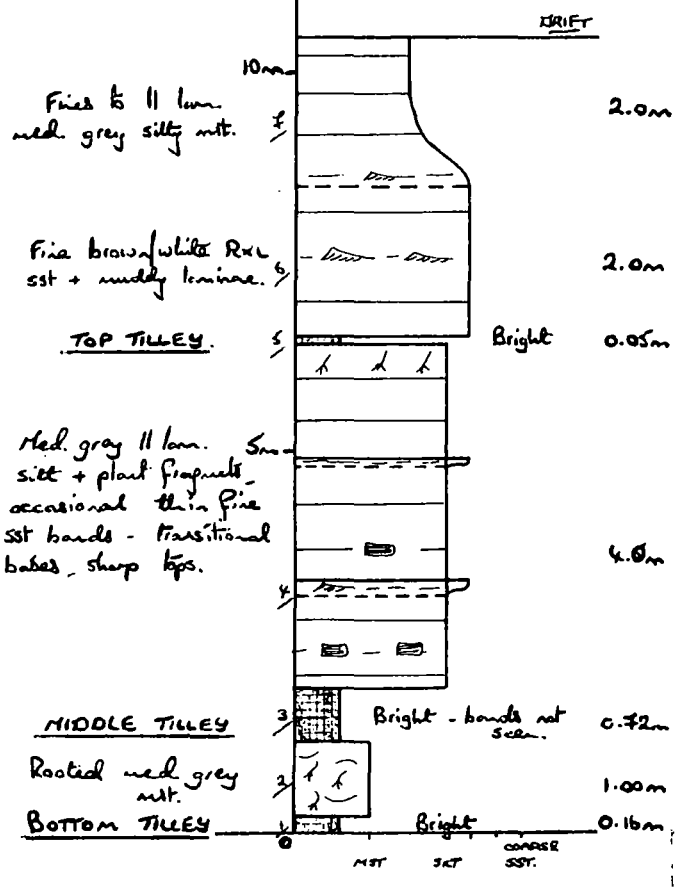
Cabin House O.C.S.

Tectonic dip ~2° to East.

G.R. FIELDING - 4.9.80.

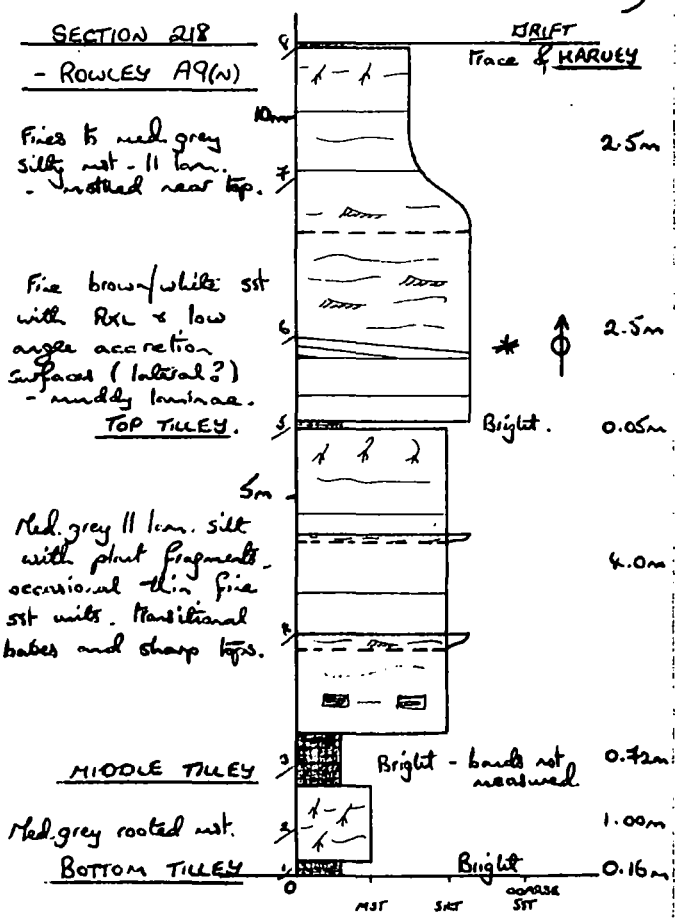
SECTION 217 - ROWLEY A10(N)

South end of Cut A10(N) - by Mid Wall



20m exposure at 4.9.80 - no facies variation. Large slump causing stability problems.

SECTION 218 - ROWLEY A9(N)



Section 218 taken 50m south of north end - trace of Harvey coal at top of face - through drift disturbed.

Washouts of previous cuts have nearly disappeared - one remnant at ~30m south of north end - bedding in silts displays shallow channel structures - P300 warps down.

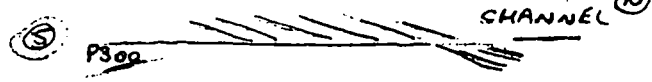


Possible lateral accretion surfaces on bottom of TTP, and more silty mst layers within "blends in" with silts below. Feature ~10m wide. Upcurrent end of channel near source? Also, 45° inclined dislocation plane, through middle - small fault.

* DIRECTIONAL DATA :-

Unit 6 - low angle accretion surfaces → 35° n = 1.

Apart from this sst displays only ripple & lamination.



40m south of 1st "washout" is 70m south of north end = remnant of another channel - again warping down of silts and overlying TTP over 10m width.



P300 dies out temporarily - more silt bands in TTP again, though not as pronounced involvement of TTP.

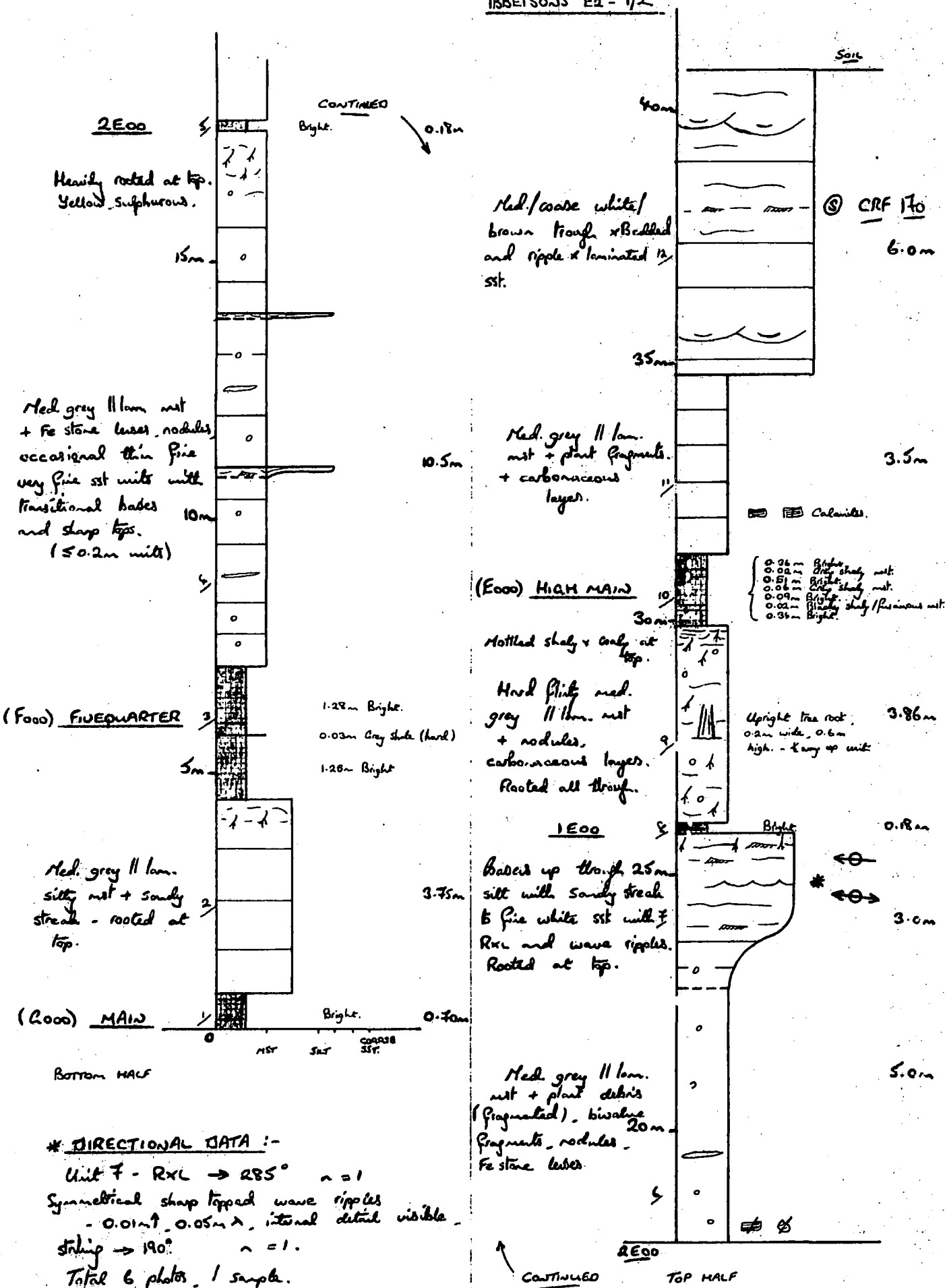
Total 4 photos of washouts.

NB Section 218 - TTP proper is cut out by interbedded silt/sst channel fill in area of "washouts" - merges upward and outward into silt/silty mst over Top Tilley Post.

Section 218 - between washouts contains little of the interbedded facies.

C.R. FIELDING - 4.9.80.

SECTION 219 -
IBBETSONS E2 - 1/2



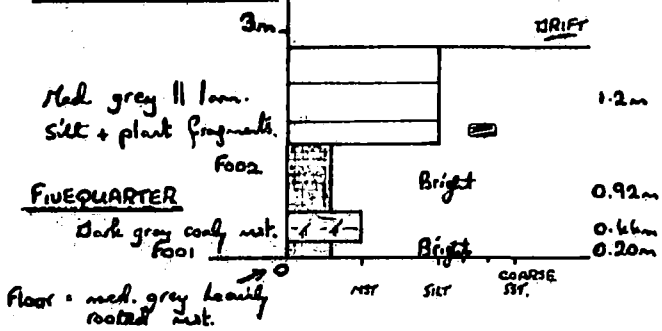
* DIRECTIONAL DATA :-

Unit 7 - Rxl → 285° n = 1
Symmetrical sharp topped wave ripples - 0.01m ↑, 0.05m λ, internal detail visible, striking → 190° n = 1.
Total 6 plates, 1 sample.
Second extension - Area A, Cuts 1 & 2.
Lateral continuity of units difficult to assess.
In High Main, bands are often discontinuous, grading in and out rapidly.

C.R. FIELDING - 4.9.80.

SECTION 220 - EDMONDSLEY - C1

Area C Cut 1
1st visit.



Floor: med. grey heavily rooted mst.

Drift downcutting randomly - not consistently in one direction. Cut trends → 098° - working more or less on outcrop. North edge of cut - seam disturbed and thinned. New site. Old works frequent - little faulting.

8.9.80. Further observations on Binchester Crags.

Simple channel section. Bivalve fragments and complete shells preserved in nodules in fine interbedded facies.

Around sst lenses - some roots round edges - surrounding sediment may well be rooted at these levels. ⇒ lowering of water table. - implied by presence of stream channel. - less nodules at these levels.

3rd sst lense - fine layers between storeys are consistent with the interbedded facies, whereas the sst bands are erosive - proved simultaneous dev. of both facies. - small streams crossing a floodplain mostly under water, but not at this time. However, some ssts do continue out into the surrounding interbedded facies - fining and thinning outward. 3rd layer in 3rd lense particularly continues out for some distance. Erosive contacts difficult to substantiate, and the lenses are very hard and possibly siderite cemented. CACT reckons that they are large concretions. Raspberry. Siderite may have exploited the contrast in sediment, but the symmetrical arrangement of layers, thickest dev. in centre, and general appearance all suggest a different depositional environment.

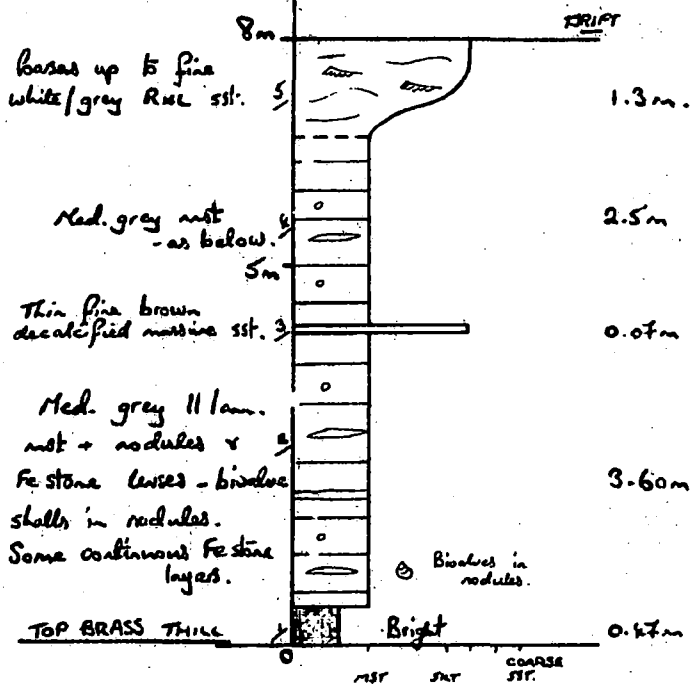
SAMPLE - nodule + bivalves - CRF171

Stream at South end - discovery of Top Tilly seam in site directly below major sst at top of section - need to measure thickness (with shovel). Also correlation of seams - "Top Middle & Bottom Tilly" now present all along face.

C.R. FIELDING - 9.9.80.

SECTION 221 - TANNERS HALL A6(S)

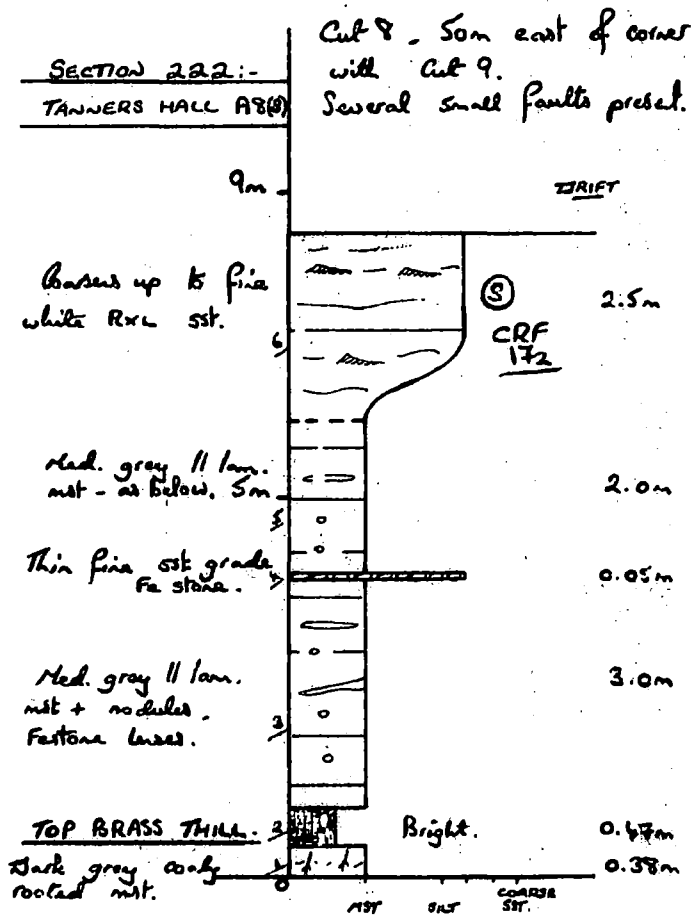
East end of - main exposure - remnant, presently being backfilled - trends E-W.



All units laterally persistent and more or less uniform in thickness.

SECTION 222:- TANNERS HALL A8(S)

Cut 8 - 50m east of corner with Cut 9. Several small faults present.

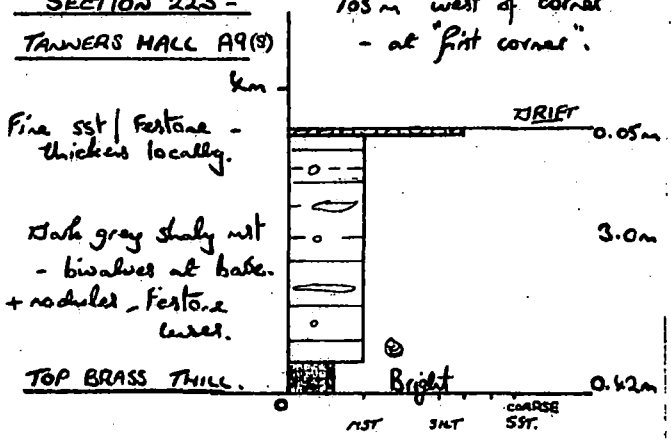


2 photos taken. NB 20m back - at level of thin sst / Fe stone - widens into a lense 0.2m thick - then thins again.

C.R. FIELDING - 9.9.80.

115m east of corner with cut 9 - start of large slippage - facies still the same - thicknesses exactly the same - except local thickening of thin sst to 0.15m. T.B.T. seam = 0.45m. Total of another 75m exposure along the face, then dragline pulling out remainder of cut, toward remnant of Cut 6. Facies and thicknesses still exactly the same.
Cut trends → 097°.
Into Cut 9 - first part trends → 125°. - distance 105m to first corner. Facies as before. 2nd part trends → 016°. Drift downcuts to m 3m over T.B.T. seam. At next corner - m100m along - sst reappears in face.

SECTION 223 - TANNERS HALL A9(S)



After this point, the thin sst is cut out for some distance to the north.
Cut continues round to NE corner of horseshoe:- facies and thicknesses very similar. Still coaling at NE corner.

LANCASHIRE TRIP - 9-14/9/80.

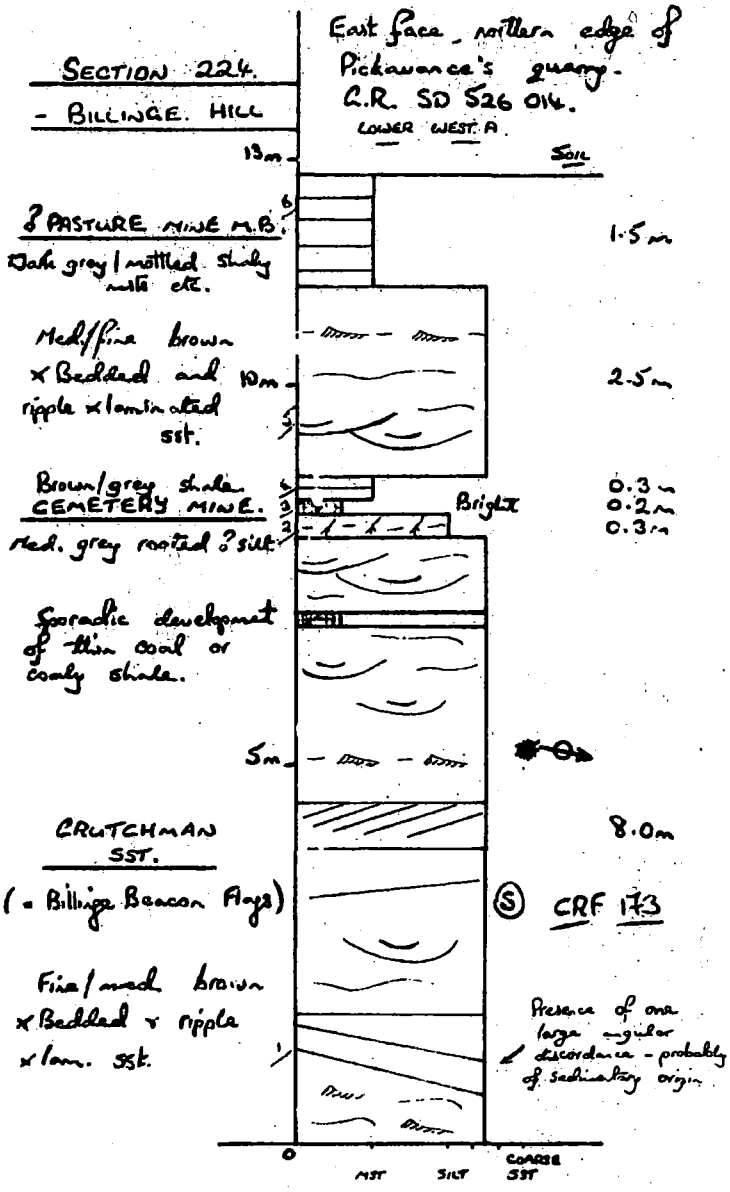
See Written Description

10.9.80

ROUGH LOG

SECTION 224 - BILLINGE HILL

East face, northern edge of Pickavance's quarry. C.R. SD 526 014.



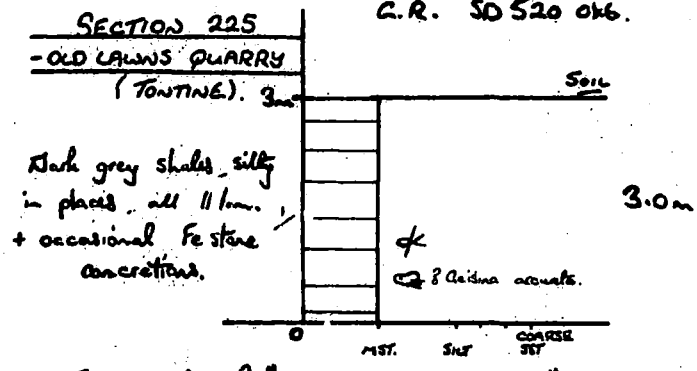
* DIRECTIONAL DATA :- (Corrected)
Unit 1 - Ripple x lamination → 125°, 172, 163, 112, 051, 152, 137, 074, 101, 112, 055 n = 11.
Θ = 110.9° C = 80.1%
Unit 1 - Trough & Tabular x sets :-
1. 0.25m / 20 / 022 2. 0.15 / 26 / 052 3. 0.2 / 15 / 225
4. 0.3 / 15 / 159. Θ = 096.9° C = 20.5%
n = 4.

Overall - Θ = 109.7°. C = 64.1%. n = 15.

SEE DESCRIPTION

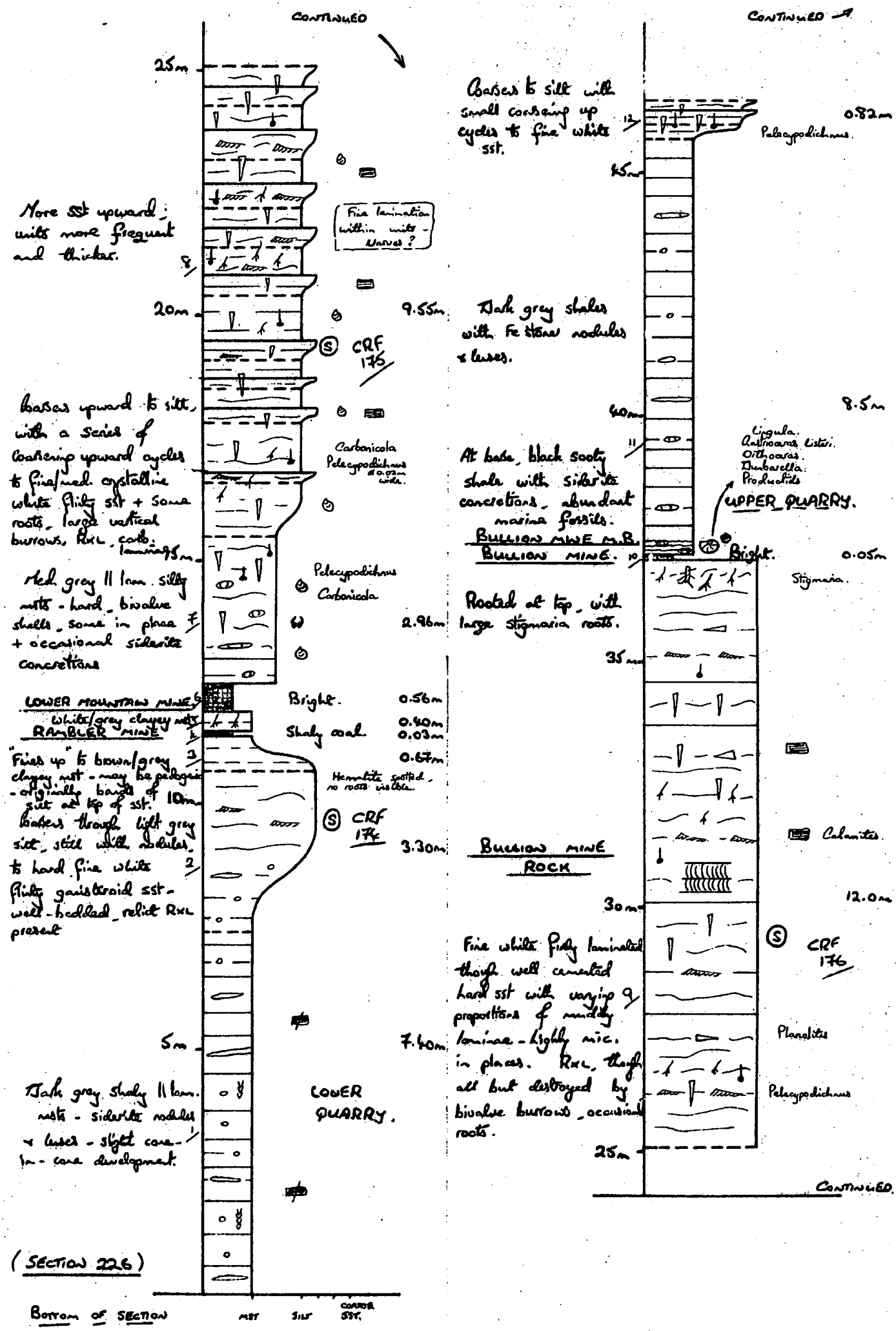
SECTION 225 - OLD LAWNS QUARRY (TONTINE).

C.R. SD 520 016.



Equivalent of "Accrington Mudstones".
MID. WEST. A.

C.R. FIELDING 11.9.80.



C.R. FIELDING - 11.9.80.

Lower and Upper Quarries - Composite log - OR SD 5120 18. Tectonic Dip 15/080.
Lower quarry - east face → 007°. Upper quarry - east face → 338°. 10 b/w photos & samples. Other details - SEE DESCRIPTION.

* DIRECTIONAL DATA :- Unit 14 - Tabular × Set - 0.2m / 23/356° n = 1.

SECTION 226 - RAVENHEAD BRICKWORK QUARRY, UP HOLLAND.

TOP OF SECTION

LOWER WESTPHALIAN A.

63m

SOIL

(Equivalent of Warrington Sst.) 60m

Traceable over 150 m laterally.

Dark grey 11 lam. shales + Fe stone nodules and 2 continuous 0.1m Fe stone bands 18 — 7.0m

Shales papery at base.

INCH MINE. 17

Coaly shale. 0.02m, 0.12m

Tough "gannister" at top. 55m 16

1.04m

Clayey white/grey heavily rooted sst. 15

Interbedded silt and fine sst - as below in small coarsening upward cycles. Heavily bioturbated. Thickness increases to north. 14 — * — 4.31m

50m

INCH MINE ROCK.

Ⓢ CRF 177 — 3.65m

Fine white RxL sst 13 - lots of vertical and horizontal burrows - disturbed lamination - hard & flinty. Occasional silt partings.

Pelecypodichnus. Planolites etc.

CONTINUED.

SECTION 227 - ROUGHDALES BUFF QUARRY, ST. HELENS.

Composite log. Tectonic dip = 8/101.

27m WESTPHALIAN C

SOIL

Silt + sst interbedded 25m 25 — varying proportions of each - micaceous partings. RxL - lenticular bedding. * — 3.0m

Med. grey shaly mst 24 Coarsening up to fine white RxL sst + nodular lumps of Fe stone → 1.52m

Fines to grey clayey nodular rooted hem spots mst at top.

Muddy laminae + tool marks. 20m

Dolomite veining. Ⓢ CRF 178 — 6.0m

Fine white poorly cemented RxL sst 23 - weathers a buff colour. * — Parting lineation present and brecciation with dolomite mineralisation. P.L. Parting lineation. Tool marks.

Brown grey shaly mst + soft brown hem./sid. concretions. 25 ← coaly near top. 0.86m

Dark grey shaly + coaly mst 24 0.39m

Mottled rooted light grey mst 23 0.41m

Mottled grey mst coarsening through 15m silt → fine white sst 22 - all rooted heavily. 2.06m

Bright 21 Coaly black shale. 20 0.32m, 0.15m

Light grey mottled → buff mst + Fe stone nodules - lumps - some primary sst - heavily rooted at top. 19 3.35m

Dark grey mst + nodules. 18 0.07m

Med. grey mst + S.S. + nodules 17 0.81m

Med. grey mst + S.S. → fine white RxL sst 16 0.17m

Coarsening up to silt + S.S. 15 0.23m

Rooted grey mst + S.S. 14 0.56m

Fine white rooted RxL sst. 13 0.08m

Fines up to grey mst + sandy streaks - rooted. 12 1.23m

Mst + S.S. coarsens up to fine white RxL sst + nodules. * 0.37m

Coarsens up to fine white RxL sst + sandy streaks. * 0.17m

Dark grey 11 lam. mst + sandy streak. 9 0.73m

Fine white RxL sst. 8 0.09m

Med grey 11 lam. mst 7 0.47m

Fine white RxL sst. 6 * 0.09m

Fines up to grey 11 lam mst. 5 0.31m

Fine white RxL sst. 4 0.15m

Med. grey 11 lam mst. 3 1.05m

Hard dull banded coal. 2 0.46m

Med. grey heavily rooted clayey mst + nodules. 2.90m

Base not seen.

0 — CHAINAGE

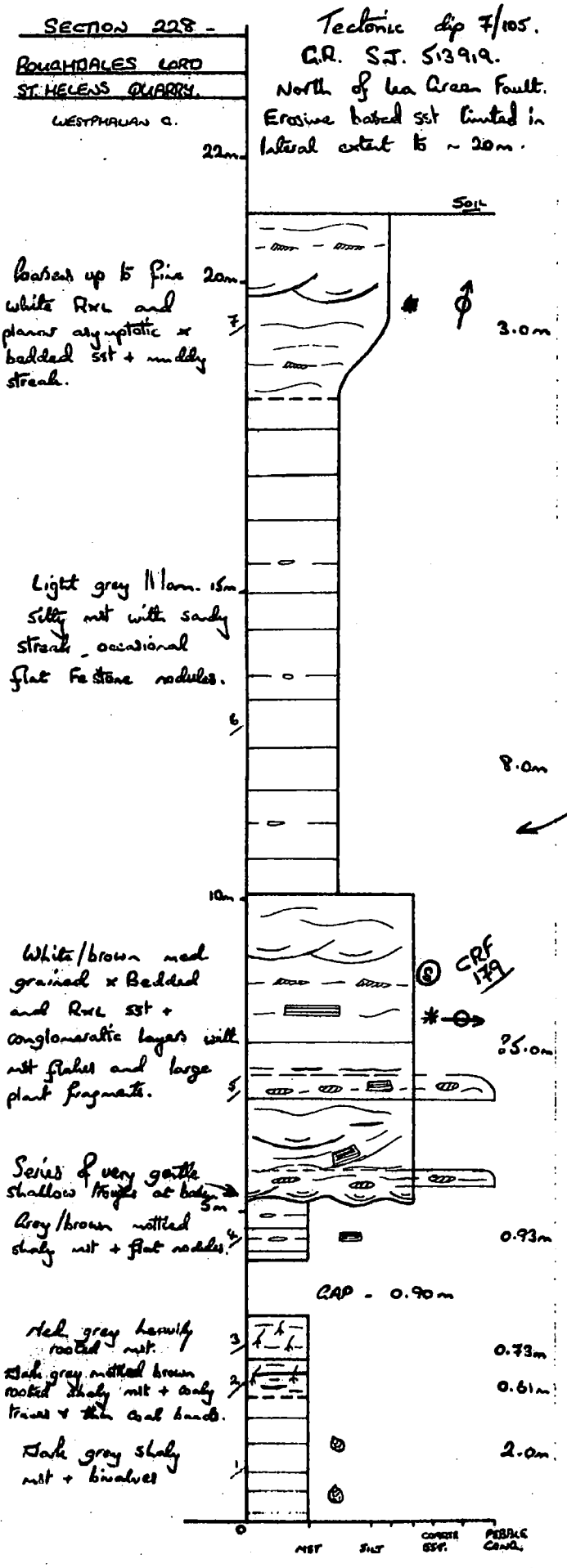
C.R. FIELDING 12.9.80.

SECTION 228 -

BOUGHDALES LORD ST. HELENS QUARRY.

WESTPHALIAN A.

Tectonic dip 7/105.
G.R. SJ. 513919.
North of Sea Green Fault.
Erosive based sst limited in lateral extent to ~ 20m.



* DIRECTIONAL DATA :- SECTION 227.

Unit 28 - Ripple x lamination → 003° $\wedge = 1$.
$\Theta = 003°$

Unit 26 - Ripple x lamination → 118°, 094°, 088° $\wedge = 3$.
$\Theta = 099°$ $\iota = 97\%$

Unit 11 - Ripple x lamination → 258°, 294° $\wedge = 2$
$\Theta = 276°$

Unit 10 - Ripple x lamination → 279°, 270° $\wedge = 2$.
$\Theta = 275°$

Unit 6 - Ripple x lamination → 339°, 032°, 315°. $\wedge = 3$.
$\Theta = 349°$

Overall - $\Theta = 336.4°$ $\iota = 33.8\%$ $\wedge = 11$.

Section also logged in Wigan Geol. guide - agreement not complete! Composite log - several faces in quarry.

* DIRECTIONAL DATA:- SECTION 228.

Unit 7 - Ripple x lamination →
006°, 013°, 354°, 045°, 022°, 028°, 024°
$\wedge = 7$ $\Theta = 018.1°$ $\iota = 96.6\%$

Unit 7 - Planar asymptotic x Sets - (0.1 - 1)
→ 007°, 050°, 008°, 358°, 051°, 020°, 050°, 011°.
$\wedge = 8$. $\Theta = 023.6°$ $\iota = 92.9\%$

Unit 7 - Overall - $\Theta = 021.0°$ $\iota = 94.5\%$
$\wedge = 15$.

Unit 5 - Rxl → E & W - no measurements.

Unit 5 - Plant fragments → 094°, 100° $\Theta = 097°$

Unit 5 - Trough x Sets →
1. 0.1m x 0.3m → /A/091°
2. Small → 089°. $\Theta = 091°$
3. Series at base → 092°. $\iota = 100\%$

Unit 5 - Overall. $\Theta = 093.2°$ $\iota = 99.8\%$
$\wedge = 5$.

Overall - $\Theta = 037.8°$ $\iota = 82.0\%$
$\wedge = 20$.

C.R. FIELDING. 4.7.80

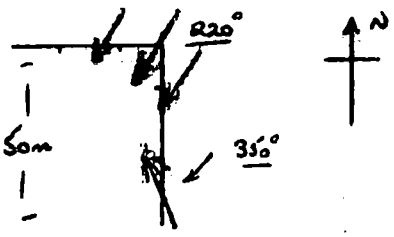
Crowbar visit to Binchester Crags.

1. Bottom Tilley in stream section is 0.22m Bright coal.
2. Top Tilley in stream section - full thickness not visible - presence of band not ascertainable - thickness estimated at 0.65m - alters Section 191 slightly.
3. Sst lenses in slough channel section - crowbar applied to top layer of 4th lense (b). - outcropping block removed - evidence still inconclusive - behind the block is a highly weathered clayey med. grey sand - sed. structures not preserved but character totally different from enclosing sediment. 3rd lense does look concretionary but then all the lenses have been preferentially attacked by siderite and may have developed as concretions - But I still think that there is an underlying reason for the preferential cementation and it is in the sedimentary history of the rocks in the lenses represent cross sections of small streams. CRF 180 181 182.

C.R. FIELDING - 18.9.80.

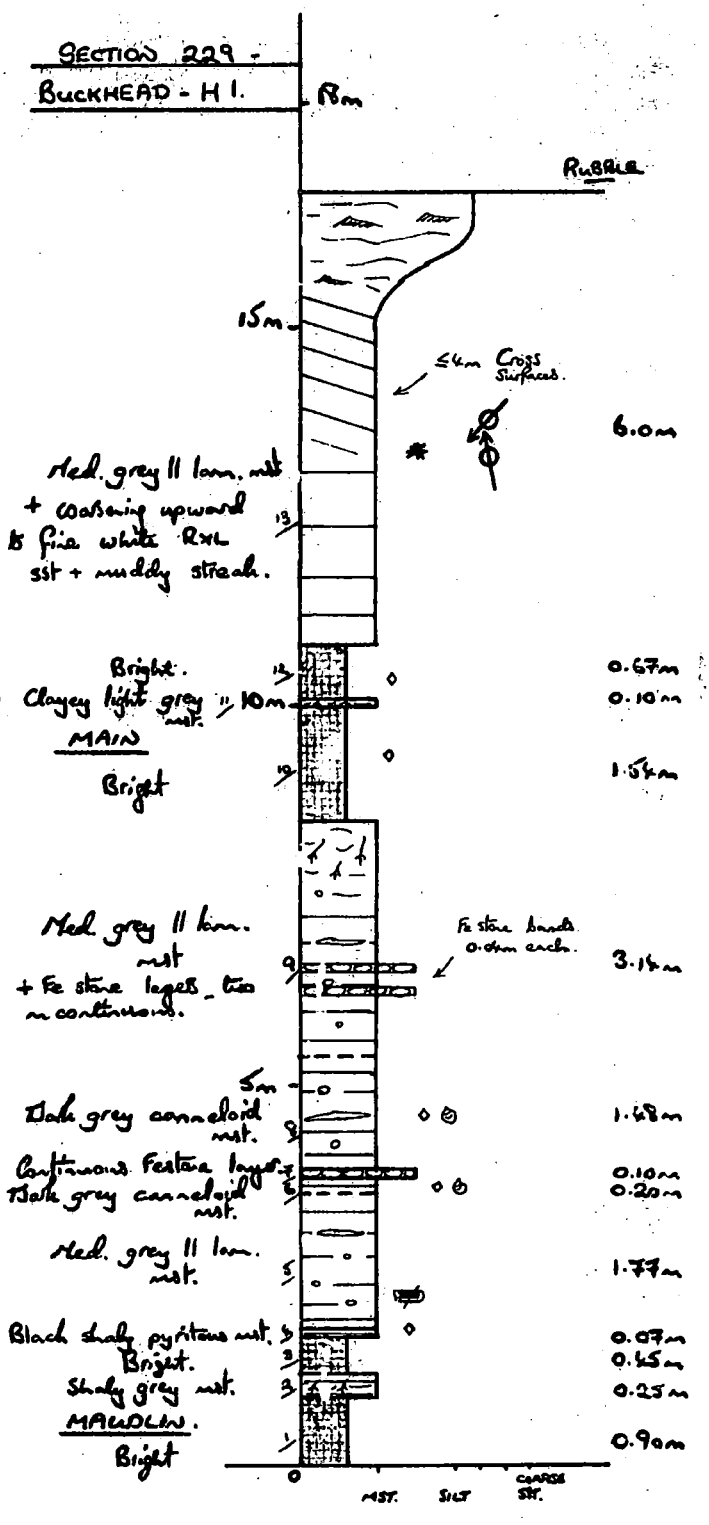
BUCKHEAD.

Area H - workings on Main and Maudlin still going - wall ~ 20m further back than on last visit. Angular discordance in mudstones over the Main is well exposed - but access not easy. 2 photos taken. Up to 4m height on cross surface. - dips toward 220°. - comes down nearly to level of coal. Another * face of smaller vertical extent (~ 2m) occurs on the N-S wall - dipping in the opposite direction (→ 350°). This infers lake filling from several directions.



Area C - Low Main Post - still reducing to coal on north side of fault. 3m of hard well cemented facies presently at base of section. Some larger * Bedding visible - more interbedding present in upper part of section.
* Trough set 1.0m/23/100°.
Long wall trends → 320°. Common occurrence of intermixed silt & sand in varying →

SECTION 229 -
BUCKHEAD - H 1.



---

proportions - no systematic change in grain size up section. Muddy laminae common in sst. plant fragments - esp. Calamites.

NB Thickness between Main and coarsing upward sequence underestimated in section 205.

DIRECTIONAL DATA :-
Unit 13 - large scale * faces dipping → 220°, 350°.

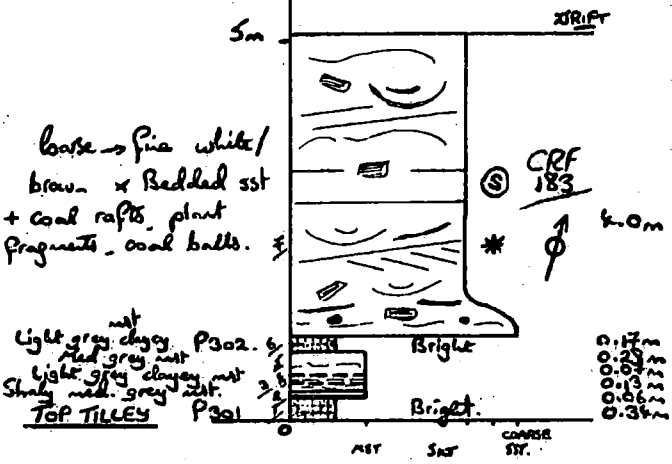
No samples. 2 photos.

Area B - presently removing drift.
Area A - coaling complete - backfilling

C.R. FIELDING - 8.9.80.

SECTION 230 - DEBORAH DV 5

Cut trends → 333°. Section taken at north end of cut. P302 variable in thickness.



* DIRECTIONAL DATA :-

Tabular x sets :- 1. 0.1 m / 19/040° 2. 0.15/28/030
3. 0.1/26/071 Θ = 047° ∧ = 3. ζ = 96%

Trough x Sets :- 1. 0.1/20/018 2. 0.2/20/035
∧ = 2. Θ = 027°

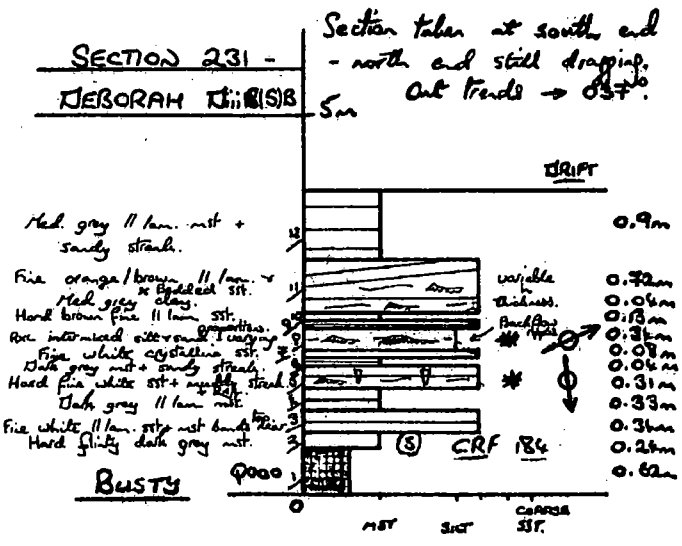
Planar asymptotic x sets :- 1. 0.1/10/356. Θ = 342°
2. 0.15/12/336° 3. 0.1/10/333. ζ = 98%

Overall Mean - 018° ζ = 81% $\hat{\wedge}$ = 3. ∧ = 8

NB Rafts of coal in TTP ≤ 2m lap. Part of previous cut exposed down to P200 - facies similar to previous cuts. Balls of coal present in TTP. ie rounded before trapped in sediment.

SECTION 231 - DEBORAH DIII B(S)B

Section taken at south end - north end still dropping. Cut trends → 057°.



* DIRECTIONAL DATA :-

Unit 8 - Ripple x lamination → 064°, 070°
Θ = 067° ∧ = 2.

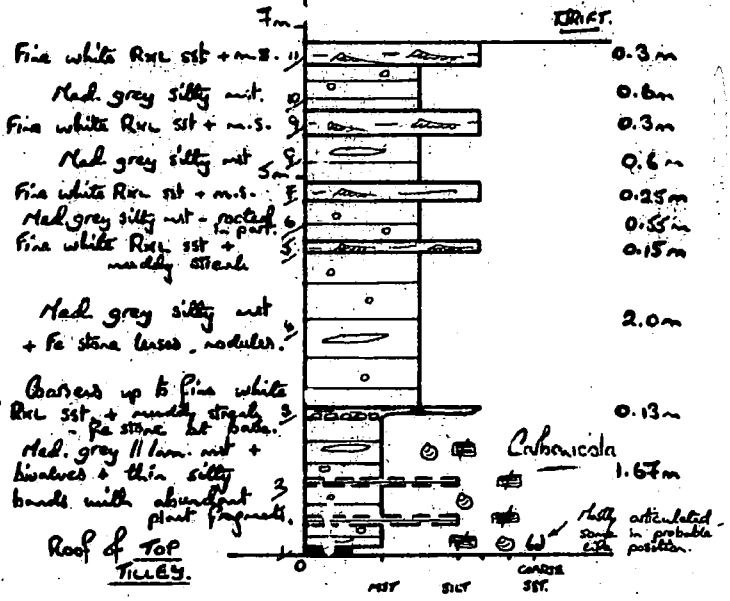
Unit 5 - Ripple x lamination → 175° ∧ = 1.

NB Hard flinty mst over Busty - lithology usually found as coal seam bands. All units laterally persistent along 40m of face - Unit 11 thickens to north. Dog leg cuts not present working

C.R. FIELDING - 24.9.80.

SECTION 232 - MOWN MEADOWS - CUT 5

East wall of cut 5 - south end by pilot cut. No coal yet exposed - heavily pillared. Cut trends → 100°.

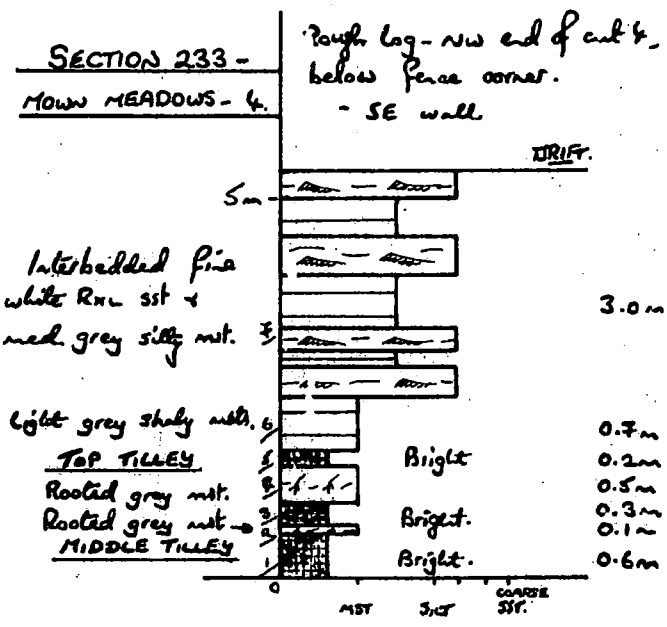


To south, thin pilot cut exposes similar rocks. Sst units thicken along face to NW.

1st two units - visible on opposite face, the drift cutout. Drift cut down to south. Pilot cut ~100m long. Presently coaling beneath fence corner at NW end of Cut 4.

SECTION 233 - MOWN MEADOWS - 4.

Rough log - NW end of cut 4, below fence corner. - SE wall

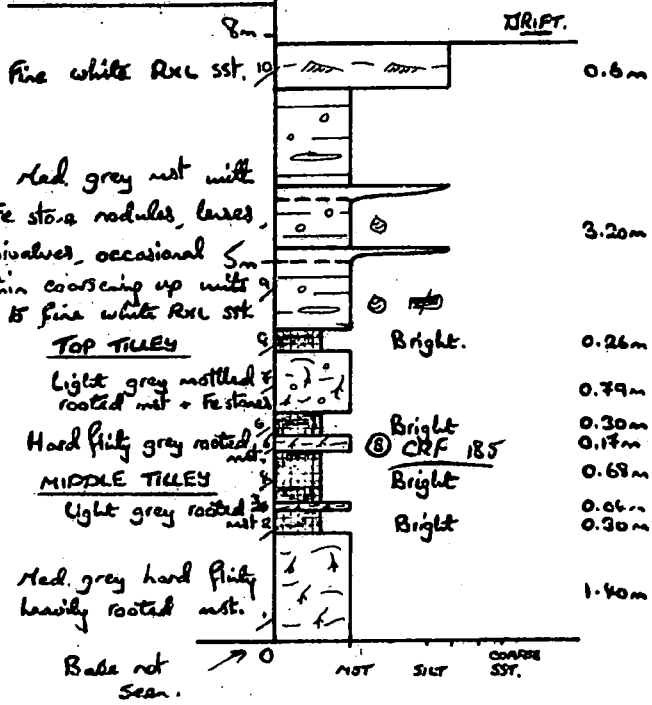


See also Section 234 - NW wall

C.R. FIELDING 24.9.80.

SECTION 234 - HOWN MEADOWS 4.

Western wall - below fence corner - Cut 4.



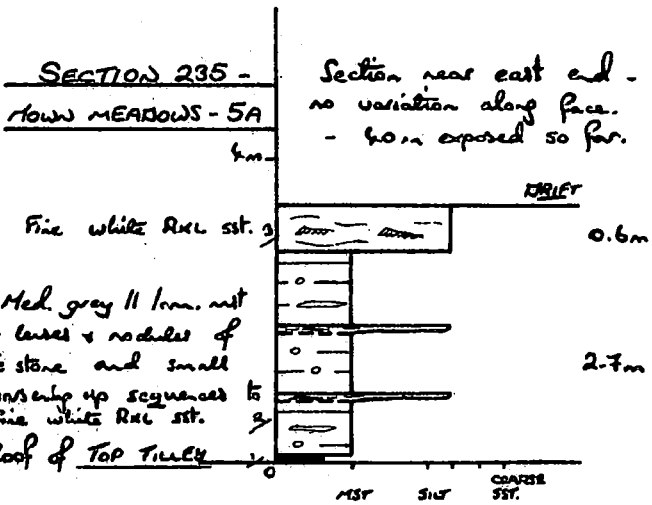
- presently reducing to Bottom Tilley.

Lateral continuity of units difficult to assess due to heavy old workings, but thin sst & sst/Festone bands appear to fade away laterally, in some cases. - uppermost unit more continuous and uniform, though the top is possibly truncated by drift.

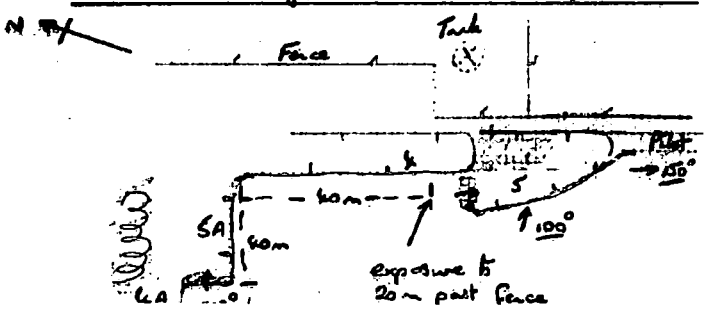
Cut 5A trends → 012° - only roof of Top Tilley presently exposed.

SECTION 235 - HOWN MEADOWS - 5A

Section near east end - no variation along face. - 4.0m exposed so far.

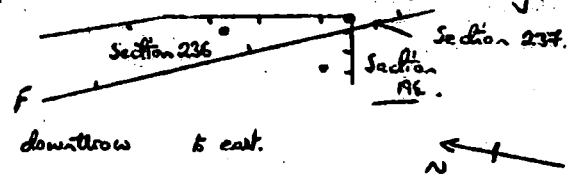


Considerable slumping due to old workings.



CABIN HOUSE

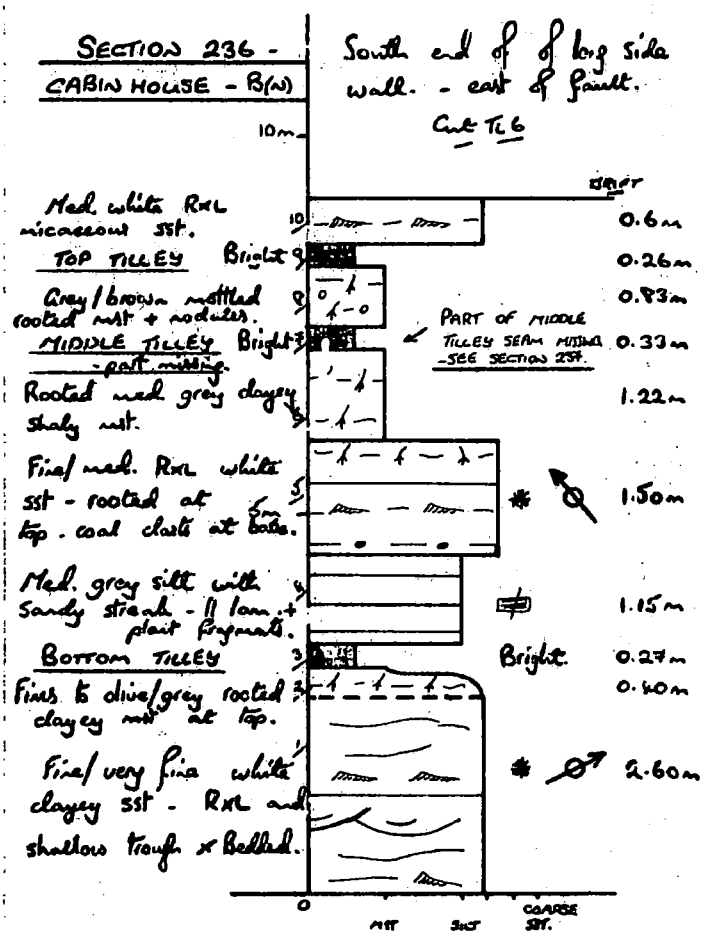
NB Section 194 Area B(N) - Bottom Bunty thickness is 0.82m. Now cooked out at south and presently dragging 4.0m to north, 20m south of corner. Sidewall ~ 10m further east than on last visit. - Trends → 334°. New clearance exposes course of a fault - runs diagonally across the cut, bringing down the Tilleys to the east - this makes part of Section 194 inaccurate, and alters the seam names along the face for the past two visits. "1P00" is Bottom Tilley.



Fault trends → 320°.

SECTION 236 - CABIN HOUSE - B(N)

South end of long side wall. - east of fault. Cut 7 & 6



* DIRECTIONAL DATA :-

Unit 5 - Ripple cross-lamination → Θ = 318°
335°, 307°, 312° ∧ = 3. ℓ = 98%

Unit 1 - Ripple cross lamination → Θ = 051°
349°, 354°, 107°, 083°, 072° ∧ = 5. ℓ = 68%

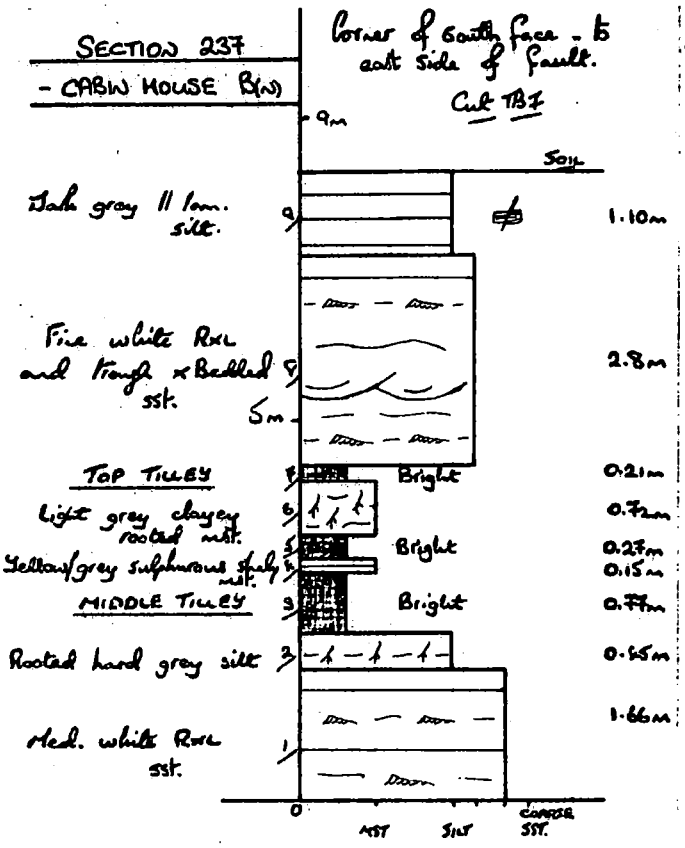
Unit 1 - Shallow trough x set.
(0.1m) → 070° ∧ = 1. Θ = 070°

24.9.80 C.R. FIELDING

SECTION 237 - CABIN HOUSE B(N)

Corner of South face - to east side of fault.

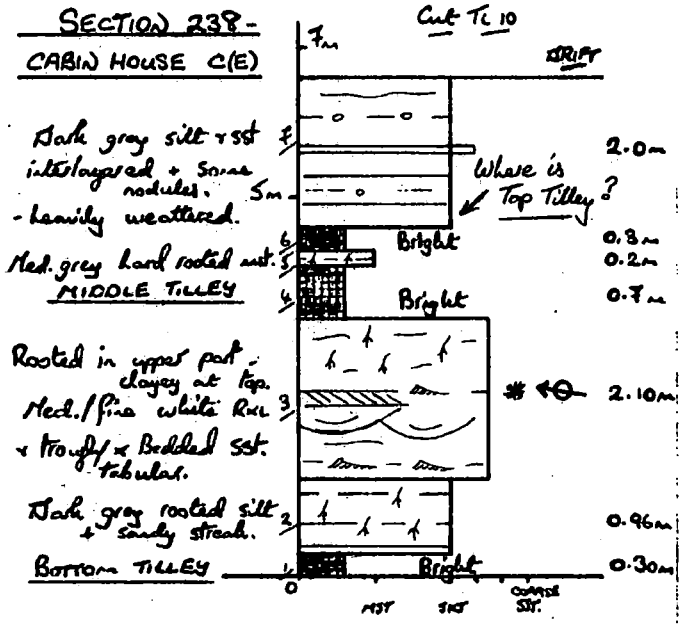
Cut TB7



Full exposure of Middle Tilley - not reduced by old workings. NB Area B(S) - platform on Middle Tilley from former visit still present - shortly to be bulldozed.

SECTION 238 - CABIN HOUSE C(E)

Cut Tc 10



* DIRECTIONAL DATA :-

Unit 3 - Ripple x lamination → 301°

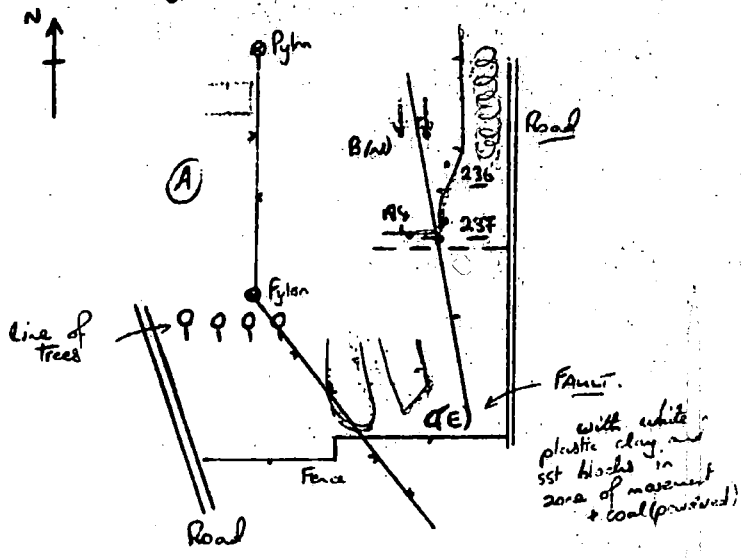
Unit 3 - Small Tabular x sets → 309°, 267° ∴ = 288°.

Overall - Θ = 293° ℓ = 95%

Section at NW end of cut.

Cut trends → 127°.

Plan of workings - 24.9.80.



Area A - One Brockwell cut on from last visit - now only 20m from northern pylon. + BTQ - still dragging - inaccessible.

Area B(N) - on same cut as last time - more coal taken - dragging from north of S. wall - shortly before long wall corner. Fault crossing cut brings down Tilleys to East - naming of seams in previous sections is wrong - and Section 194 is in part inaccurate. Side wall now more or less sheer.

Area B(S) - platform of previous visit on Middle Tilley still present - shortly to be removed.

Area C(W) - as per last visit.

Area C(E) - One cut further on Middle / Bottom Tilley workings - remains of previous cut presently being tipped in.

Line of pylons trends → 163°. At pylon immediately to north of line of trees - change of direction to ~ 110°.

Measures over Brockwell - ~ 6m 11 lam. mixed grey silts - sst above probably cut out by drift. Little lateral or vertical variability visible. + BTQ

No samples or photos. Some day.

NB Cabin House - Sections affected by fault - now corrected :-

173, 174, 175 - 1.8.80.

194 - 27.8.80

201, 202, 203 - 28.8.80.

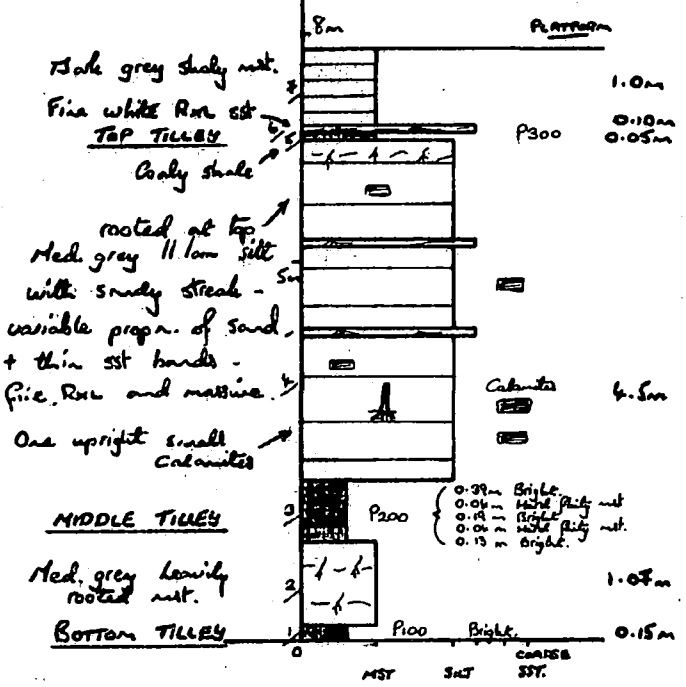
Long Section.

Correct Sections - 236/7.

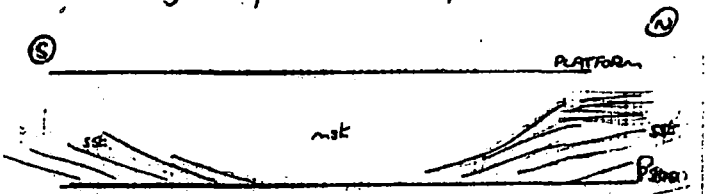
C.R. FIELDING 25.9.80

SECTION 239 - ROWLEY A10(W)

65m north of midwall. (End of slumping).

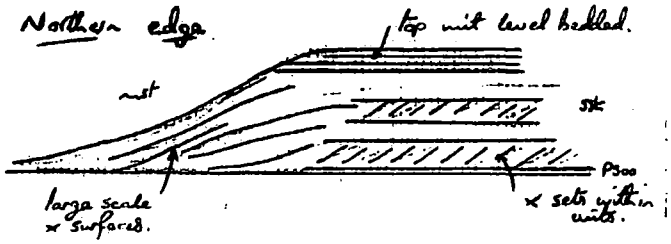


At this point, progressing to north, the Top Tilley Post wedges out more or less completely - place taken by dark grey shaly mstk. comes back in 55m along face. Possible channel bedding at margins of sst - 3 plates.



P300 present throughout as thin coaly shale.

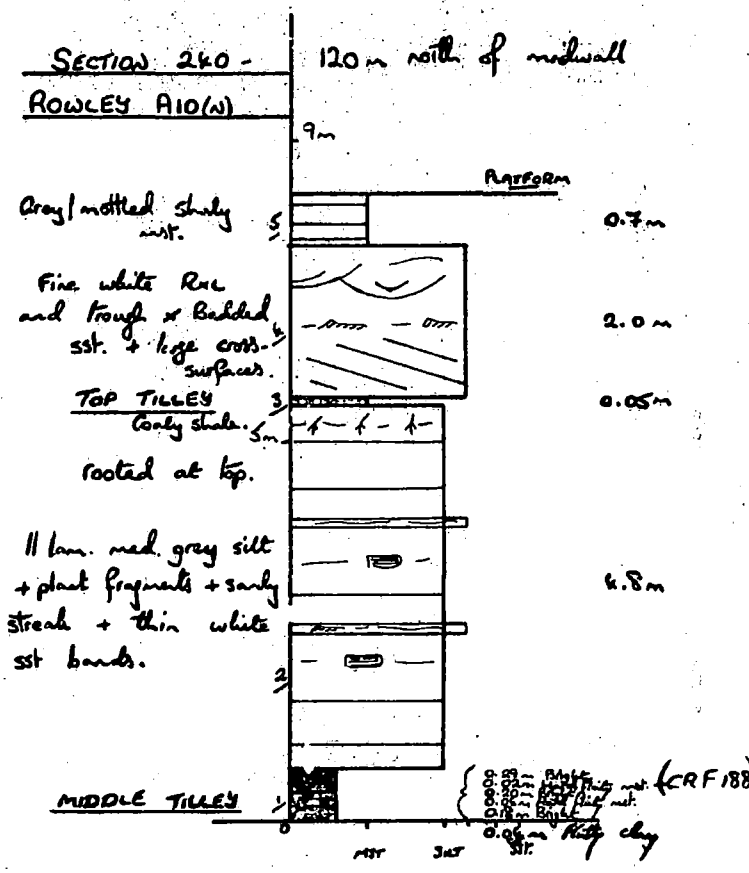
Facies otherwise very consistent along face to north - thin fine sst bands traceable to north
At 120m north of midwall, sst coming back in.



Further ~60m exposure in total 180m - dragline still working - facies display no variation in character or thickness along the rest of the face. Little x bedding or warping visible in FP - sst bands in silt unit laterally persistent. Washouts ?. Above platform - mostly ~2m of silts & mstk + some sst horizons (some discontinuous), thin trace of coal below

SECTION 240 - ROWLEY A10(W)

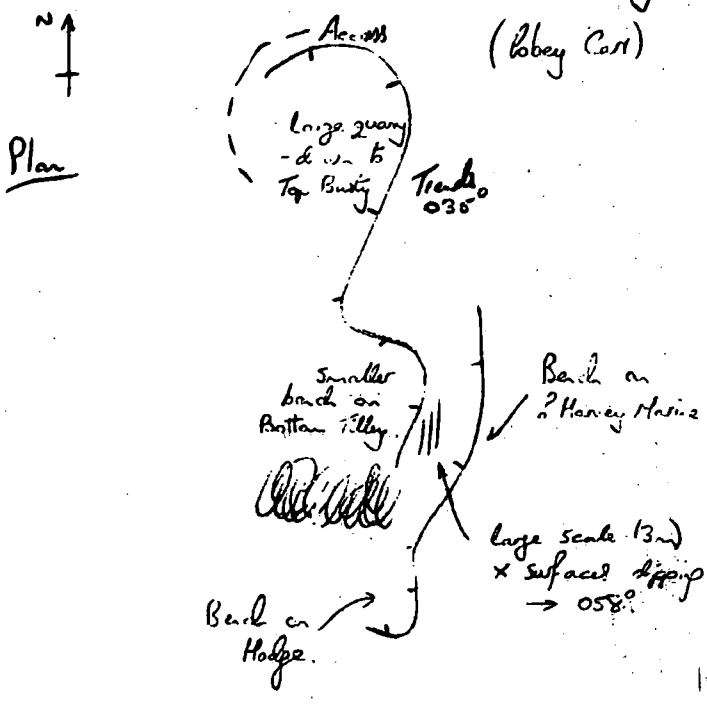
120m north of midwall



C.R. FIELDING - 26.9.80.

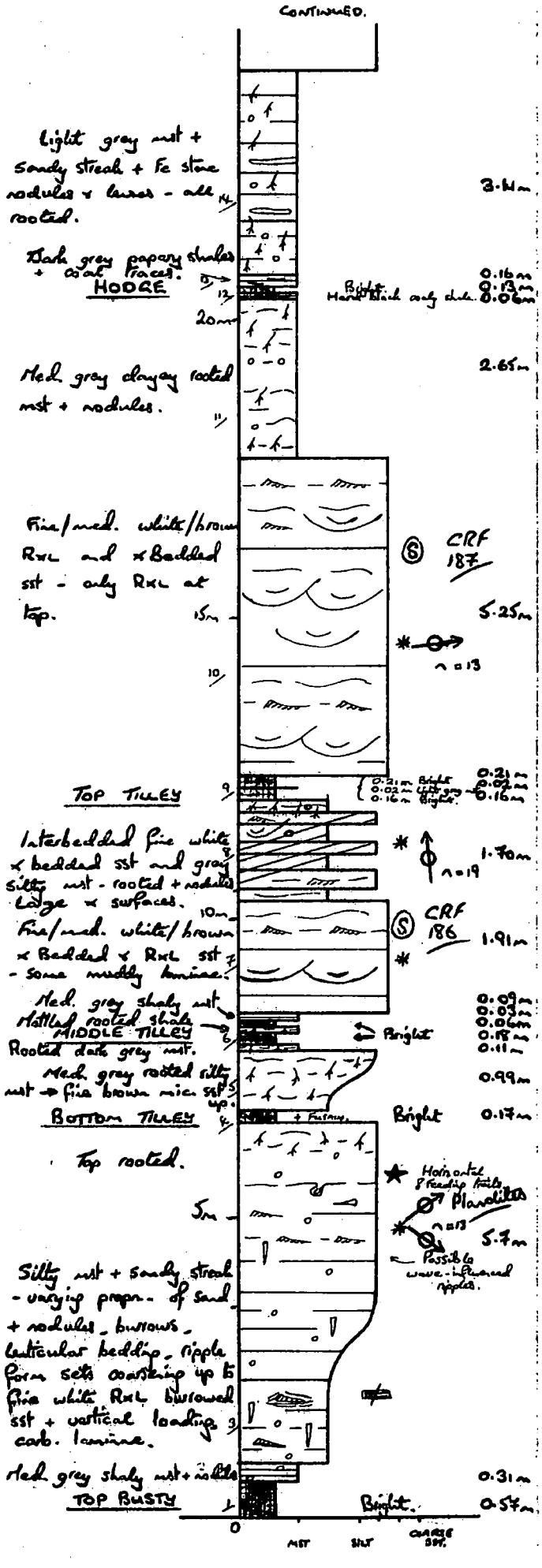
Toshills Quarry (Tobey Cast)

Plan



Composite section - 241 - over - not complete on this visit.
Total section Top Busty → Harvey Marine +.

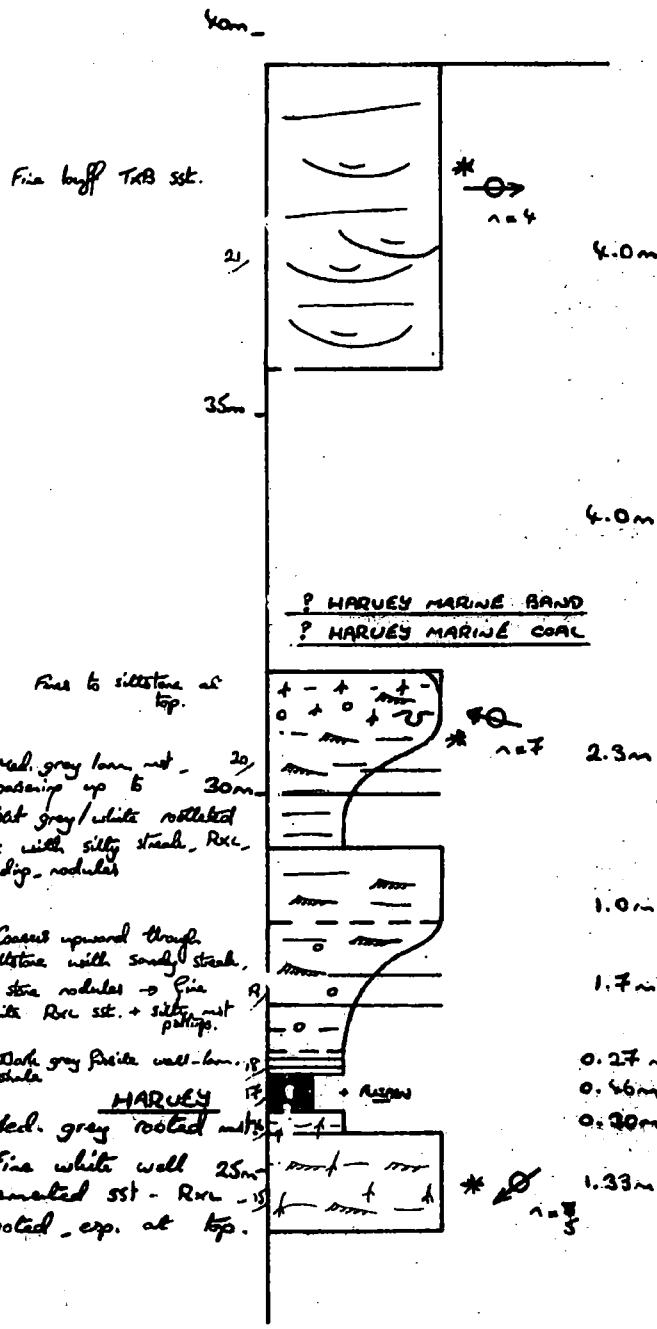
CRF 26.9.80 & 12.5.82.



NB Unit A contains a 30m wide, 1m high channel cross-section, further to the south - inaccessible.

SECTION 241
COBEY CARR QUARRY.

Composite section.

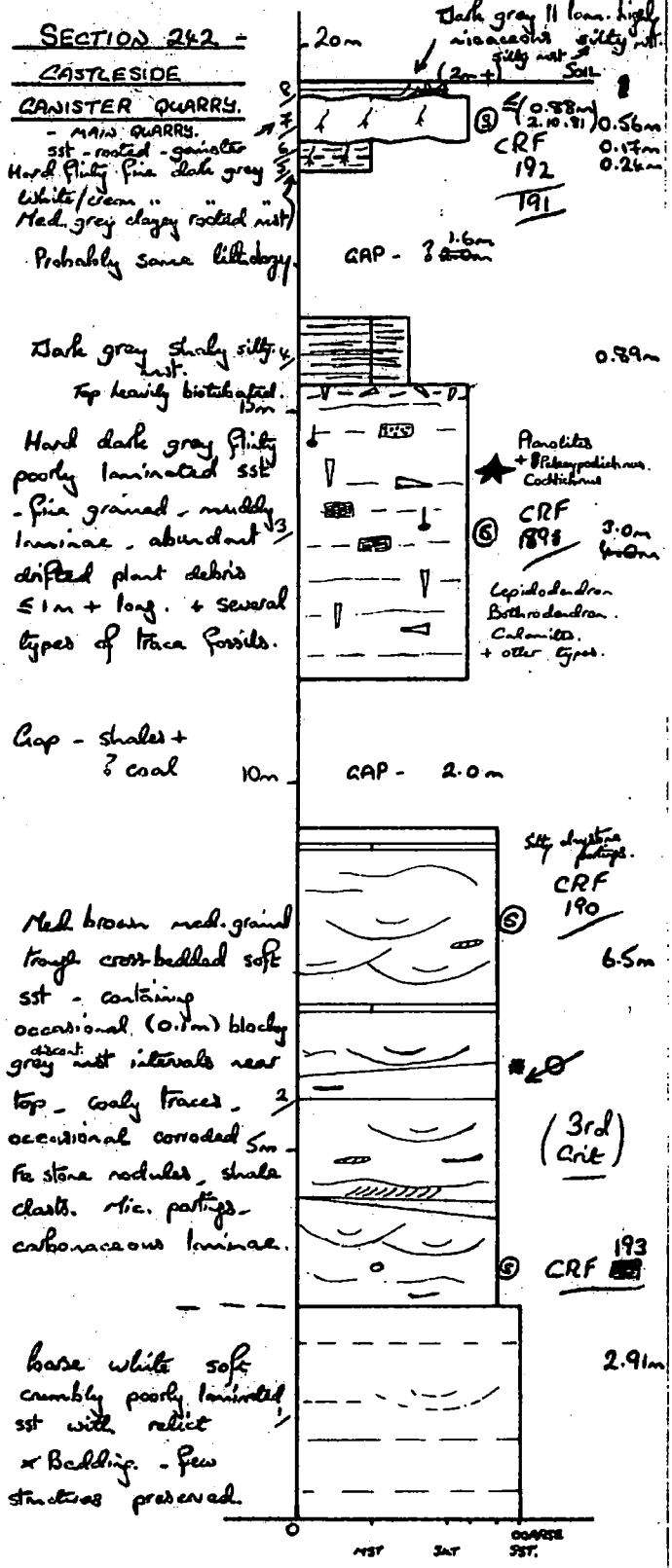


C.R. FIELDING - 14.10.80

Corrections made - 2.10.81.

= BESSY'S BANK QUARRY

SECTION 242 - CASTLESIDE CANISTER QUARRY. - MAIN QUARRY.



* DIRECTIONAL DATA :- Unit 2 - Trough

x Bedding - n = 23

0.4/16/258 _ 0.4/12/228 _ 0.26/10/288 _ 0.5/16/245 _
0.5/6/252 _ 0.2/13/230 _ 0.6/14/267 _ 0.7/8/210 _
0.3/12/235 _ 0.8/6/211 _ 0.5/10/199 _ 0.2/12/268 _
0.15/10/246 _ 0.15/10/229 _ 0.3/12/237 _ 0.3/12/252 _
0.1/8/240 _ 0.1/10/243 _ 0.3/9/230 _ 0.2/9/244 _
0.1/12/267 _ 0.2/14/245 _ 0.15/12/263.

Θ = 242° ℓ = 94% n = 23.

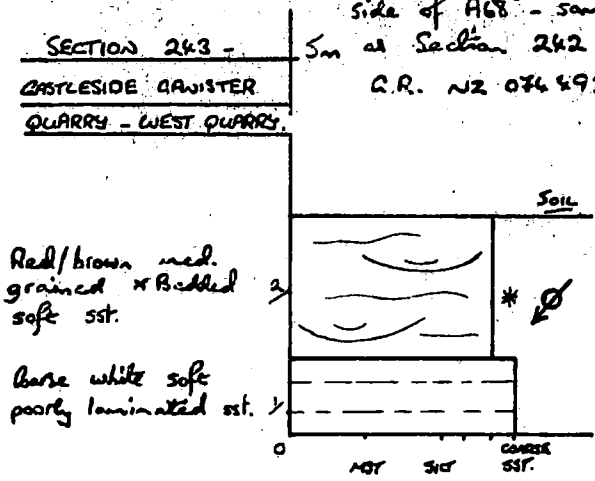
C.R. of main quarry = 076 495 (NZ)

Face trends → 050°.

Section 242 is composite.

SECTION 243 - CASTLESIDE CANISTER QUARRY - WEST QUARRY.

Small quarry on west side of A68 - same levels as Section 242 - C.R. NZ 074 493.

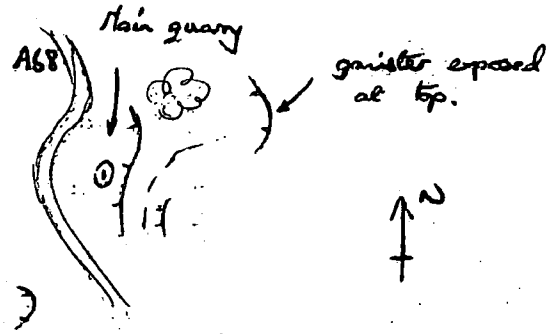


* DIRECTIONAL DATA :- Unit 1 - Trough

x Bedding - 0.2 m/12/231. n = 1.

NB Junction between Units 1 & 2 is at various levels round the quarry - red colouration has moved down into the coarse unit.

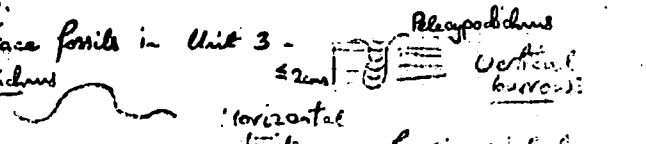
PLAN OF QUARRIES



Notes Tectonic dip negligible - very slightly to east. - doesn't affect x Bedding.

Stratigraphic horizon uncertain - probably "3rd Grit" - between Quarrington & Kayley Lea Mb.

Trace fossils in Unit 3 -



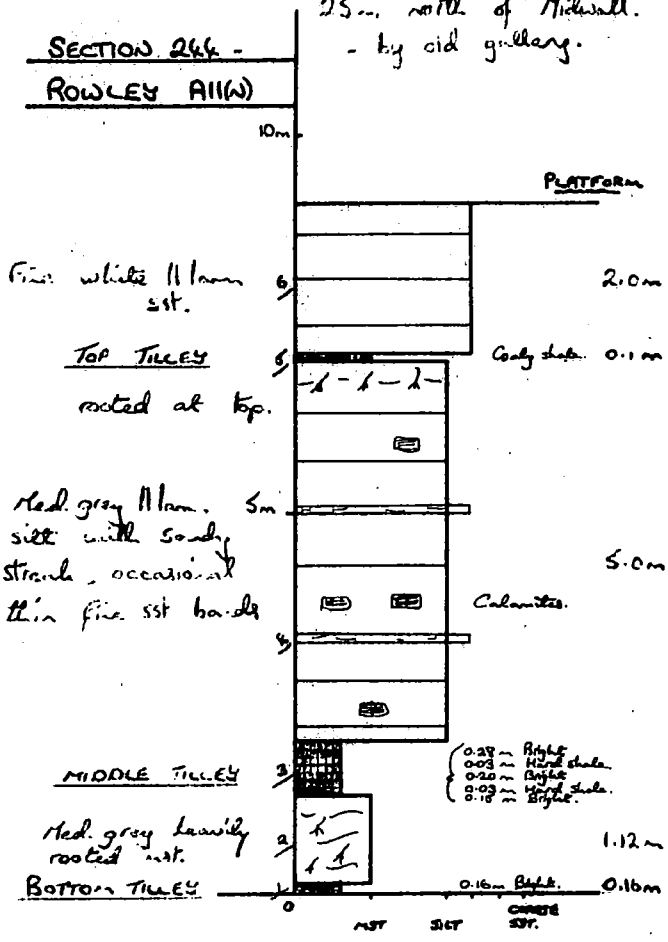
NB Visit to Rowley 30.9.80

- CRF 10.0

C.R. FIELDING - 23.10.80.

SECTION 246 - ROWLEY A11(N)

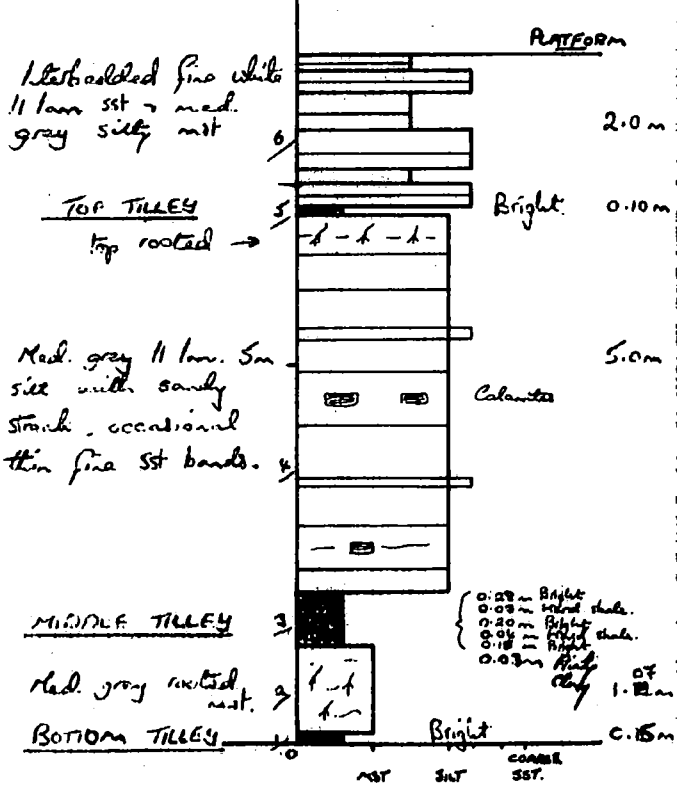
25m north of Midwall. - by old gullery.



Sst bands in silt mst only very occasional. Marked uniformity in facies along face.

SECTION 245 - ROWLEY A11(N)

55m north of mid-wall.



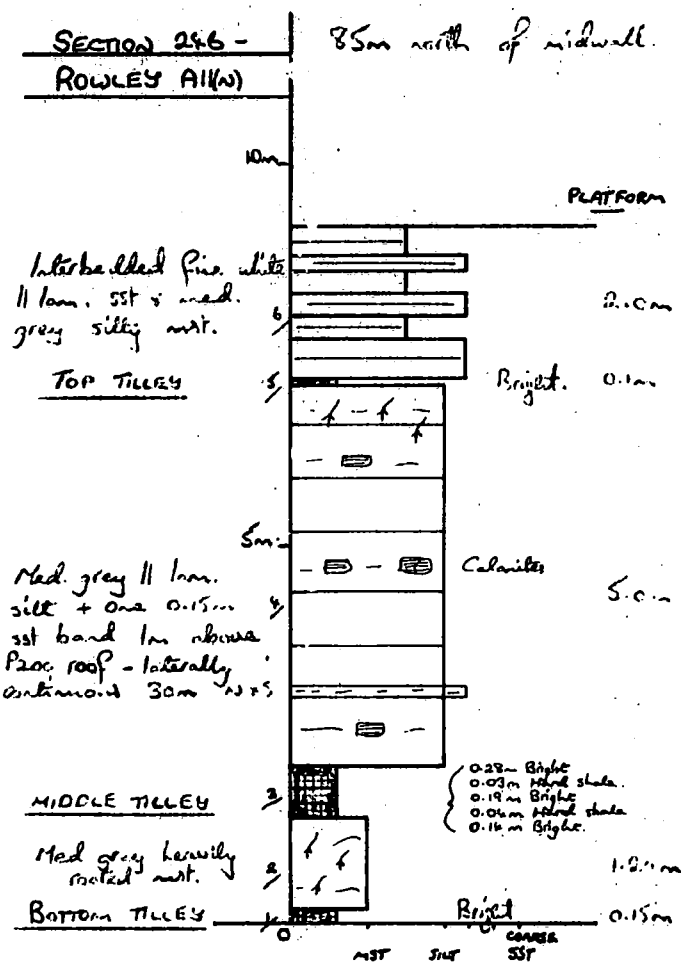
NB Interbedded facies of Top Tilley Post lies over the solid sst to the south - cuts down to the north.

Channel structure in T/T - sst sst mst

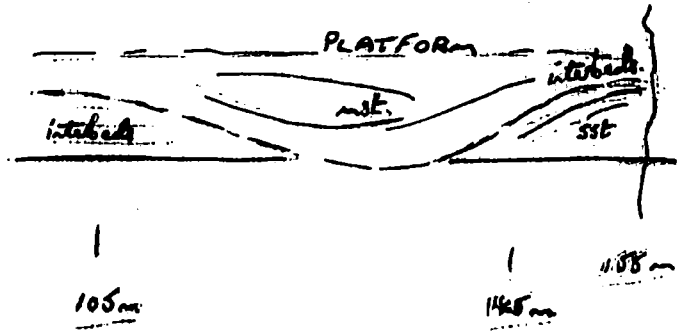
- starts coming down 25m to south - centre 5m to north - interbedded facies continues to north.

SECTION 246 - ROWLEY A11(N)

85m north of midwall.



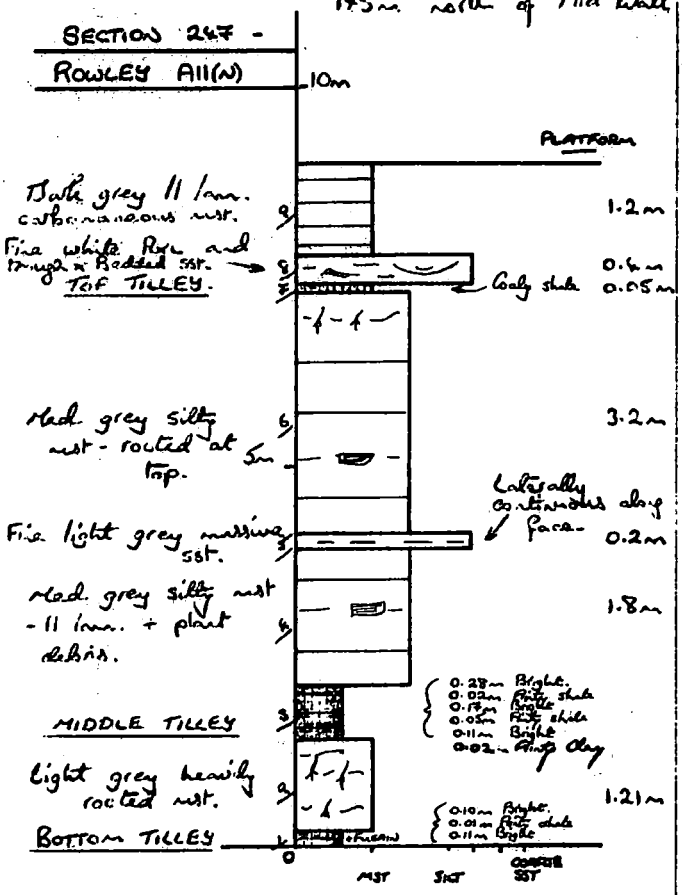
NB Presently - another 20m of exposure down to P10c - then 50m down to P200 - dipping at 15° north. At 105m north - mst cuts down over Top Tilley Post. another shallow channel - continues for 40m to 145m - then solid sst comes back in - in middle of channel - lithology is med. grey mst - no sst or P3oc.



C.R. FIELDING. 28.10.80.

145m north of Mid Wall

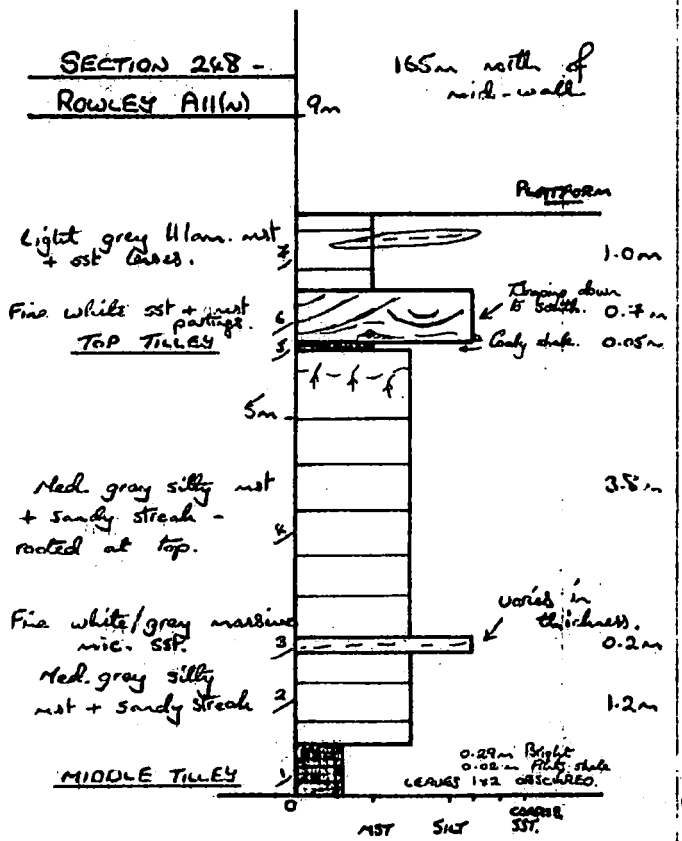
SECTION 247 - ROWLEY A11(N)



Top Tilley Post coming back in after 2nd washout. At this point TTP sst has only very thin mst laminae - to north thicker mst partings develop within the sst. Draping effect (down to south) in sst apparent for another 20m to north. 160m north - proximal step onto P200.

165m north of mid-wall

SECTION 248 - ROWLEY A11(N)



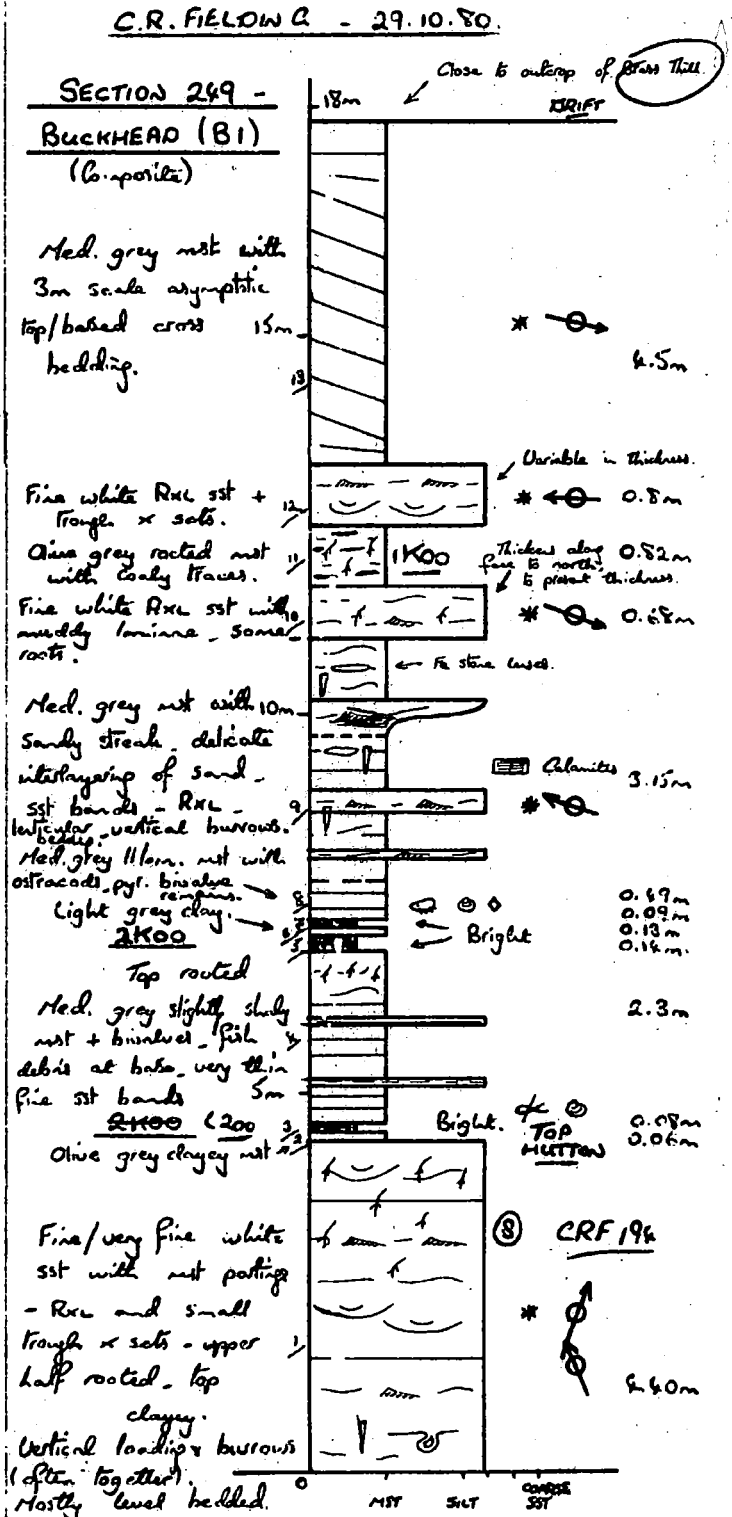
NB Unit 3 though laterally variable in thickness is continuous along the face. Units 2 & 4 contain very thin fine laterally discontinuous sst bands along the face.

Section continues for another 30m then pilot cut 30-40m to end of cut - facies very uniform along the face - thin sst unit laterally continuous. P300 grades into coal - TTP becomes 2m solid sst overlain by 1m med. grey silty mst + lenses of fine white sst

2 colour slides taken.

C.R. FIELDING - 29.10.80.

SECTION 249 - BUCKHEAD (B1) (Composite)



* TIDAL INFLUENCE

C.R. FIELDING - 29.10.80.

* DIRECTIONAL DATA - SECTION 249.

Units 9-13 Overall $\theta = 359°$ $\iota = 23\%$

Unit 13 - 3m asymptotic topped / based cross-sets - → 112° ^ = 1

Unit 12 - trough x sets 0.6m↑ → 265°, 287°, ^ = 2 $\theta = 276°$

Unit 10 - ripple x lamination → 140°, 165°, 087°, 112°. ^ = 4. $\theta = 121°$ $\iota = 92\%$

Unit 9 - ripple x lamination → 330°, 307°, 117°, 320°, 351°. ^ = 5. $\theta = 336°$ $\iota = 60\%$

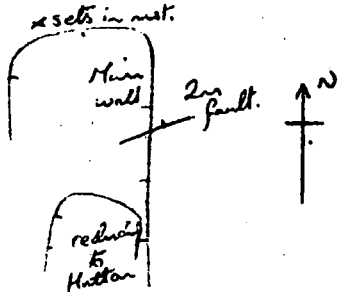
Unit 1 Overall $\theta = 023°$ $\iota = 89\%$

Unit 1 - ripple x lamination → 020°, 065°, 017°, 360°, 030°, 052°. ^ = 6 $\theta = 031°$ $\iota = 93\%$

Unit 1 - trough x set - 0.1m / 22 / 335°.

OVERALL $\theta = 016°$ ^ = 1 $\iota = 46\%$

Buckhead Area B - Cut 1 PLAN



Under bottom of section, ~2m mst down to Hutton, exposed as pillars in bottom of cut. Top sst variable in thickness along face - no muddy laminae (sst beneath contains muddy partings) / colour slide taken. Some of the thin fine sst bands are laterally persistent

Area C - still excavating to Low Main.

Area H - presently digging new cut to Main & Maudlin.

Afternoon - Deborah

- Site progress -

Area Niii - Cuts 10_19_21

Busty.

Niv 41_40 - Top Tilley.

Nv 6 - Tilley 8

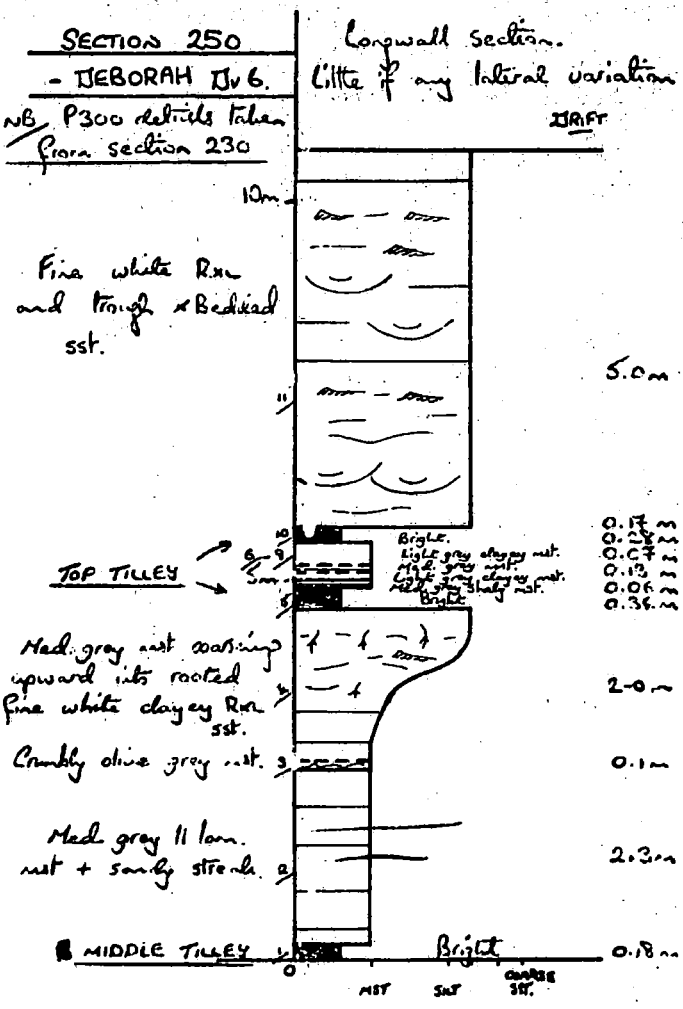
Niv 5 - Tilley 8

8 - Harvey

SECTION 250 - DEBORAH Nv 6.

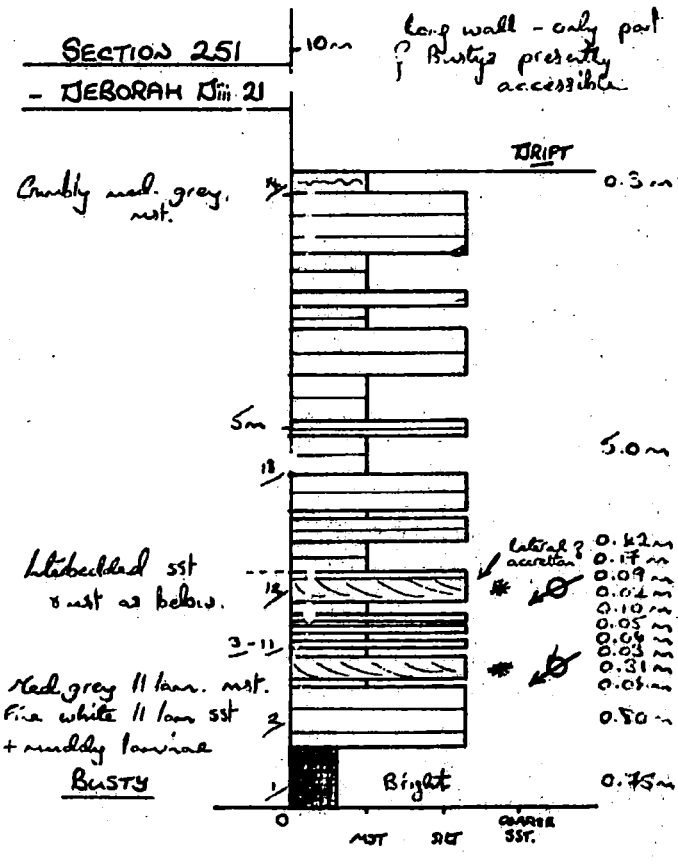
NB P300 details taken from section 230

Longwall section. Little if any lateral variation



SECTION 251 - DEBORAH Niii 21

Long wall - only part of Busty presently accessible



* DIRECTIONAL DATA.

Unit 12 - trough x set 0.3m / → 232°. ^ = 1

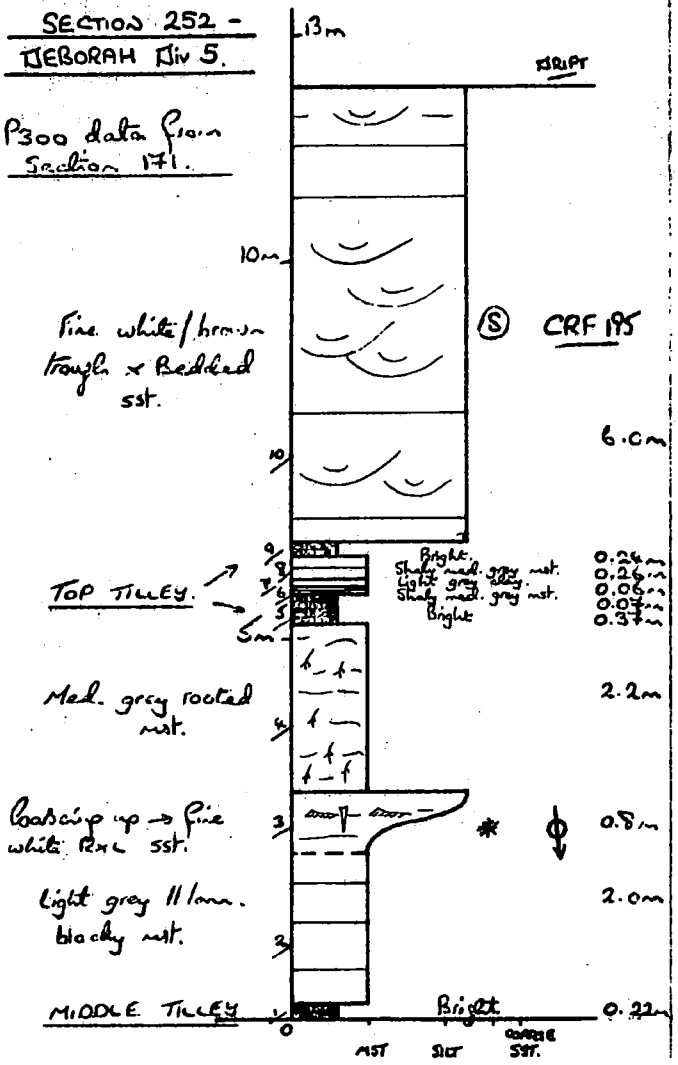
Unit 4 - trough x set 0.3m / → 224. ^ = 1.

No consistent direction of thickening or thinning - some

C.R. FIELDING - 29.10.80.

SECTION 252 - DEBORAH DIV 5.

P300 data from Section 171.

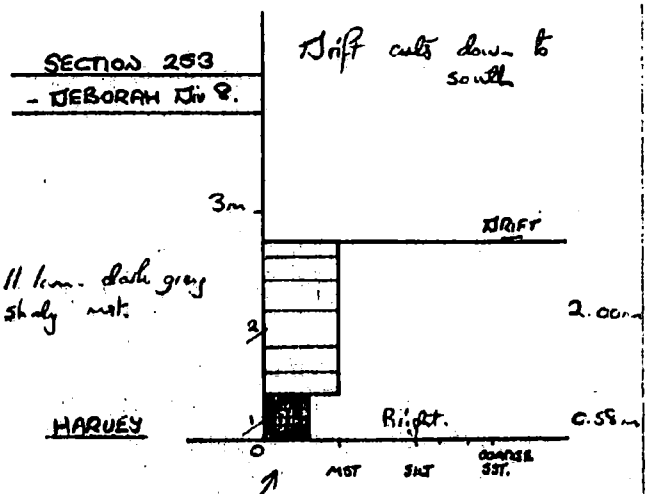


* DIRECTIONAL DATA :-

Unit 3 - RxL → 184°, 159°. n = 2.

NB Coarsing upward sequence is not readily apparent in outcrop. 1 colour photo taken. Cut trends → 200° - N. end at fault with 32m displacement - Busty brought up to north - fault ll to pylons - 20m to east.

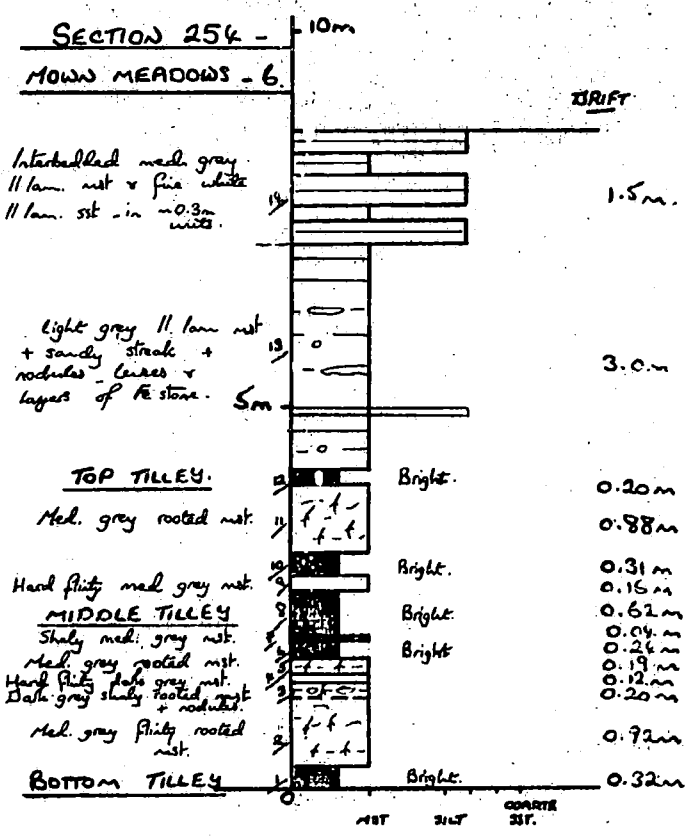
SECTION 253 - DEBORAH DIV 8.



Bottom half obscured - 0.17m thick - separated by 0.10m mst parting.

C.R. FIELDING - 4.11.80.

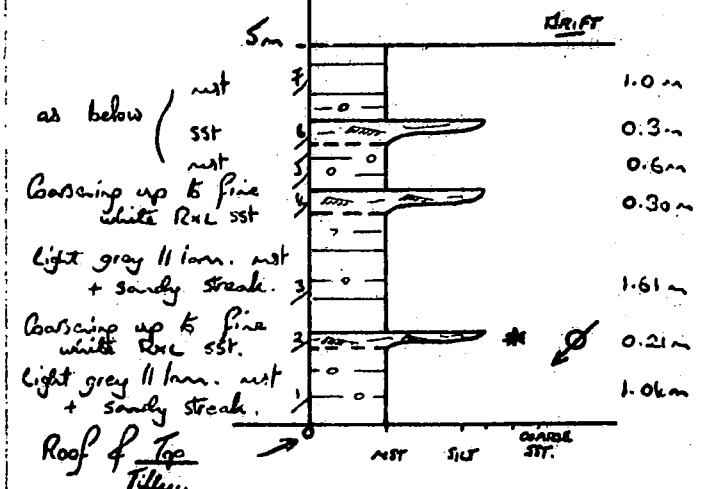
SECTION 254 - MOWN MEADOWS - 6.



Cut 6 long wall - half wall along - trends → 095°. Considerable disturbance due to pillaring. Little lateral visible variation - Cut trends diagonally away from the fence.

Nears corner with Cut 6.

SECTION 255 - MOWN MEADOWS - 7A



* DIRECTIONAL DATA :-

Unit 2 - ripple x lamination → 230°, 251°, 213°, 228°. n = 4. Θ = 230° L = 97%

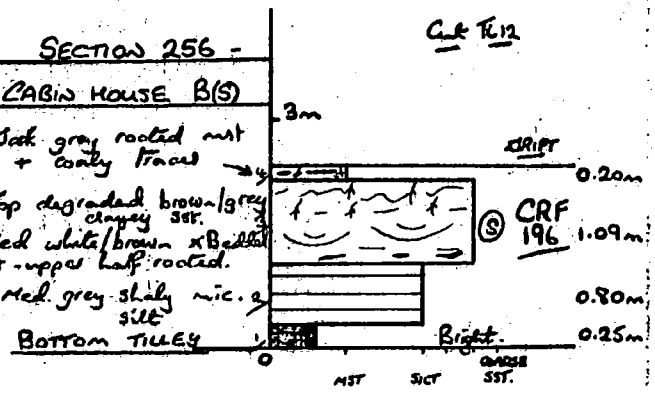
NB Facies laterally persistent over 10m of exposure.

No samples - 1 colour slide.

C.R. FIELDING - 4.11.80.

SECTION 256 - CABIN HOUSE B(S)

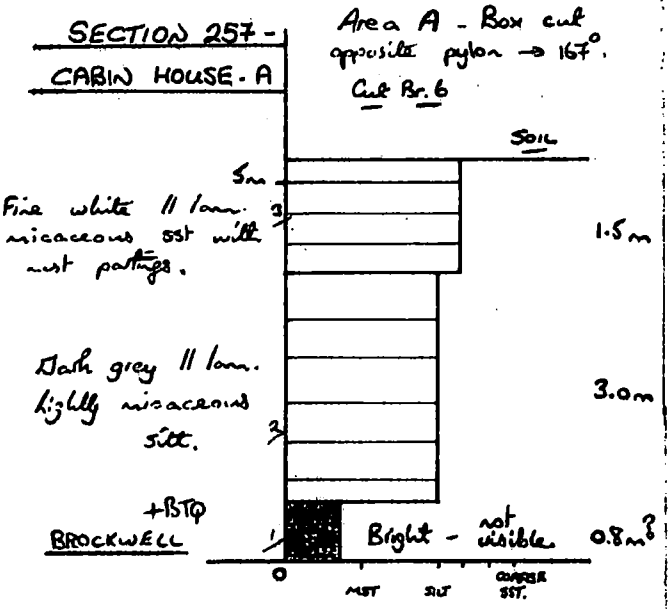
Cut Tr.12



Shallow bank cut tr.dip 164° - NB On south side of fault. Pillared exposure of basal coal. Little lateral variation along face - directional measurements not possible - crudely outcrop.

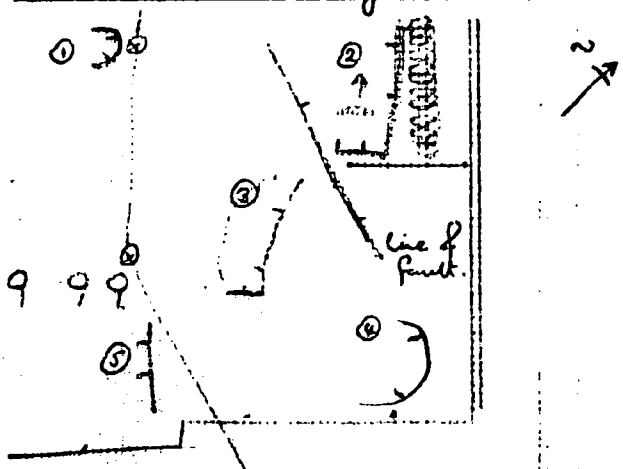
SECTION 257 - CABIN HOUSE - A

Area A - Box cut opposite pylon → 167°.
Cut Tr. 6



NB Presently reducing to coal

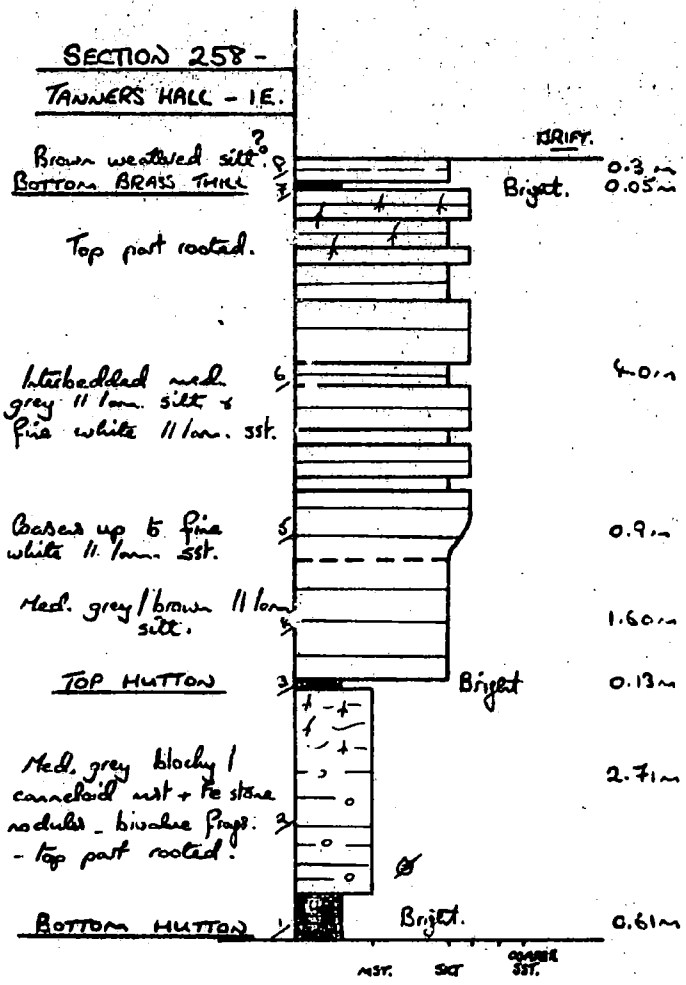
CABIN HOUSE - Workings as at 4.11.80.



① Brockwell cut - under pylon.
② New cut to Tilley? - still reducing.
③ Shallow platform on Bottom Tilley.
④ Outcrop working on ? Top Tilley - former Tilley workings backfilled.
⑤ New cut on Top Bursty - right behind

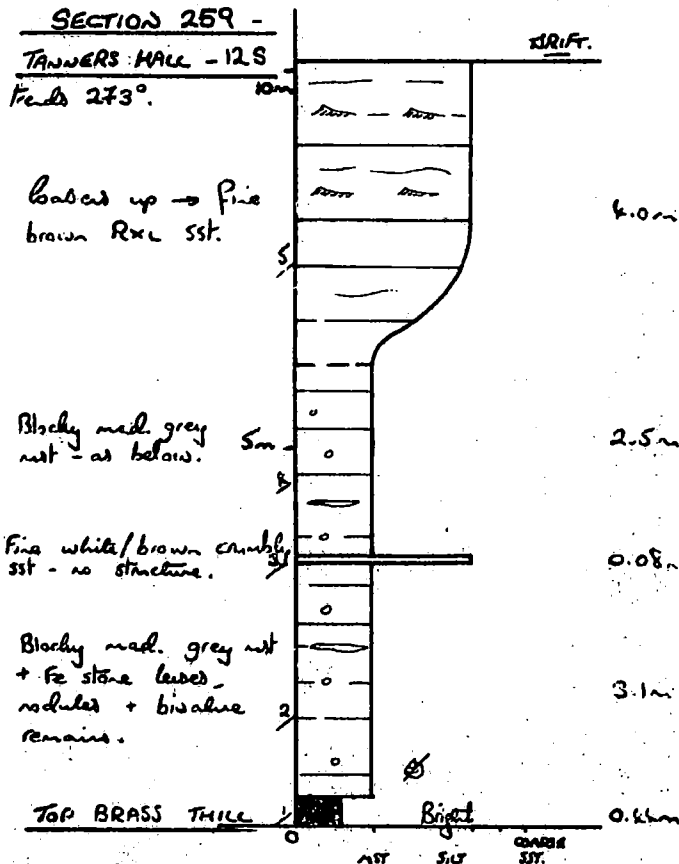
C.R. FIELDING - 5.11.80.

SECTION 258 - TANNERS HALL - I.E.



Roughly ½ way along wall - tr.dip → 170°. Individual sst units and thin bands traceable along the wall up to 50m in both directions. First cut in E. area - due to strike working west.

SECTION 259 - TANNERS HALL - 12S

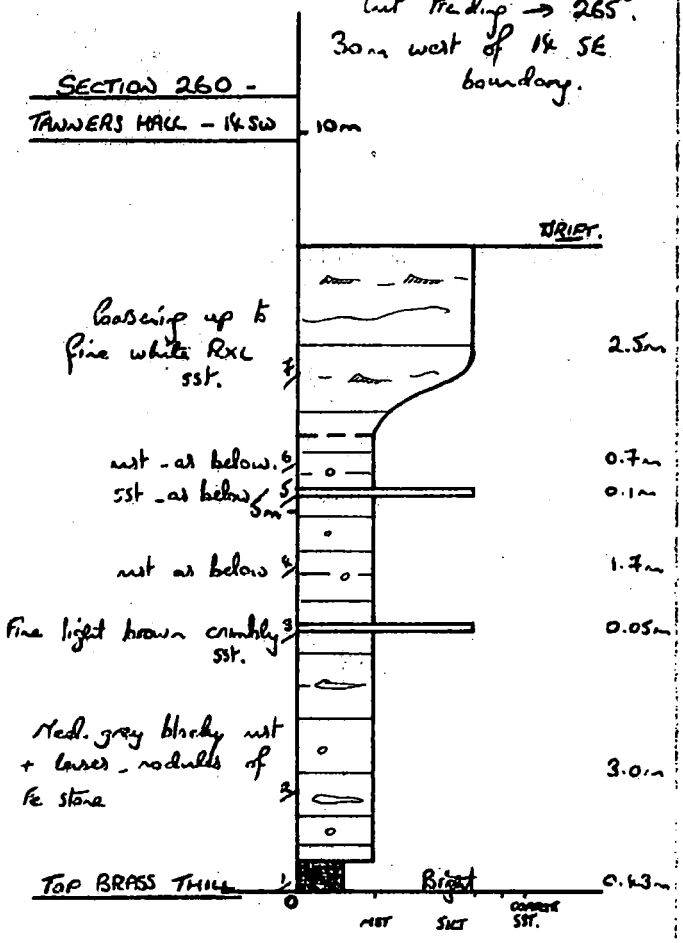


Position 50m west of bounding fault. Another ~30m

C.R. FIELDING 5.11.80.

SECTION 260 - TANNERS HALL - 14 SW

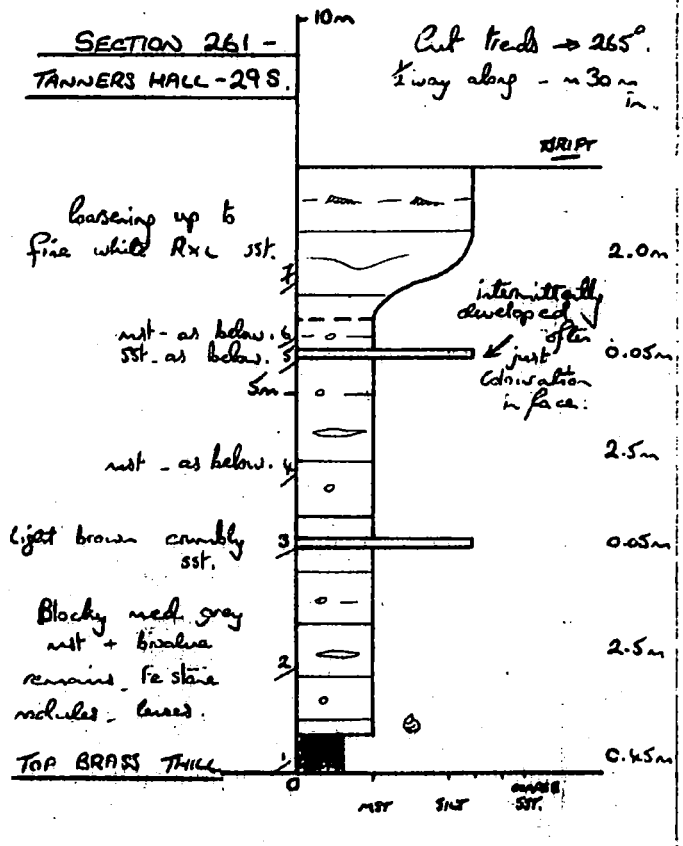
Cut trending → 265°. 30m west of 14 SE boundary.



NB Second sst only becomes apparent ~10m west of boundary - continues for ~50m to west - but only just present in places.

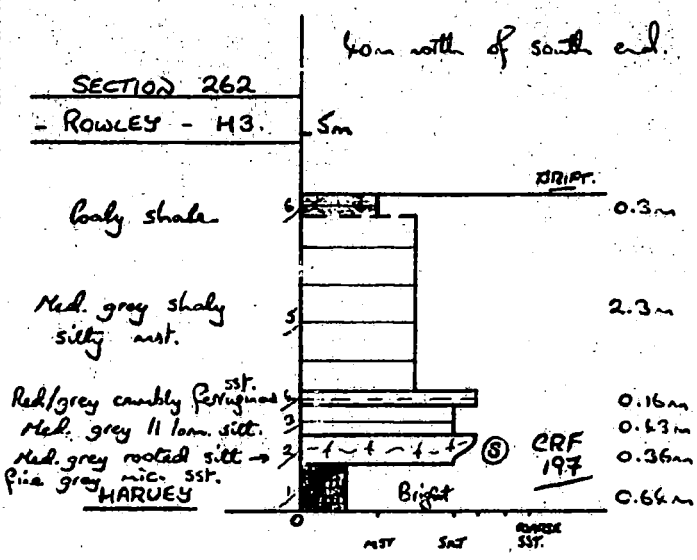
SECTION 261 - TANNERS HALL - 29 S.

Cut trends → 265°. ½ way along - ~30m in.



SECTION 262 - ROWLEY - H3.

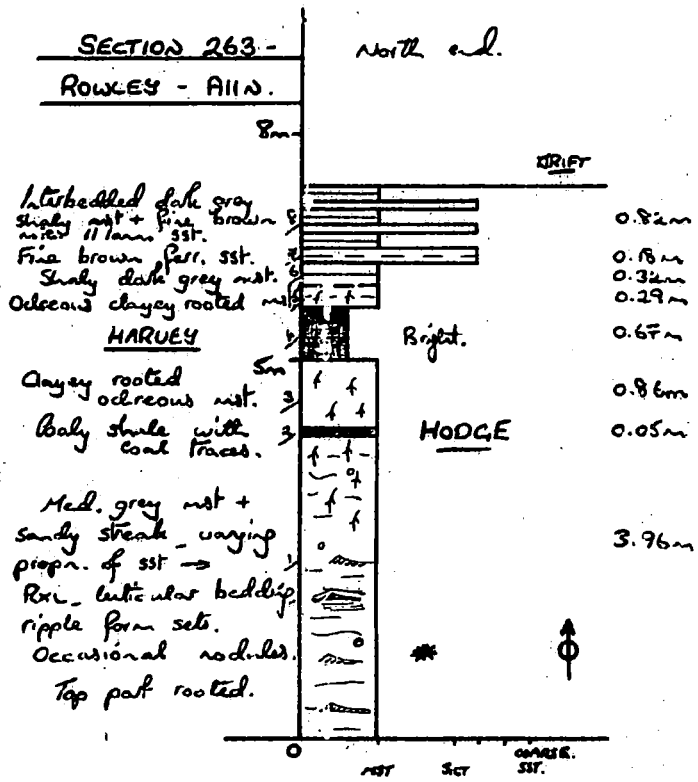
40m north of south end.



Another ~40m exposure to north - presently dragging. Cut will possibly be renumbered 12_ to coincide with the next Tilley cut - A12N now just starting reducing. Lateral variation above Harvey difficult to assess.

SECTION 263 - ROWLEY - A11N.

North end.

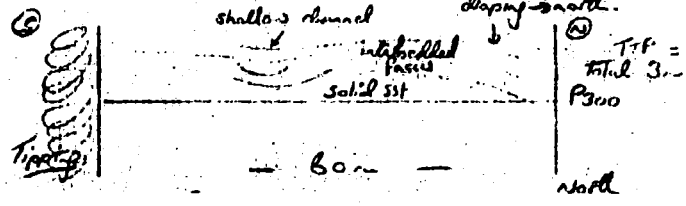


* DIRECTIONAL DATA :-

Unit 1 - RxL → 359° n = 1.

NB Under base of section - Total 3m of white RxL & trough x-bedded sst overlain by interbedded white sst & grey mst = Top Tilley Post.

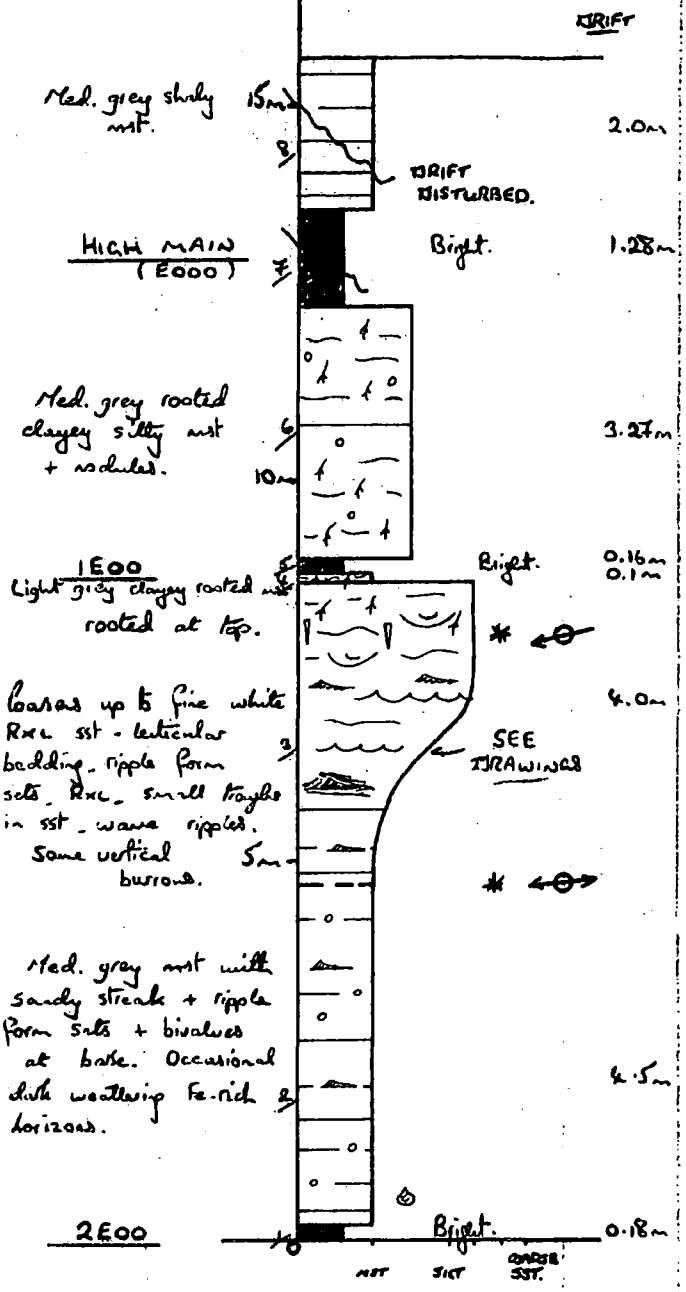
Cut stopped short due to heavy old workings.



C.R. FIELDING - 3.11.80.

SECTION 266 - IBBETSONS (Ex.2/3)

2nd extension - Cut 3. Reducing on various benches.



* DIRECTIONAL DATA:-

Units 2 & 3 - ripple form sets & Rxc →

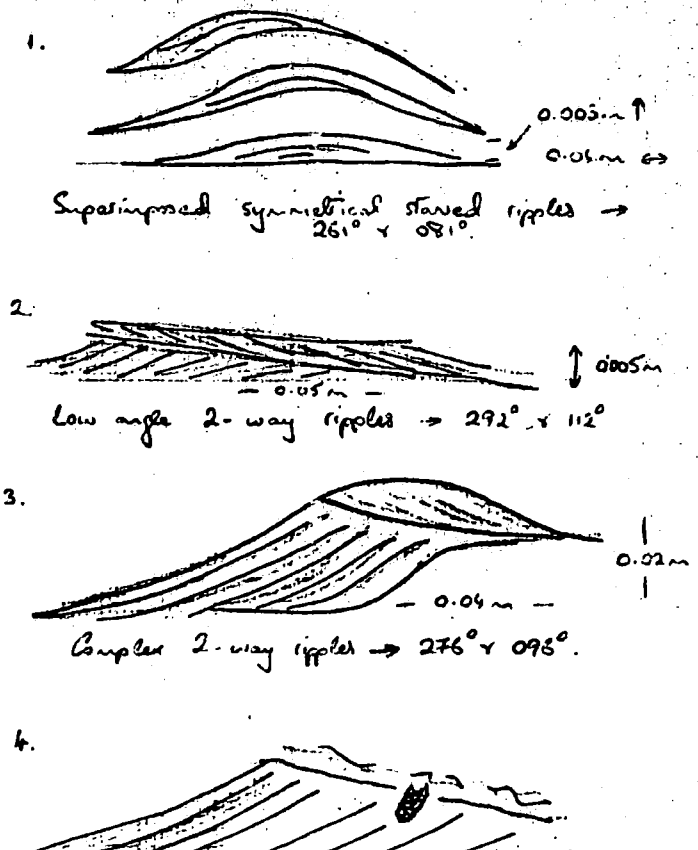
101° 077° 055° 051° 055° 241° 261° 081°
292° 112° 276° 096° n = 12 Θ = 078°/93%
& 280°/98%

Unit 3 - Trough & Bedding
0.1m / 10/ 2Rt n = 1.

Overall Θ = 078°/273°. C = 93% / 95%

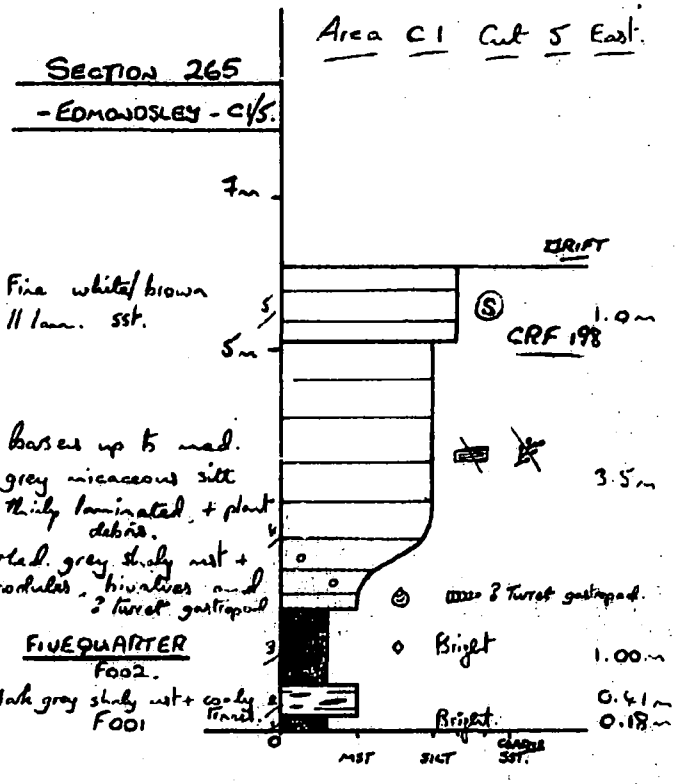
1 colour slide photo. No samples.
Freezewater in cut 2 probably being backfilled.
See drawings of wave ripples.
Little lateral variation visible.

Wave Ripples. - Units 2 & 3 Section 266.



SECTION 265 - EDMONDSLEY - C1/5.

Area C1 Cut 5 East.



1 colour photo. Total ~100m long well exposed.
Little lateral variation - Solid sst coned in at top below drift in places.

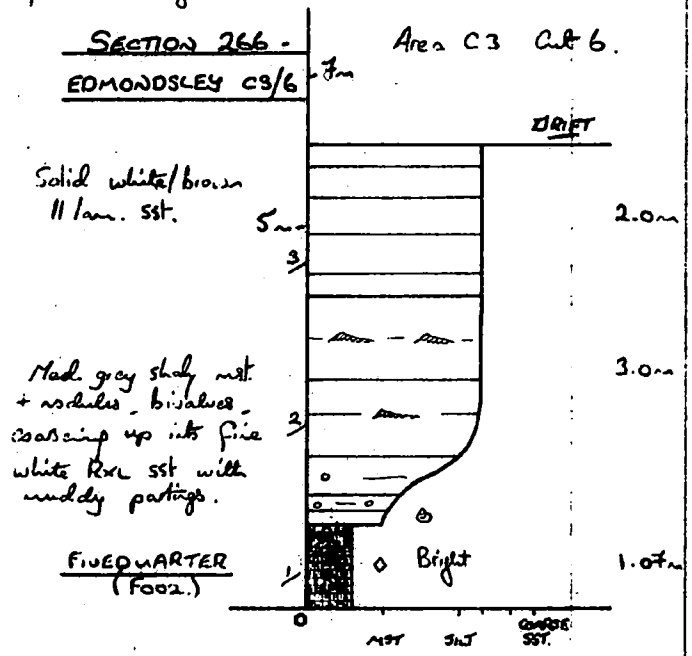
C.R. FIELDING. 13.11.80.

NB Area C subdivided — C1 - middle
C2 - east
C3 - west.

Area C1 cut 5 (west) - Facies very similar to Cut C5 (east) but mst → silt unit above Fivequarter rapidly coarsens into fine white Rxl sst with mst laminae and partings - then solid white/brown fine sst above. Coarsing achieved via thickening of sst beds and more frequent occurrence. Exposure not brilliant due to collapse of old workings.

SECTION 266 - EDMONDSLEY C3/6

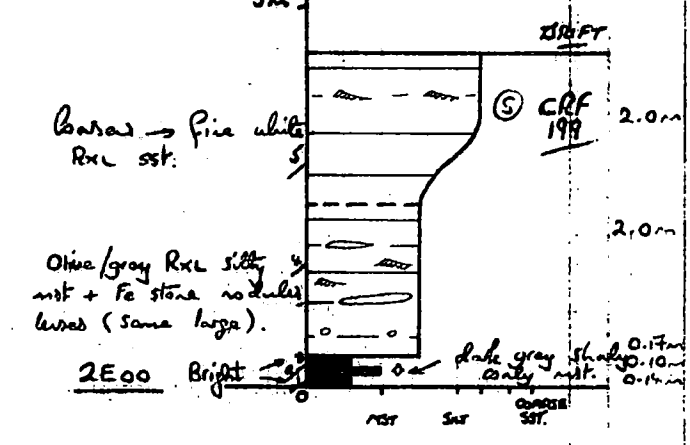
Area C3 Cut 6.



Presently working pillars at west end of cut - some tectonic disturbance also.

SECTION 267 - EDMONDSLEY C2/2

Area C2 Cut 2 - Horseshoe-shaped cut.

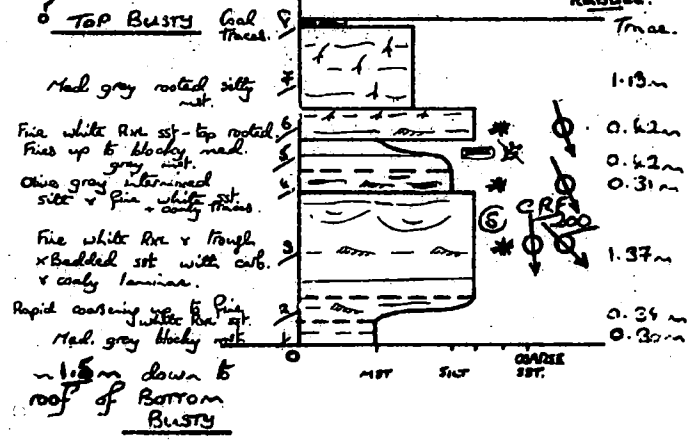


Top level presently working on site - ~20 yds back from S/4 cuts.
Lateral variation not assessable.

C.R. FIELDING - 17.11.80.

Long cut to Bottom Bursty - eastern margin of Area C(W). Cut trends → 320°. North End.

SECTION 268 - CABIN HOUSE C(W) Cut BB7



* DIRECTIONAL DATA :-

Unit 3 - Rxl → 160°, 103°, 085°, 109°, 100°, 150°, 153°, 141°, 123°, 136°, 116°, 161°, 113°. n = 13
Θ = 127° ζ = 91%

Unit 3 - Trough x set 0.3m/15/173° n = 1.

Unit 4 - Rxl → 143°, 155° Θ = 149° n = 2.

Unit 6 - Rxl → 156° n = 1.

Unit 3 Overall - Θ = 130° ζ = 96%

OVERALL - Θ = 136° ζ = 91%

Trough in Unit 3 is ~5m wide - ripple x lamination arranged in tiny cosets within the trough foreset. (Rxl → 113°) Planar erosional top to trough. Little facies variation visible along face.

Rest of site

Area B(N) - little further than last visit, on same cut. Rough section -

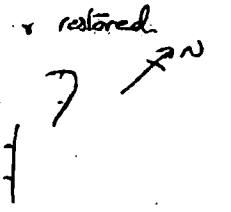
(Middle Tilley)	Mangled coal etc.	2.5m
	sst	1.5m
(Bottom Tilley)	coal	0.3m
	mst	2.0m
	sst	2.5m

not accessible due to dragline working / (slow slide photo.

Area B(S) - same platform on Bottom Tilley as per last visit.

Area C(E) - completely backfilled + restored.

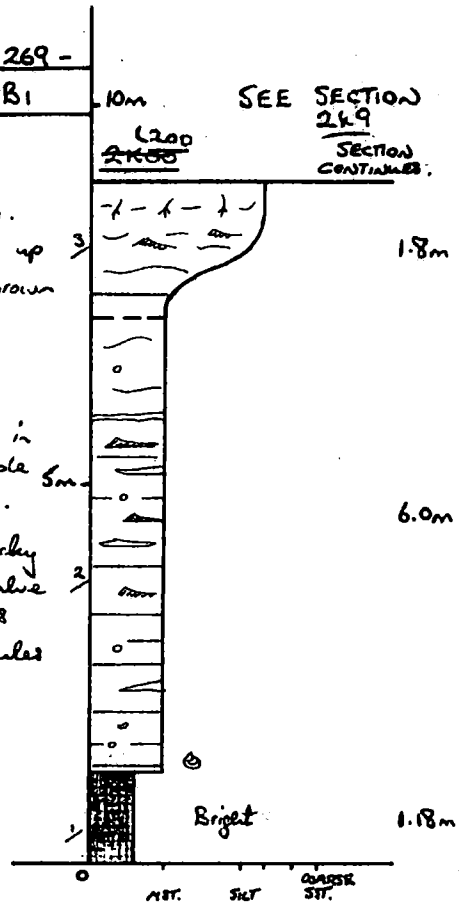
Eastern edge of C(W) -



Small cut not accessible.

C.R. FIELDING - 20.11.80.

SECTION 269 - BUCKHEAD - B1



Same cut as per last visit - measures down to Hutton exposed at south end of cut - NB Section 269 taken half way along → north end of cut. Little lateral variation in facies. 1 colour slide photo.

Matrix is the same light gray fine sst as the unit above. Planar, probably erosive base to the cong., directly over the coal. Maximum clast size 0.08 m typ.

In sst above, some large shale clasts up to 1.0m long.

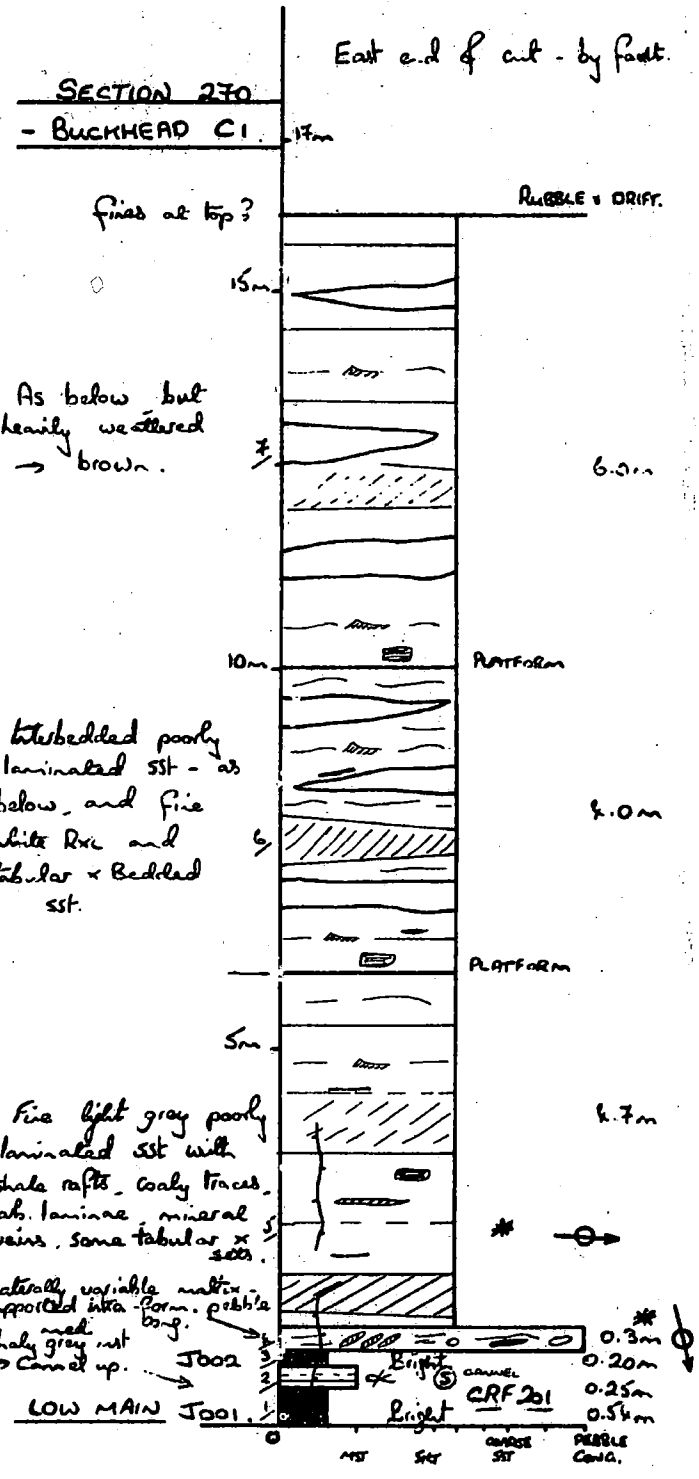
Passing through sst, and down to coal is a development of displacive and replacive mineral veins, containing galena, fluorite, pyrite, marcasite. (S) CRF 202 - source possibly in nearby Carlisle Dyke. = Cleveland Dyke Tertiary!

Presently coaling Low Main at east end by fault. 2 colour slide photos - 1 of conglomerate 1 panorama. Film finished.

Area L - presently stripping drift, and low Main post, working low Main and other Seams - steep dips involved

SECTION 270 - BUCKHEAD C1

East end of cut - by fault.



* DIRECTIONAL DATA :-

Unit 5 - Tabular × Sets - $\theta = \overline{094}°$

1. 0.6m/14/107 2. 0.3m/3/090. $\hat{r} = 2$.
   - both in lowest part of sst.
2. Unit 4 - Pebble Imbrication → 339°
   ⇒ flow toward 159°.

Conglomerate - Matrix supported, ~ 3-5% clasts - fairly well rounded Fe stone, partly rounded sst, angular to subangular shale and peat - elongate clasts imbricated, dipping → 339°, implying flow → 159°. Imbrication is largest axis downward. Max. development 0.3m but not present at all in places, lies directly over coal, had a very abrupt top - matrix

C.R. FIELDING - 20.11.80.

Area H - Cut 1 - Extension. Presently digging extension at NE end of cut to Main and Maudlin - facies as before - little lateral variation - large scale foresets visible over Main.

Main. Bright coal 0.67m
Med. grey clayey rooted mst 0.07m
Bright coal. 1.52m

DIRECTIONAL DATA.

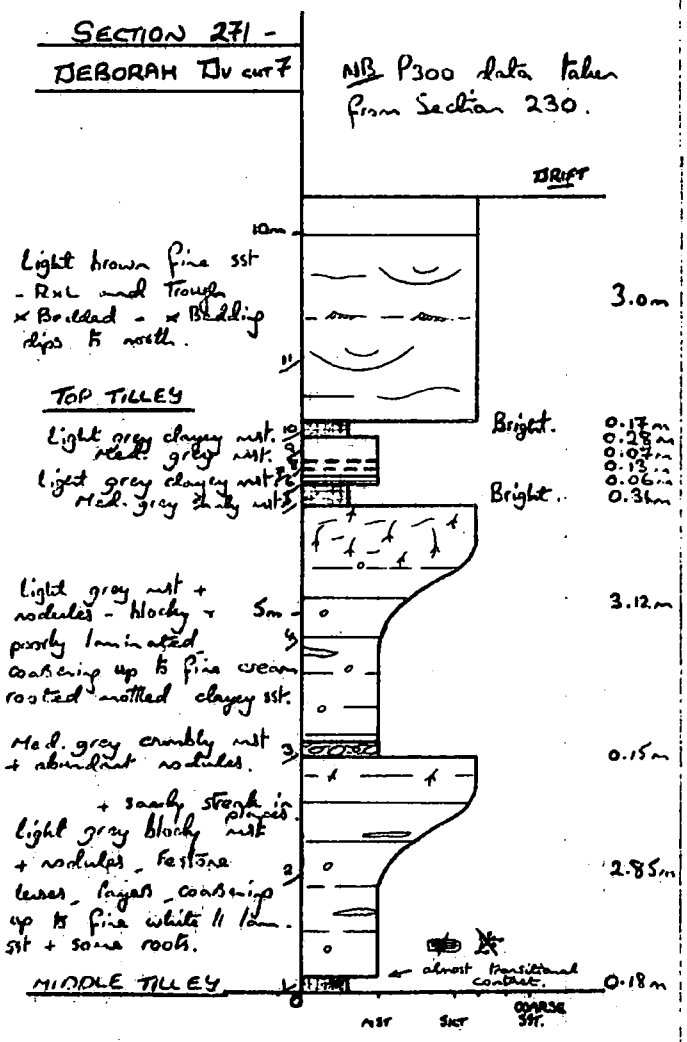
* Large scale foresets in mst - 2 visible, dipping → 12.5° and underneath → 222°. Steep tectonic dip 13/360.

Sequence - Main, then ~5m mst with large scale foresets, ° coarsening up - thin coal stringer - fine sst & mst (5m) - rooted mst - coal - med. grey mst (2m) - then Fivequarter coal (1.03m) - drift disturbed. - should be 3 leaves.

C.R. FIELDING 1.12.80.

SECTION 271 - DEBORAH Div cut 7

NB P300 data taken from Section 230.

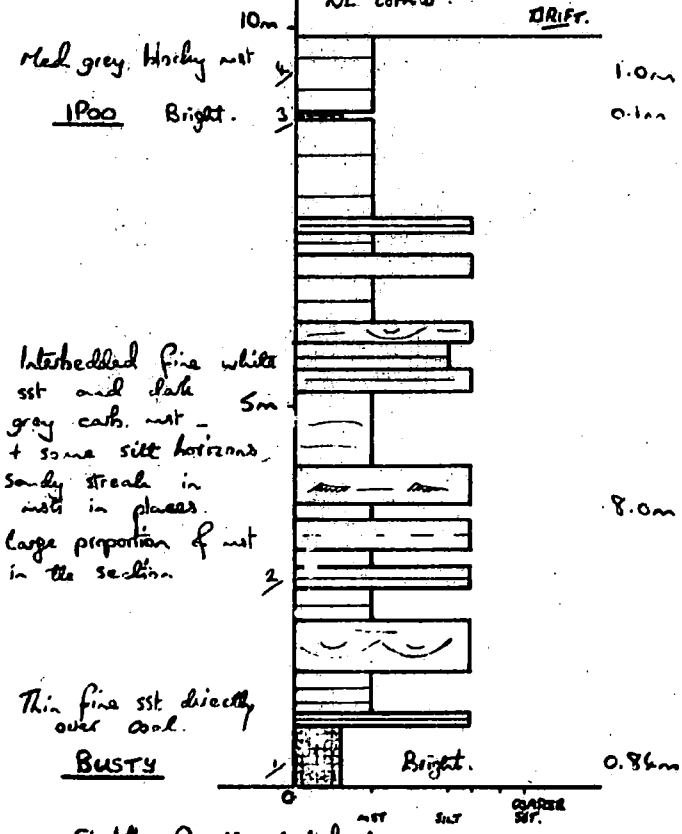


Section taken half way along cut. - presently digging at south end.

C.R. FIELDING 1.12.80.

SECTION 272 - DEBORAH Div 23 (S)

South end of cut - presently digging ~30m north. Approaching edge of washout. Coal thickness reduced at present NE corner.

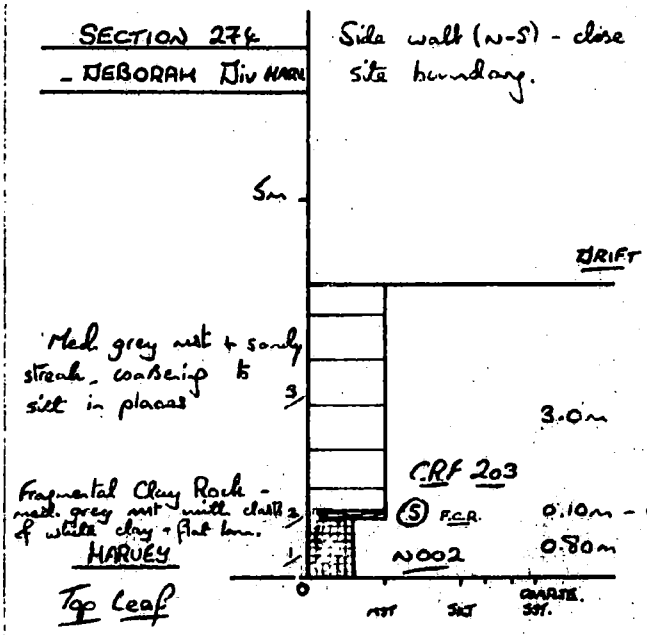


Slightly fault disturbed.

SECTION 273 - OVER.

SECTION 274 - DEBORAH Div HARV

Side wall (N-S) - close to site boundary.



SAMPLE - F.C.R. - Clasts all "flatly laminated" up to ≤0.02m long.

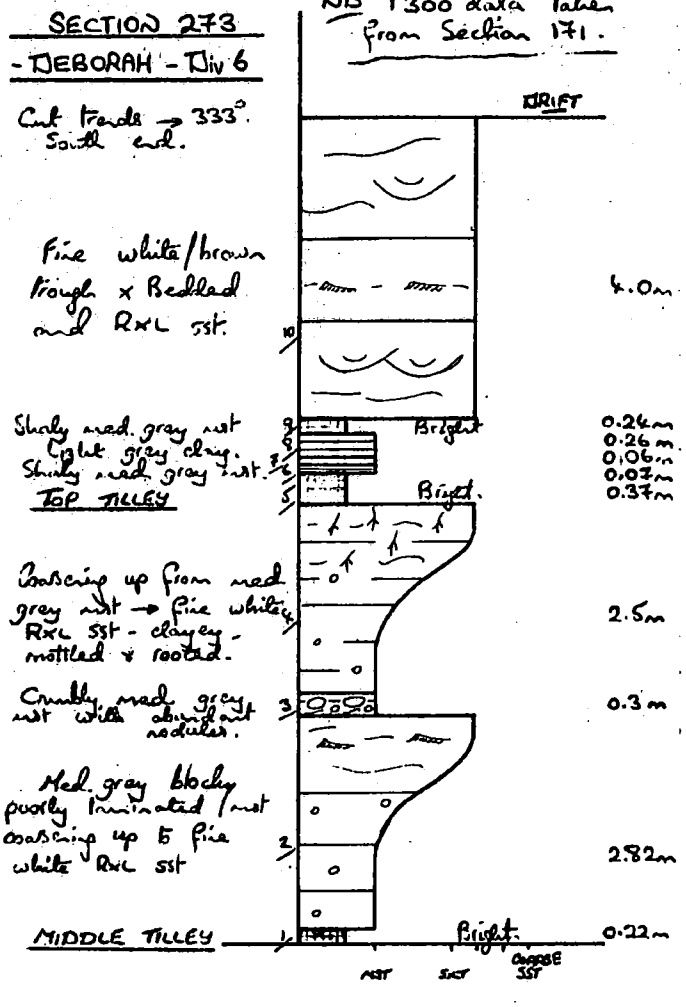
Northern end of cut marked by large fault - brings up 1P00 & P100 to north - F lies just over Harvey. Minor faulting also in Harvey.

C.R. FIELDING - 1.12.80.

SECTION 273 - DEBORAH - Div 6

NB P300 data taken from Section 171.

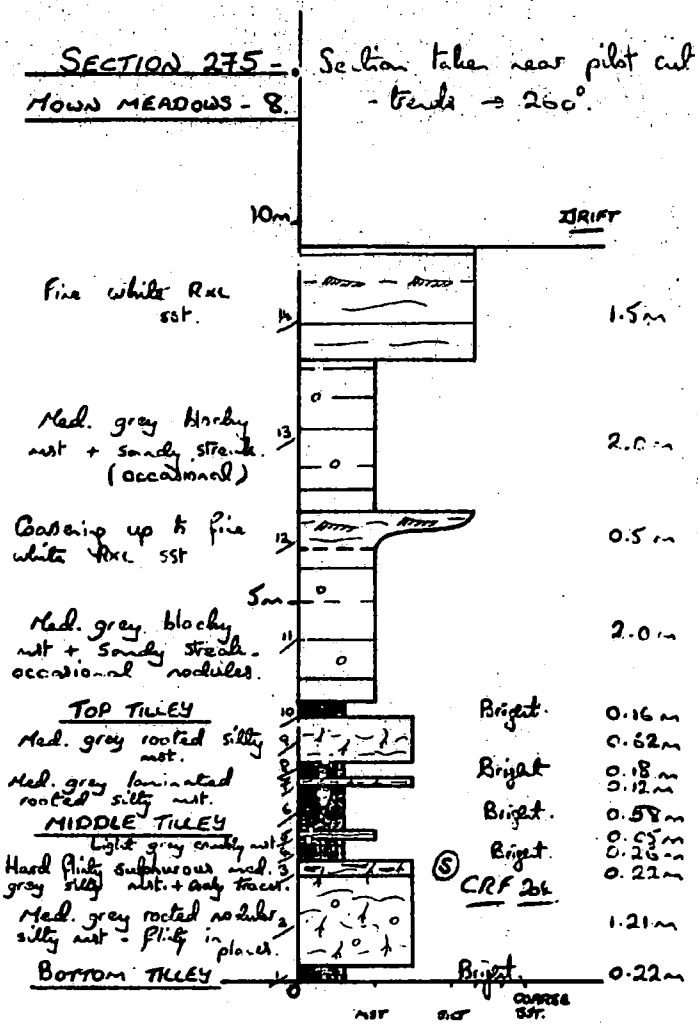
Cut trends → 333°. South end.



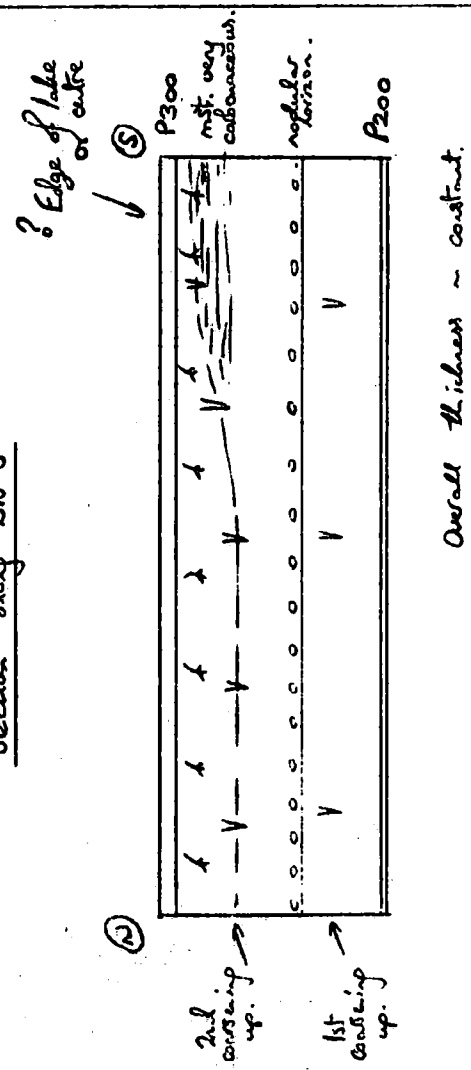
C.R. FIELDING - 5.12.80.

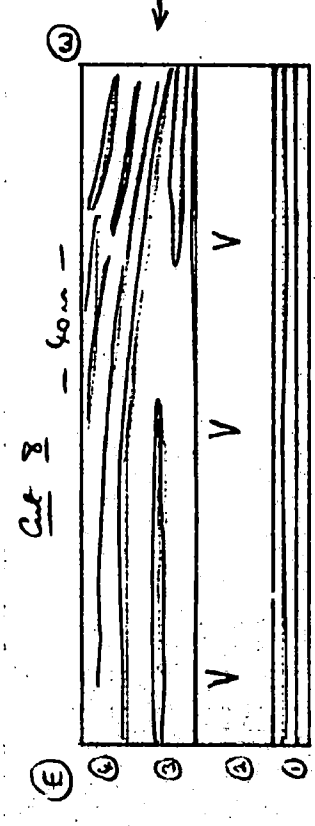
SECTION 275 - MOWN MEADOWS - 8.

Section taken near pilot cut - trends → 260°.



Presently - 3/4 km along - 2/3 of cut dragged. Unit 13 decreases in thickness to west - See drawing. Cuts getting shorter.





4. Fine white RxL sst. with mst laminae at east end - and mst units at west end - dipping to west - and also dipping to west.
3. Mst with shaly streak occasional thin discontinuous layers of sst at east end - and one more continuous 0.15m sst at west end.
2. Mst with shaly streak coarsing up to fine RxL sst.
1. Development of white - Top Tilley coals.

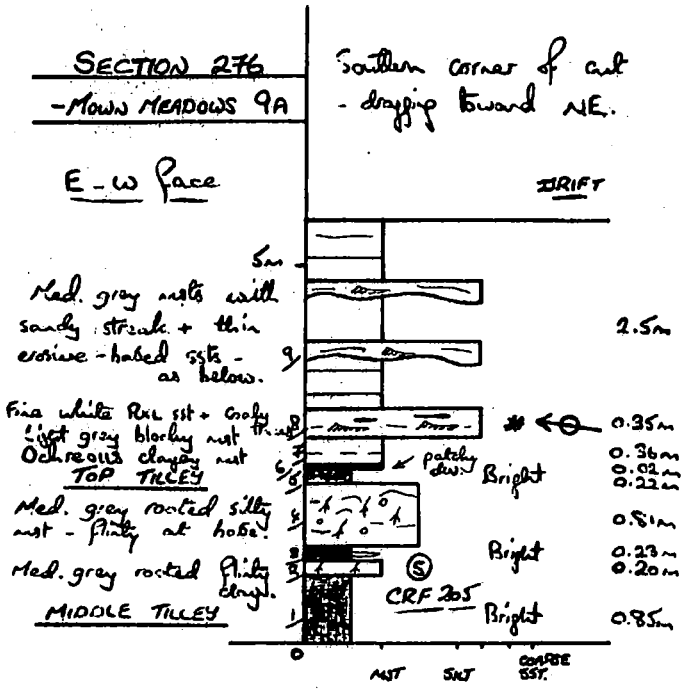
NB Pilot Cut (backhoe) - exposure of Unit 4 is almost solid sst.

C.R. FIELDING - 5.12.80.

SECTION 276 - MOWN MEADOWS 9A

Southern corner of cut - dipping towards NE.

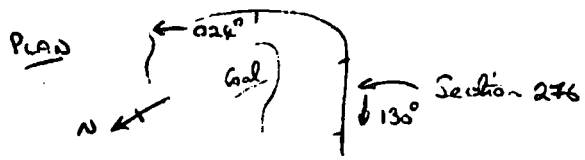
E - W Face



* DIRECTIONAL DATA

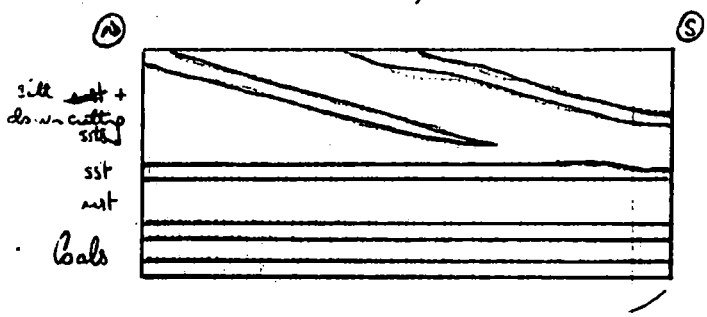
Unit 8 - RxL → 306°, 265°, 303°. n = 3.
θ = 292° ζ = 95%.

NB Unit 6 - laterally discontinuous.
Unit 7 - grades into silt on the N-S wall.
Unit 3 - 0.1m × 0.6m lens of very hard pyritous medium grade massive sst. - contained within seam - dark red/brown colour.

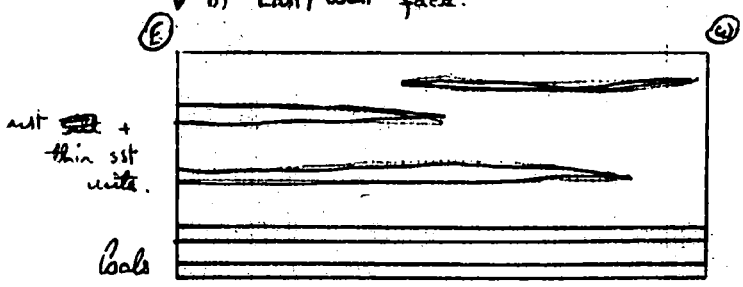


Drawings of Cut 9A.

a) North / South face.



b) East / West face.

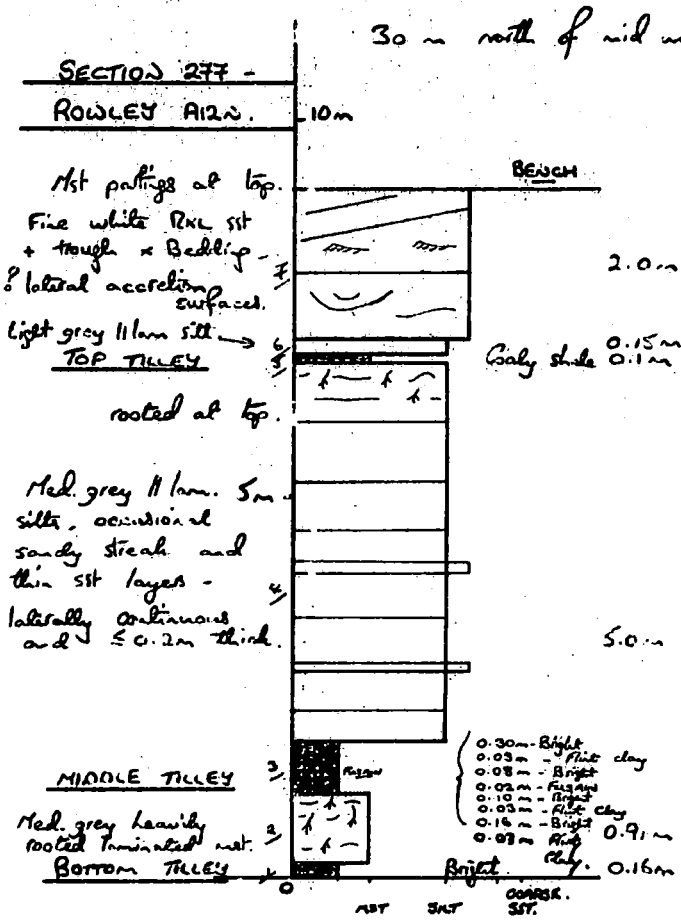


Correlation sst units + downcutting relationships difficult -

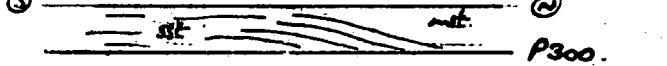
C.R. FIELDING - 10.12.80.

30 m north of mid wall.

SECTION 277 - ROWLEY A12 N.

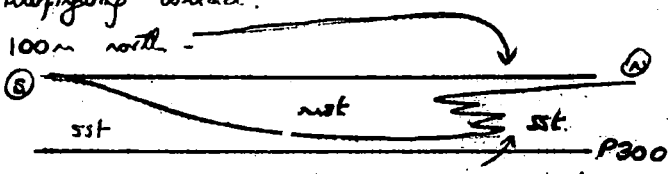


Pacing up cut - solid sst in Top Tilley Post from south end. 5m north - low angle accretion surfaces in sst dipping to north - sst starts to wedge out, mst fill takes its place.



95m north - centre of mst channel - still 0.5m solid sst at base, then 2.0m dark grey 11 lam. mst + sst intercalations - asymmetric north edge (5m to north) - mst base does not rise up surface - layers of sst come in - interfingering contact.

100m north -



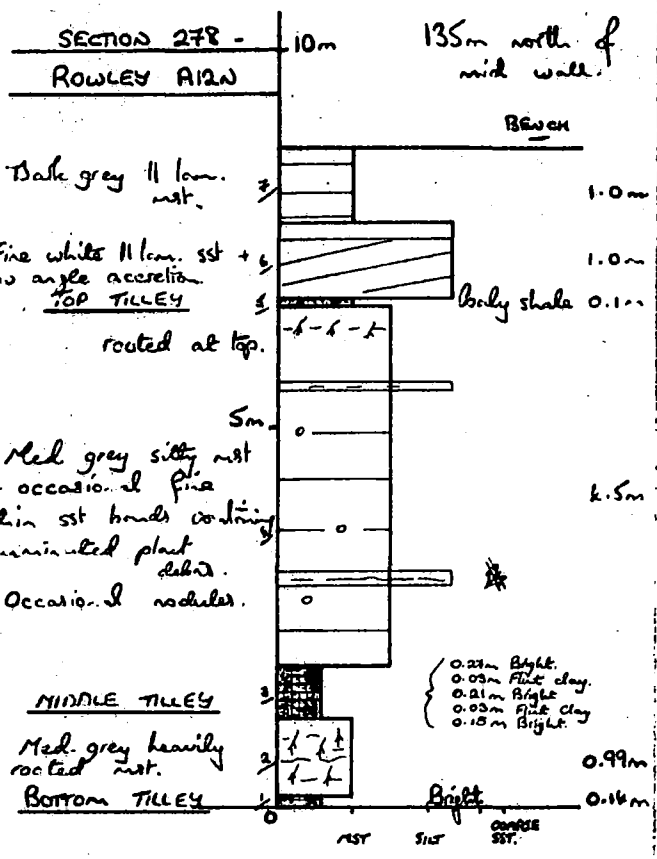
solid sst again, with mst laminae.

135m - southern margin of 2nd mst channel fill - again, low angle accretion surfaces dipping to north - dark grey 11 lam. mst fill. - completely removes sst this time.

C.R. FIELDING - 10.12.80.

SECTION 278 - ROWLEY A12N

135m north of mid wall.



Sst completely cut out by 140m. At 175m sst starts to come back in - remains thin (0.3m) for another 10m - then begins to rise again. At 200m sst reaches full thickness again. - c. 2.5m - some mst intercalations, especially at top - low angle accretion surfaces dipping to south. Sst continues with mst partings to present north end of cut - dipping ~ 5° from north end.

At 235m - 1m sst then 1m mst - base of mst rises and disappears ~10m to north and south - another shallow channel?

Dark grey 11 lam. mst in fill.

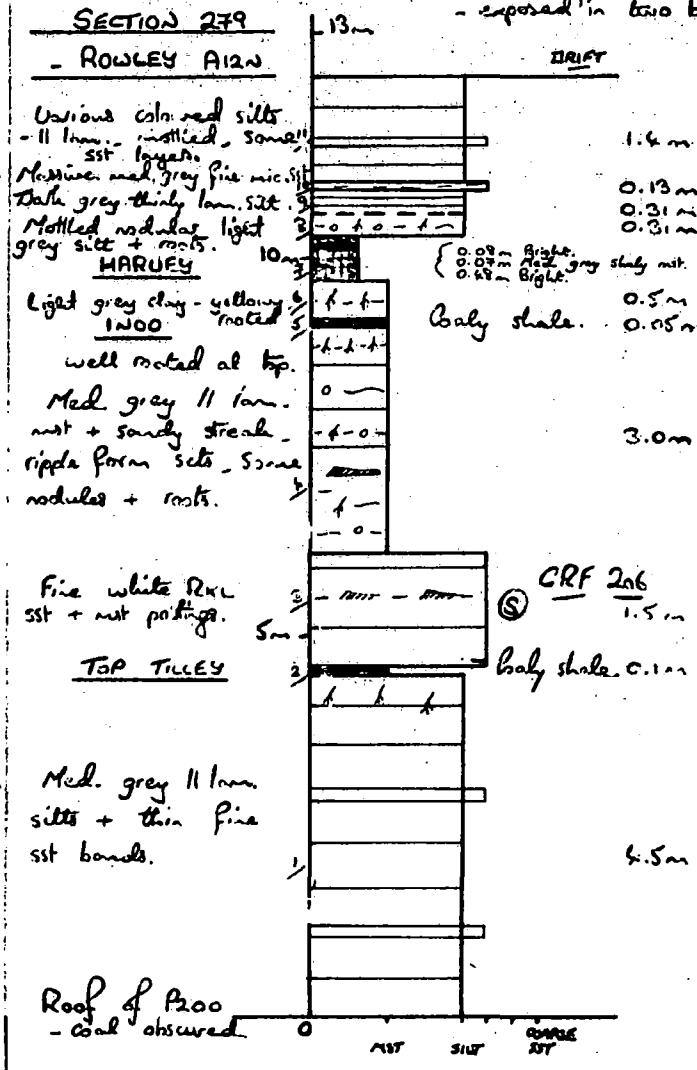
Presently dragging at 260m north. - 1.5m solid sst exposed as TTP.

Total 1 sample - no photos.

See Section 263

260m north of mid wall - exposed in two benches

SECTION 279 - ROWLEY A12N



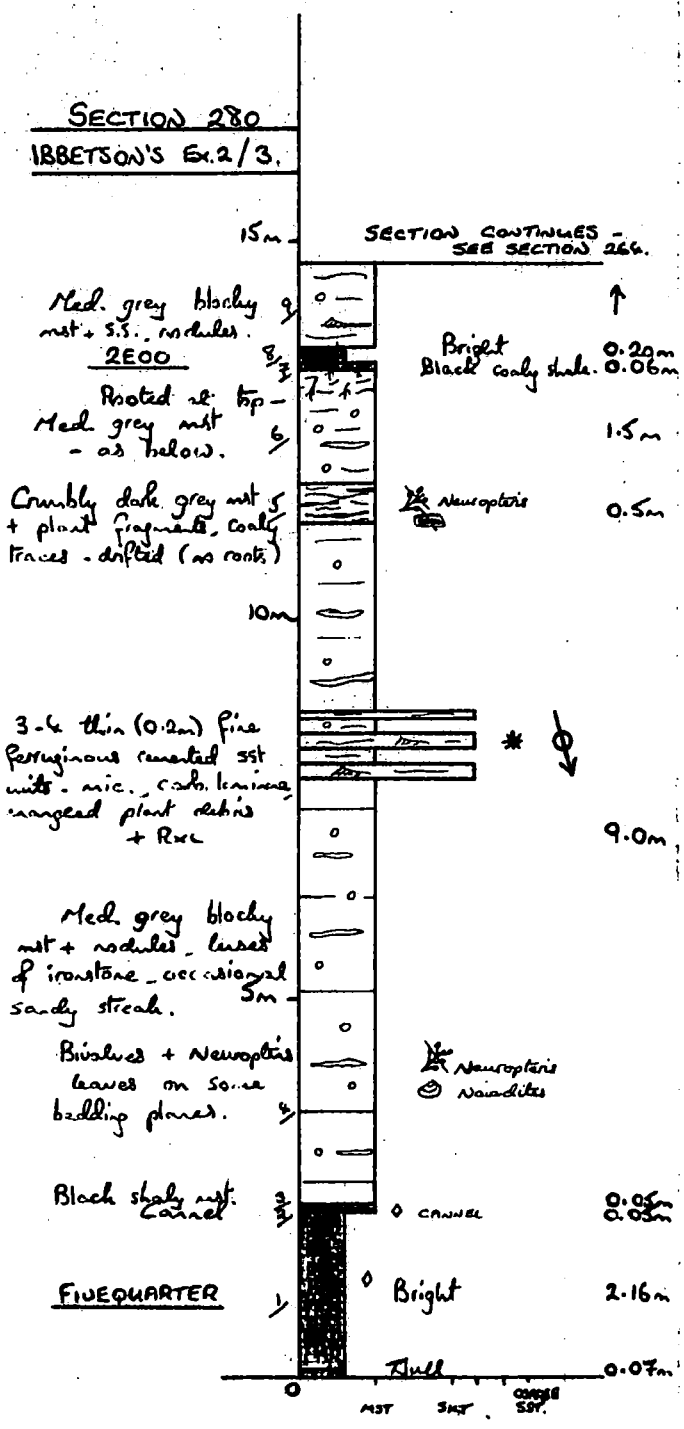
NB 0.3m fine white crumbly massive sst below coaly shale (rooted) disappears at 260m - wedges out to north

BSRG Field Trip - Northumberland Coal Measures - Seaton Sluice sst

Sample CRF 207

C.R. FIELDING - 18.12.80.

SECTION 280
IBBETSON'S Ex.2/3.



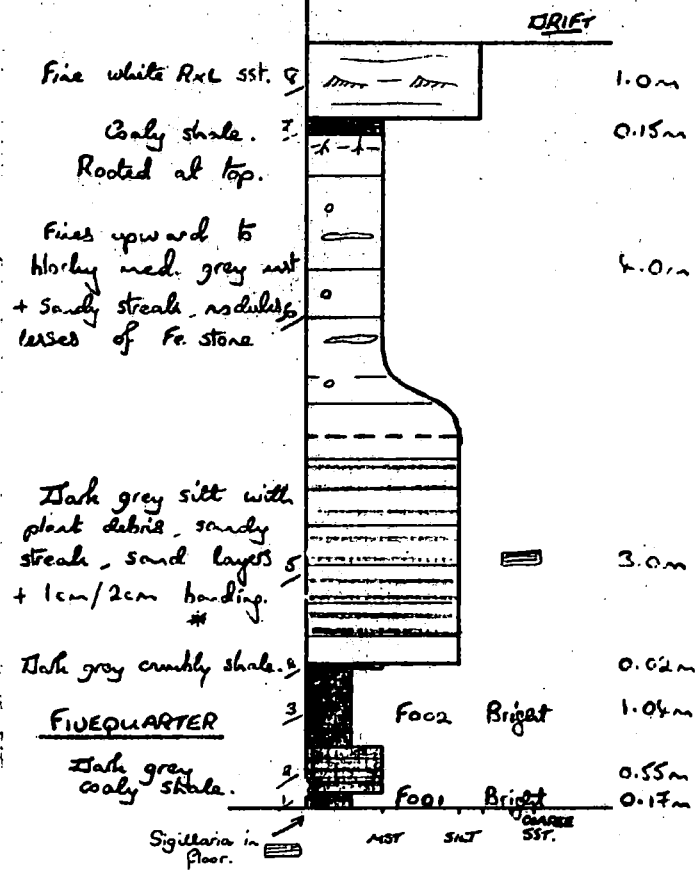
* DIRECTIONAL DATA:-

Unit 4 - Thin sst layers - RxL
→ 141°, 170° n = 2.
● = 155°

5 b/w panorama photos taken.
Extension 2, part 3. Very little lateral variation seen in face.

SECTION 281
EDMONDSLEY C1/6E.

Cut 6 East end
Area C1.

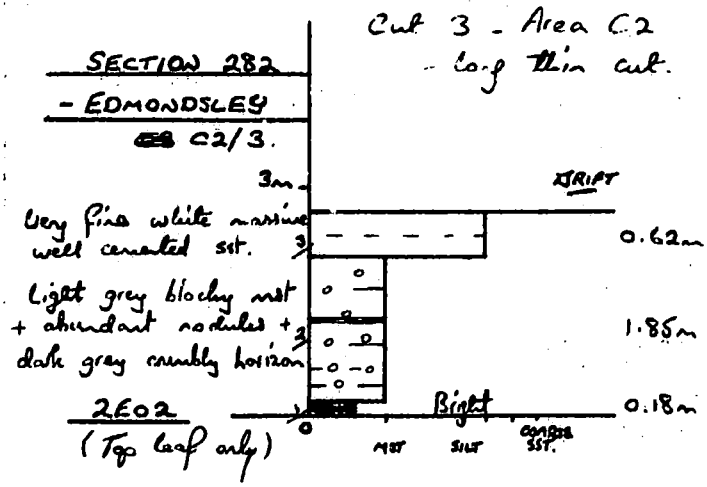


* Alternating light sandy layers ~2cms & dark carb. layers in 1cm

---

Cut 3 - Area C2
- Log thin cut.

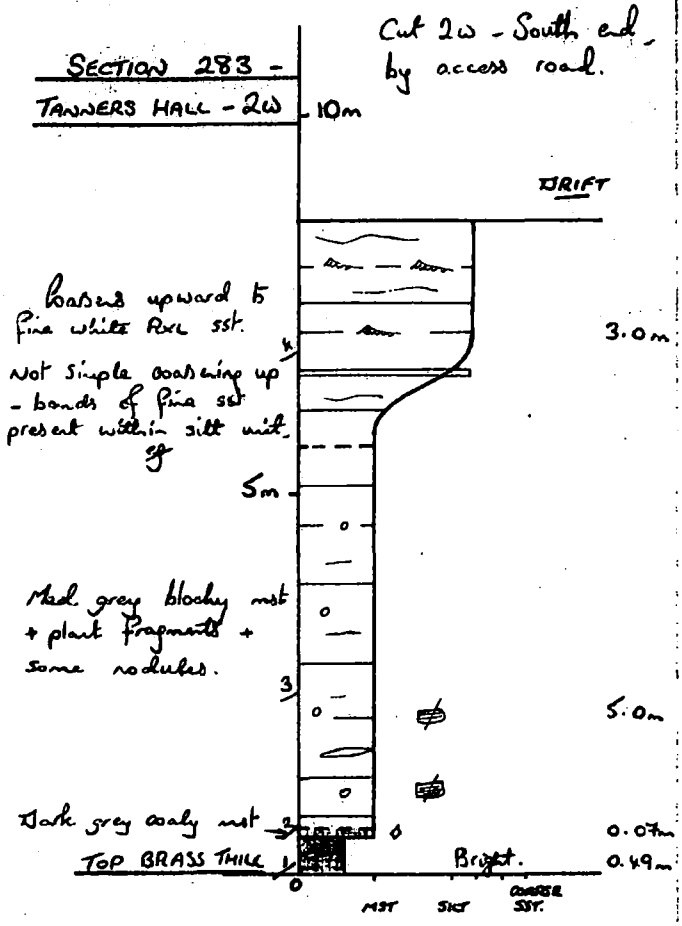
SECTION 282
- EDMONDSLEY
C2/3.



C.R. FIELDING - 22.12.80.

SECTION 283 - TANNERS HALL - 2W

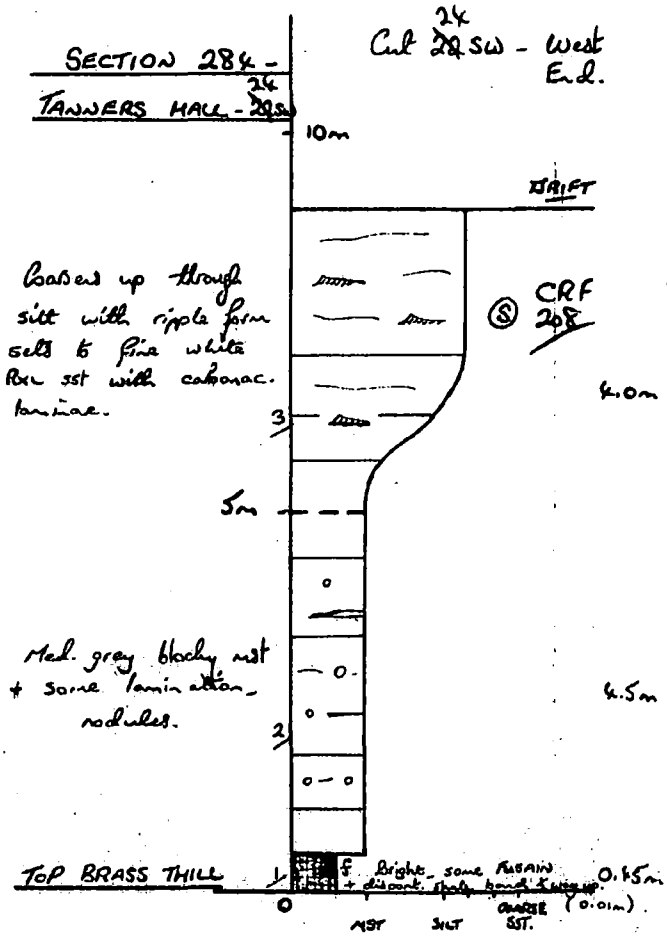
Cut 2W - South end, by access road.



Total ~100m exposed - little lateral variation - 1 b/w photo. Some bedding planes laterally traceable.

SECTION 284 - TANNERS HALL - 24SW

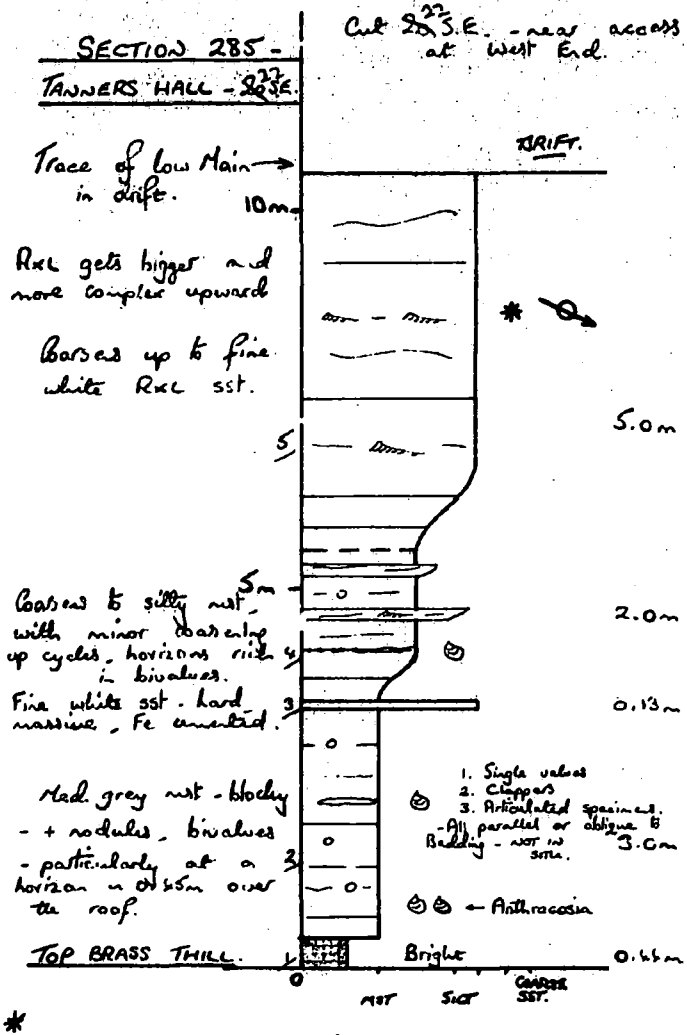
Cut 24SW - West End.



Little lateral variation - considerable slumping. Some dipping towards east - tectonic?

SECTION 285 - TANNERS HALL - 22SE.

Cut 22SE. - near access at West End.



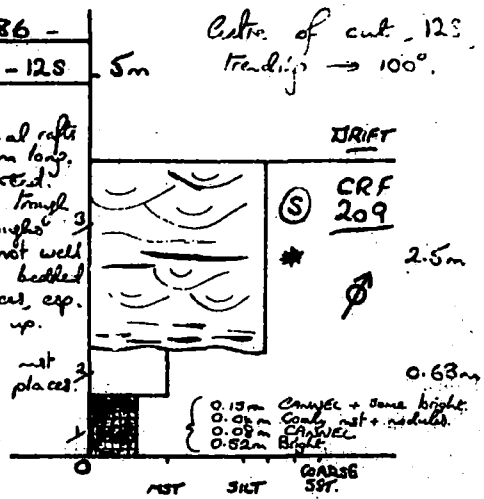
* DIRECTIONAL DATA :- Unit 5 - RxL → 127° n = 1.

Thin fine sst seems to die out to west.

NB Not simple coarsening up - several minor cycles.

SECTION 286 - TANNERS HALL - 12S

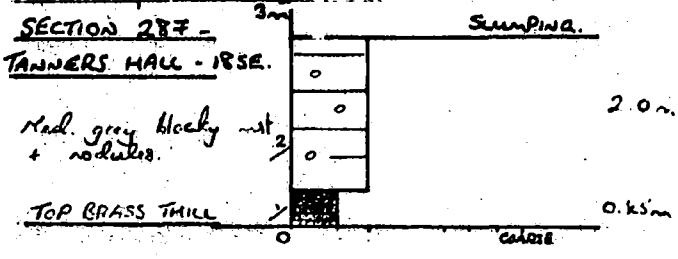
Centre of cut - 12S trending → 100°.



* DIRECTIONAL DATA :- Unit 3 - Trough x Beds
1. 0.5m/15/003 2. 0.3m/16/063°. 3. 0.5m/14/035°
4. 1.0m/18/072°. n = 4. $\theta = 038°$ $\zeta = 92\%$

Section at high angle to flow direction. Poor quality coal in this area.

SECTION 287 - TANNERS HALL - 18SE.

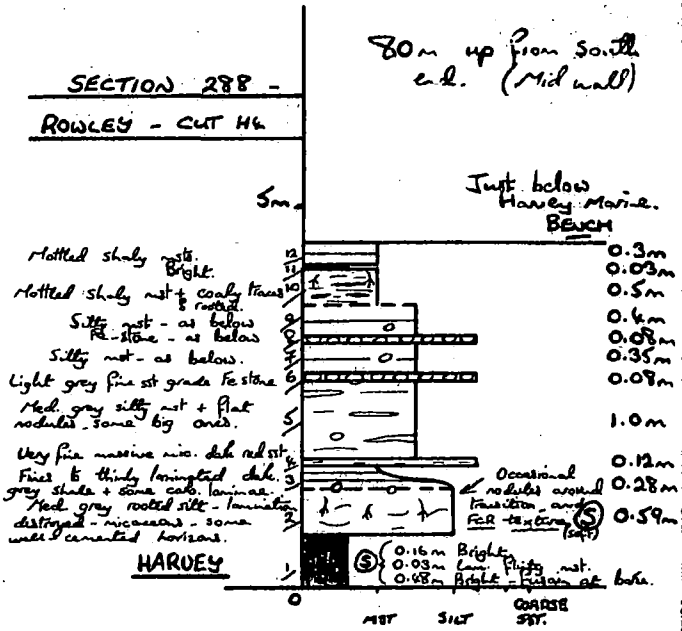


C.R. FIELDING - 9.1.81

Rowley - Cut A12N complete - just started dragging A13N - presently at south end.
Harvey - cooling Cut 4 - at north end.
- pacing north from south end. (mid wall)

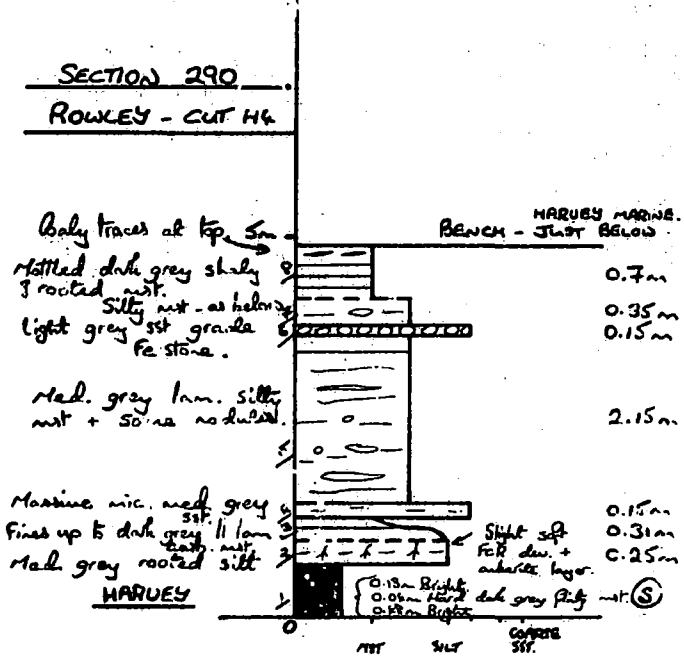
SECTION 288 - ROWLEY - CUT H4

80m up from south end. (Mid wall)



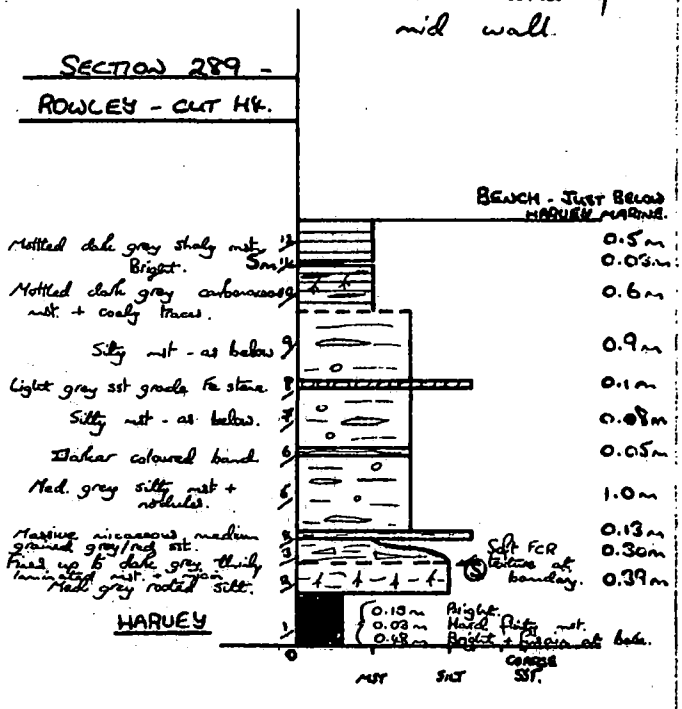
SECTION 290 - ROWLEY - CUT H4

240m north of mid wall - close to cooling point - another 85m exposure - then dragging with ~50m to take.



SECTION 289 - ROWLEY - CUT H4.

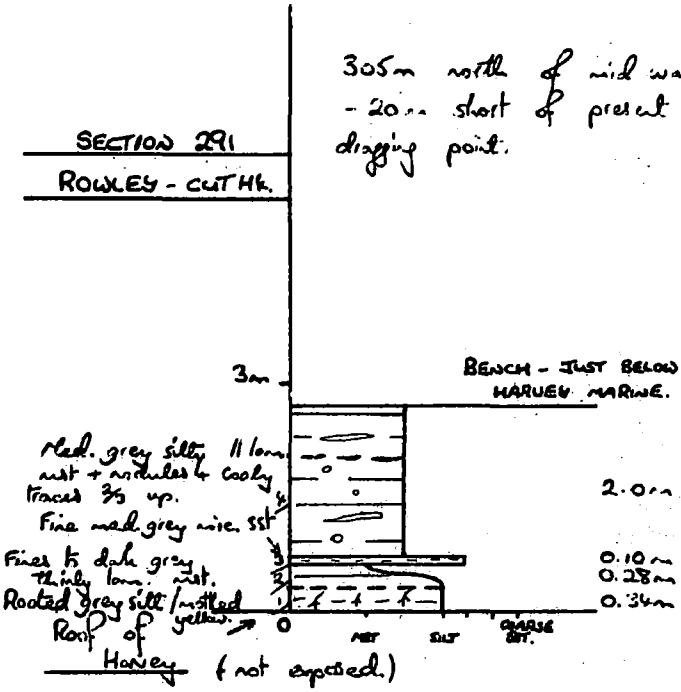
170m north of mid wall.



NB Transition between units 2-3 contains very thin laminae (1mm) of arborite + Sapropel - never base of transition.

SECTION 291 - ROWLEY - CUT H4.

305m north of mid wall - 20m short of present dragging point.



Total 2 b/w photos & samples.
Harvey Marine coal on bench above - cored out - no decent exposure - papery dark grey shales overlie coal.
No exposure in Cut A12N.

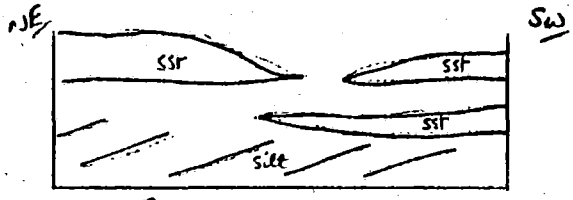
C.R. FIELDING - 15.1.81

Trip to Deborah - Cut Div 42:- little exposure over P300 - drift sand cover. Div 24 - L shaped cut - along edge of washout. Div 7 - tipping Div 5 - presently reducing - access not possible. Div 8-9 Harvey seen last time.

(Div 24) Bushy cut - starting at SW end and pacing to E via N. At SW end, close to Bassel edge ∴ coal highly drift disturbed - 1.02 m shaly coal - with thin rides often above in boulder clay.

55m down - solid cover starts to come in - coal appears washed out, though exposure is not very good - large proportion of sst in the section.

90m down - interbedded fine brown mic. sst with ll lamn. + abundant coaly debris and fairly blocky med. grey silt with coaly debris.



Slight draping of silts to N.E.

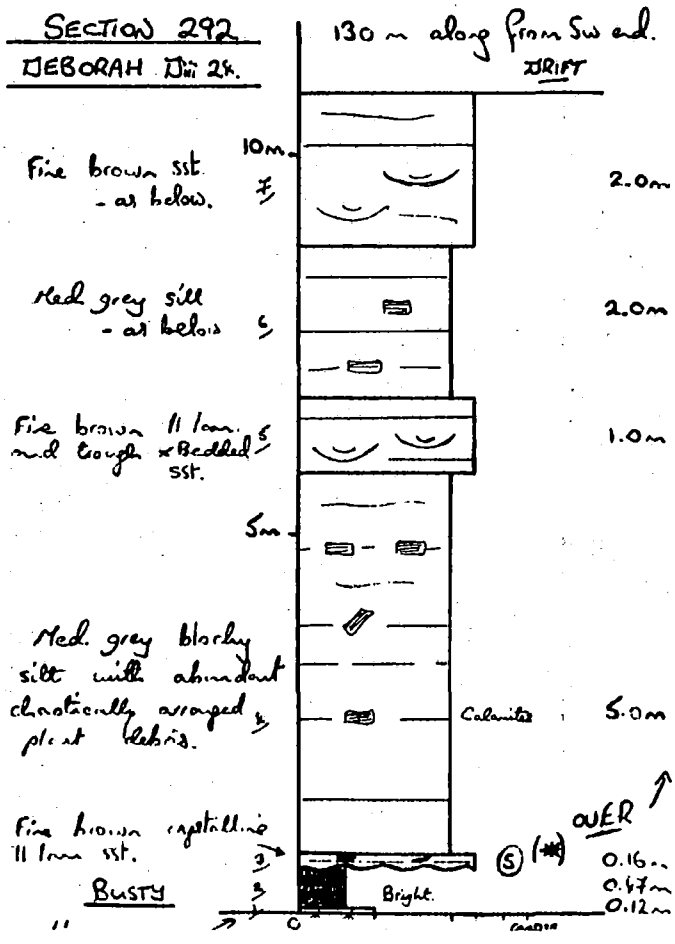
Mostly level bedding present.

At 130m - edge of washout - coal comes back in - section above all silt for 5m.

SECTION 292

DEBORAH Div 24.

130 m along from SW end.



Some draping of sediment toward NE. Exposure for another 50m - then dragline - flooded under dragline. Coal thickens up - and over the coal is a development of thinly interbedded facies - levee deposits.

Directions in interbedded facies :-

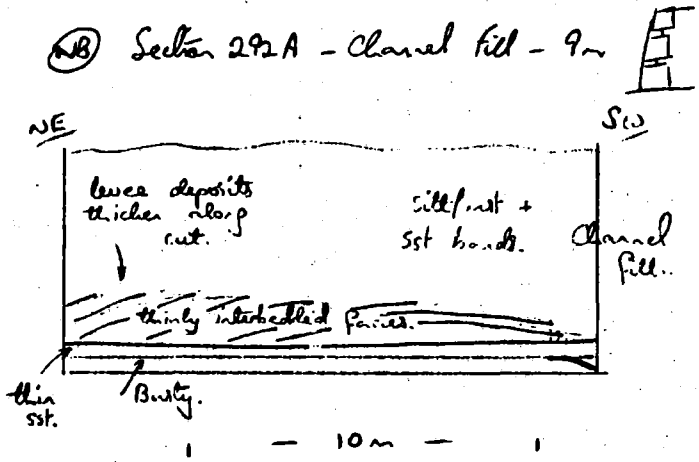
* DIRECTIONAL DATA :-

Trough x Sets 1. 0.05m/10/323
2. 0.1m/8/331 n = 2
θ = 327°

Ripple x lamination - 278°, 272° n = 2
θ = 275°

- all from sst units - units ≤ 0.3m thick, mostly much less. Common thin mst drapes between sst units - also thicker mst units.

(NB) Section 292A - Channel fill - 9m



Interbedded facies - fine crystalline white RxL and ll lam. sst with lamination partly destroyed by burrowing (SAMPLES) + med. grey blocky silt with abundant plant debris and coaly traces at all angles to bedding + dark grey carbonaceous mst. Silt and silty mst often with linear bedding (sandy streak) + ripple form sets. Interbedded unit thickens away from channel - and individual beds gain slightly in thickness. Burrows - several types present - straight & sinuous horizontal tubular vertical dichotic vertical straight, vertical U, vertical curved - see SAMPLES - mostly found at top of arch - all except horizontal tubular type. Planolites Arenicolites ? Arenicolites Arenicolites

NB Configuration of levee - arched profile and draping off to NE - all within 10m. Thin sst directly over coal probably continuous - exposure not too good. Coal should return to normal thickness by end of cut.

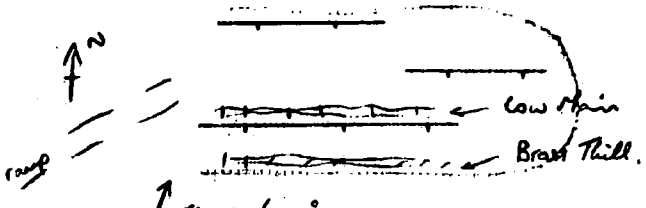
Sediment above - channel fill etc. - varies in grain size between mst & silt. Interbedded sst & silt (as in section 292) continues at the higher level down to the cut end.

Cut 24 just touches the edge of the big washout.

C.R. FIELDING - 27.1.81

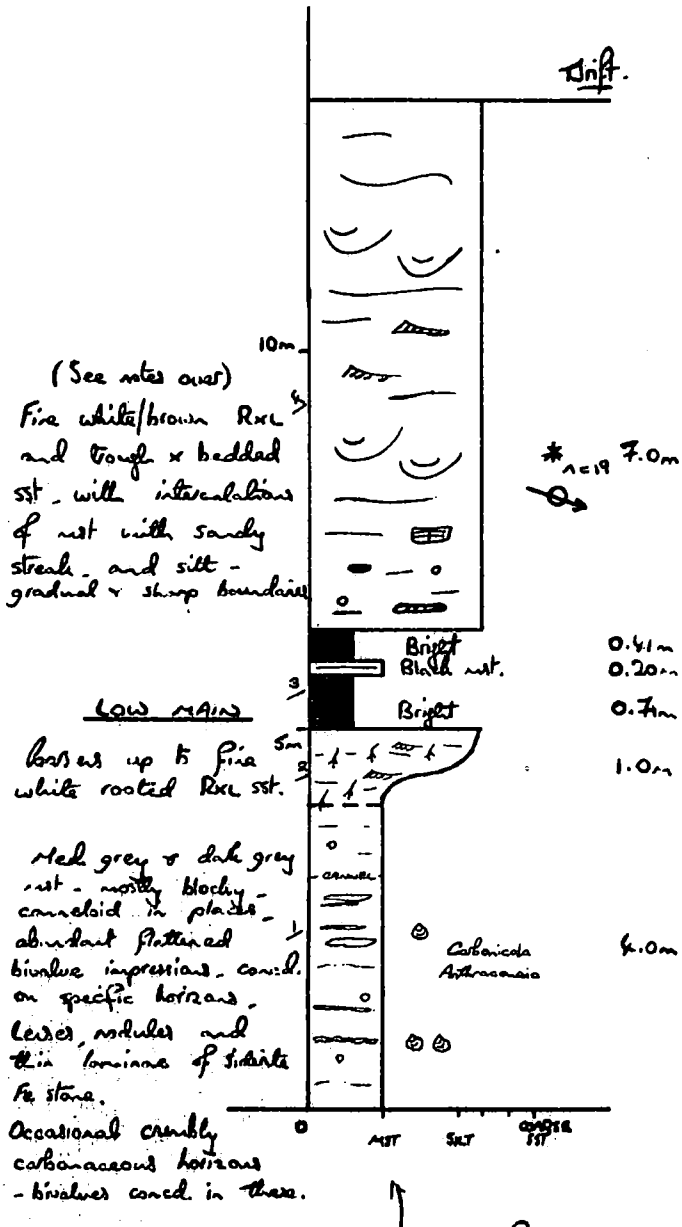
BUCKHEAD

Cut 1
Area L - measures around Brass Thill and Low Main exposed in big face → 110°, steeply dipping ∴ section not completely exposed.



SECTION 293 - BUCKHEAD - L1

Low Main → Brass Thill paths 11.50m.



Base of unit not seen - possibly ~2m above Brass Thill.

* DIRECTIONAL DATA - Unit L.

Ripple x lamination → 208°, 206°, 225°, 206°, 191°, 178°, 209° (near base) n = 7

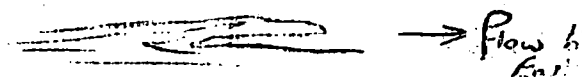
102°, 073°, 092°, 070°, 093° n = 5.

Trough x sets (3m wide) → 0.3m/30/081
0.3m/38/039
(10m+ wide) 0.5m/23/084
0.6m/28/069
n = 4

Ripple form sets. → 107°, 089°, 117° n = 3.

Notes on Low Main Post outcrop:- varies in grade from mst with sandy streaks to fine brown sst - gradual and sharp contacts between units - some layers with very high concentrations of plant debris, coaly fragments and some rounded coal clasts - chaotic arrangement. Steep dip → measurement of vertical section not possible, but observations taken from near base of sst, upwards. (Base not visible).

In lowest part of sst, much mst with sandy streaks and heterolithic sediment - displaying RxL → south (minor delta?) - occasional solid sst units, mostly massive. RxL with some steep side preservation. Further up - mostly solid sst with wide shallow trough x bedding, carbonaceous laminae & layers with abundant plant debris and chaotic bedding. → rapid deposition. Some partly rounded shale clasts & rounded Fe-stone clasts + Fe stone concretionary growth. Some Fe rich layers. Patchy pyrite development. Lateral continuity of units difficult to assess. RxL and ripple form sets in fine sediment. Some very small scale contorted laminae present - probably movement in direction of flow.



Horizontal axis plane to fold - closing to East.
Current lineation present on sst in places.
Upper level - solid sst with carb. laminae at top of exposure - top of sst not seen - cut out by drift - possibly 10m exposure.

(Area H) - Laundry Extension
- See over.

C.R. FIELDING - 27.1.81.

(Area H) - Laundy extension - immediately to south of old pit heaps - working Maudlin, Main and Fivequarter in pillars - mostly; Patchy exposure. Exposure of 3m low angle tabular x surfaces - base ~ 2m over Main roof - * dips → 067°. Mst at base → fine white RxL sst at top of x set.

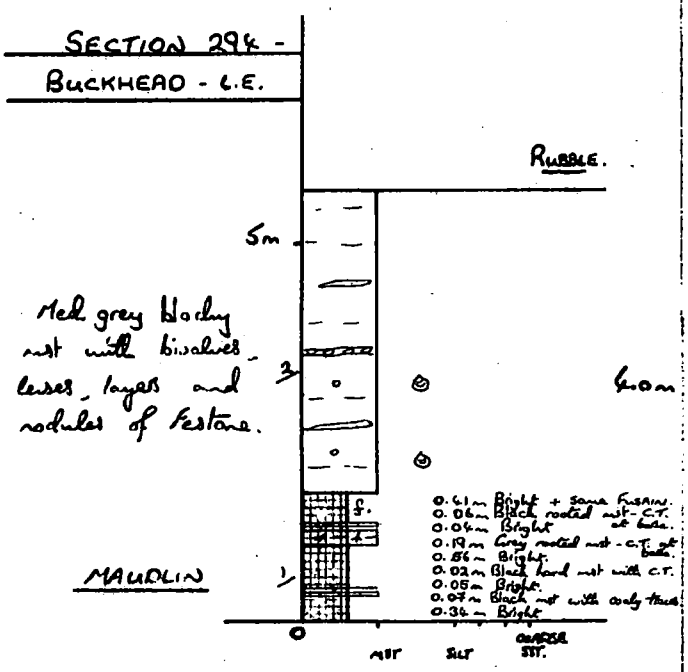
* DIRECTIONAL DATA - RxL → 285°, 272°, 282°, 120°, 087°, 098°

$\wedge = 6$.

Rib & Furrow → 043° $\wedge = 1$.

Down to Maudlin - 2m seam with several soft rooted olive grey mst bands ≤ 0.1m

SECTION 294 - BUCKHEAD - L.E.



Norther end of area - exposure of Fivequarter - detail -

	Roof - fine grey RxL sst.	
	0.02m - Soft grey sandy mst	
	0.95m - bright + some dull + pyrite.	
SAMPLE →	0.05m - soft grey mst.	
	0.20m - Bright.	
	0.02m - Fusain + pyrite, coal traces.	
	0.20m - Bright + pyrite bands.	
	0.03m - Dark grey mst + coaly traces.	
	0.33m - Bright.	

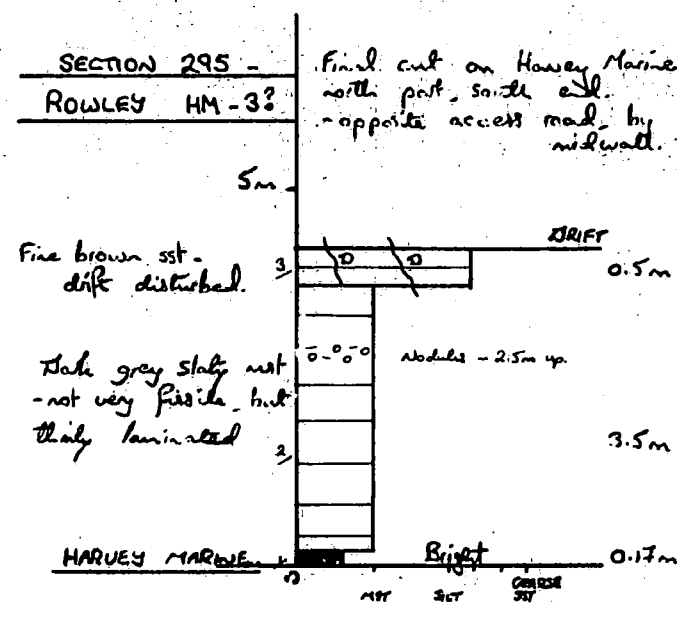
Area C - long cut to low Main and reducing to Brass Thill - detail left for next visit.
Area B - (Hilton) - Cut 1 finished - presently reducing to second cut (also Cut 1).

Total 1 sample, 7 photos.

C.R. FIELDING - 3.2.81

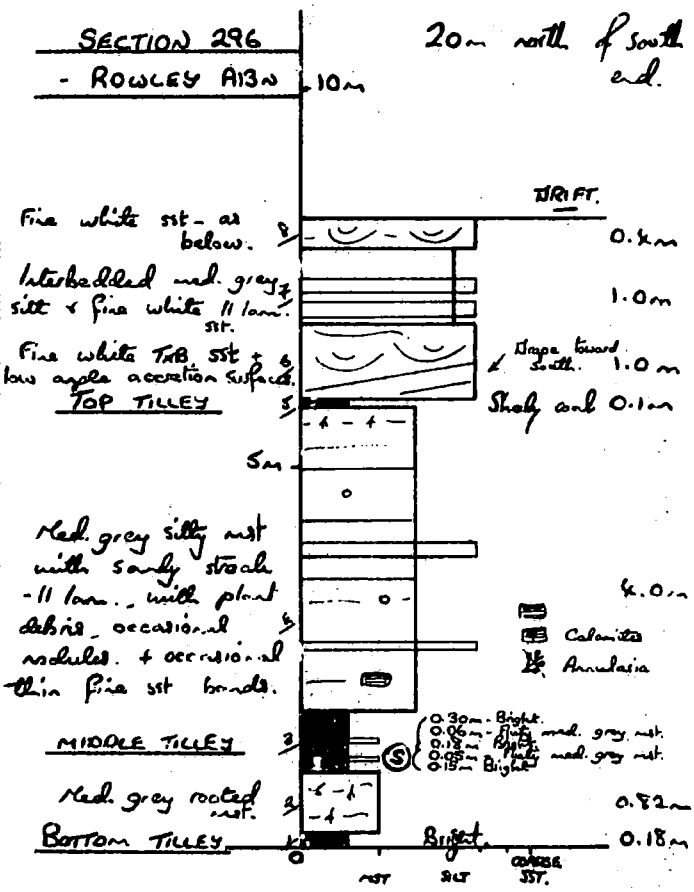
SECTION 295 - ROWLEY HM-3?

Final cut on Harvey Marine - north part, south end. - opposite access road by midwall.



SECTION 296 - ROWLEY A13N

20m north of south end.

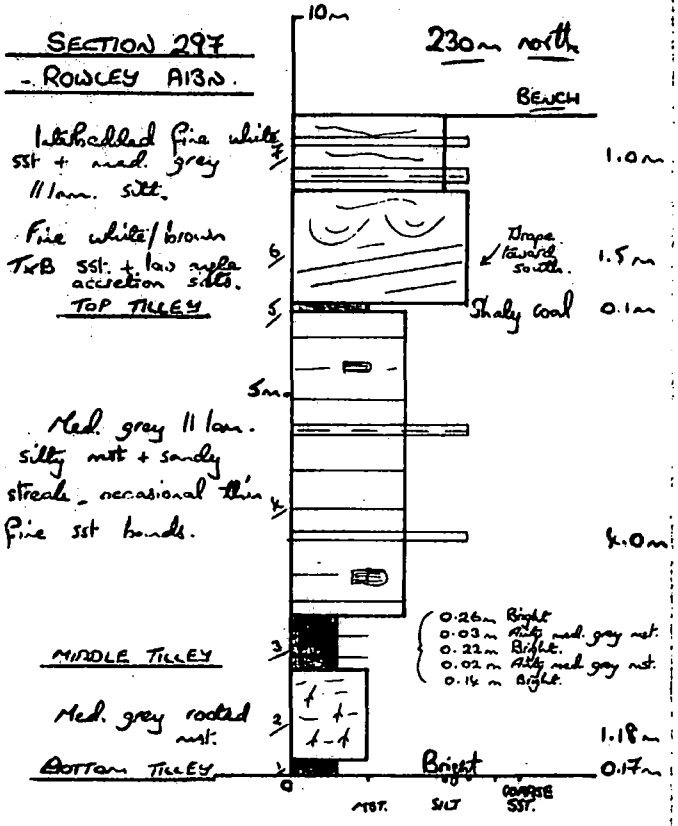


Progressing along cut, measures between P_1-P_2 and P_2-P_3 are laterally very uniform - not so above P_3. NB Cuts are getting shorter.
50m north - interbedded facies starts to cut down gently - top sst dies out. 90m north - middle of "1st washout" - still 0.4m solid sst, then 2.2m interbedded facies. 110m north - 0.6m sst, then 1.0m interbedded facies. At 125m, 0.3m sst, 1.2m interbedded facies - dipping - start of second washout. Mst fill starts to come in at the very top. At 150m, 0.2m sst then 2.0m mst - interbedded facies

C.R. FIELDING - 3.2.81

At 200m sst starts to thicken up again 215m - 0.6m sst then 1.2m interbedded facies 0.3m mst 230m - 1.5m sst then 2.0m interbedded facies

SECTION 297 - ROWLEY AIRN.



Sst and interbedded facies in roughly equal thickness to present end of cut - ~300m - possible presence of mst at top - from second washout fill. Northern edge of second washout displays sedimentary draping very similar in appearance to lateral accretion x sets. Sst starts to thin again at extreme north end of cut. Dragging nearly complete.

Total 1 sample - 6 photos.

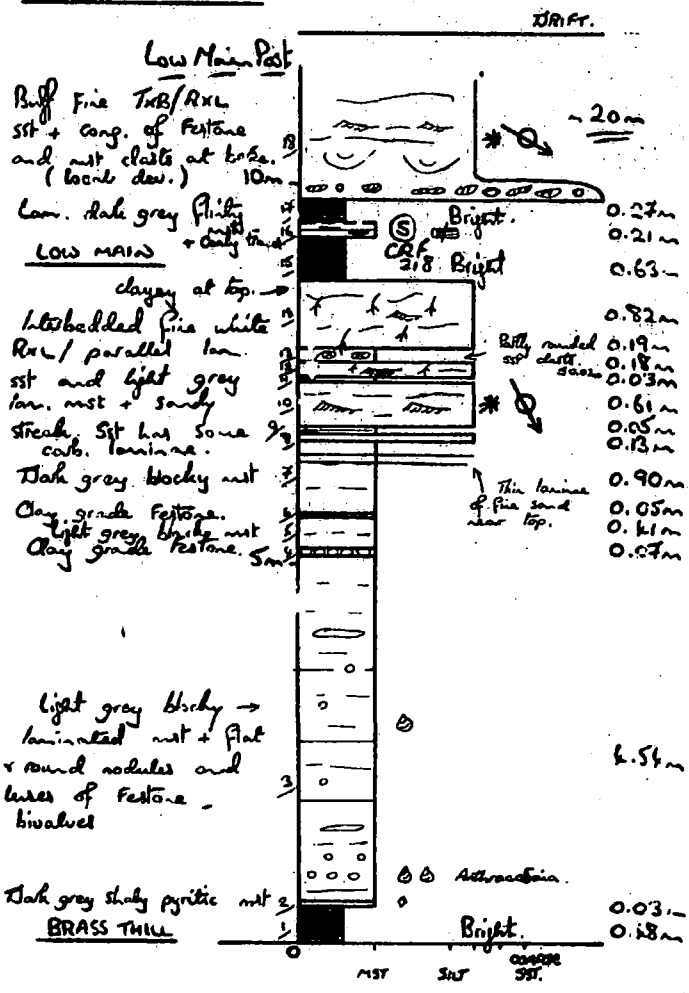
On south wall of cut - buff mst is quite massive - no basal conp. developed. Further up - some draping toward S.E. NB Single Brass Till coal on north side of site. Lateral variation in facies limited - splitting of 1st sst under over Brass Till downcurrent (SE) - pods of massive sst in log form.

Presently starting to reduce for second cut.

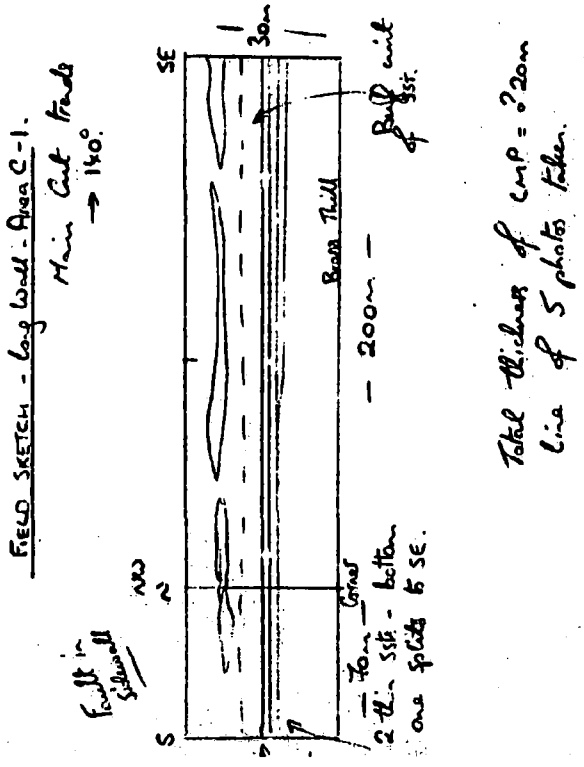
Total 5 photos - 1 sample.

C.R. FIELDING - 12.2.81.

SECTION 298 - BUCKHEAD - C1. Composite section.

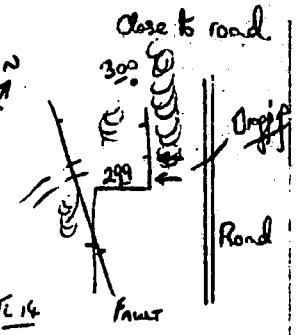


* DIRECTIONAL DATA. Unit 10 - Type B RxL → 163°, 184°, 158°. n = 3.
Unit 18 - Trough cross-bedding 0.3m/15/124°. (just above base) n = 1



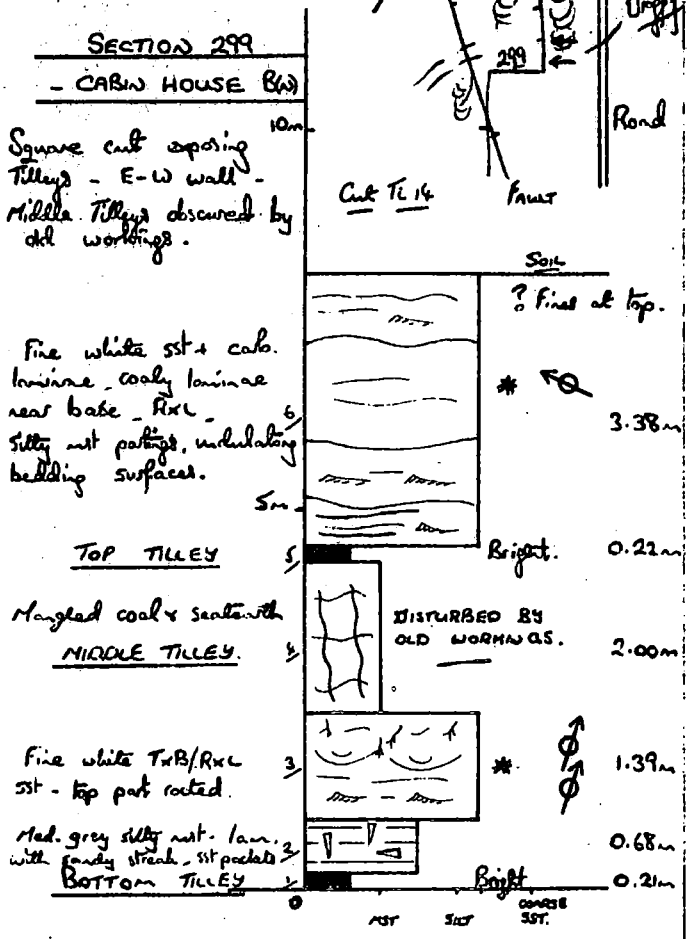
C.R. FIELDING - 13.2.81

Area B(N)



SECTION 299
- CABIN HOUSE B(N)

Square cut exposing Tilleys - E-W wall - Middle Tilley obscured by old workings.



Little lateral variation visible - much pillowing.

* DIRECTIONAL DATA :-

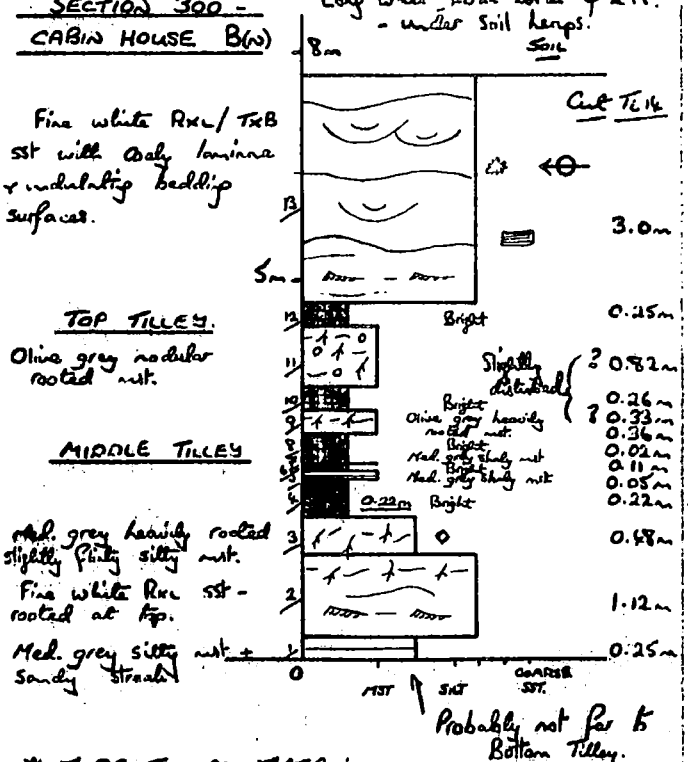
Unit 3 - RxL → 037°, 005° n=2 (Type A/B)

" - Trough - 0.2m/20/027° n=1.

Unit 6 - RxL → 307° n=1. (Type A).

SECTION 300 -
CABIN HOUSE B(N)

Long wall 50m north of 299. - under soil temps.



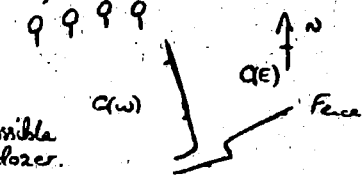
Probably not far to Bottom Tilley.

* DIRECTIONAL DATA :-

Unit 13 - Troughs 0.2m/20/291
0.15m/20/262
n=2

Area A presently inaccessible - Areas C(E), C(W), B(S) complete except for bounding cut - see below.

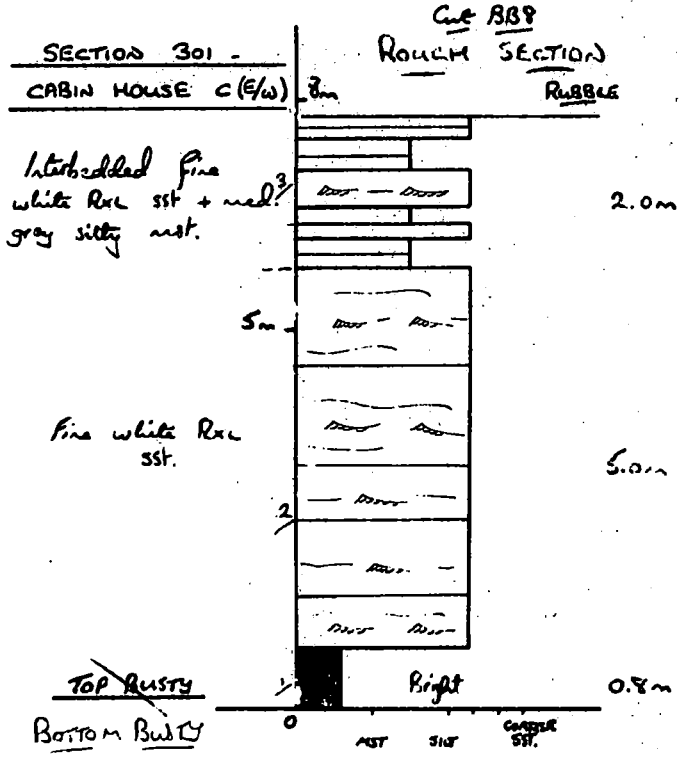
Area C (E/W) - long cut → 330° to Top Rusty.
- one cut further than last visit.



Access not possible - manic bulldozer.

Cut BBB
ROUGH SECTION

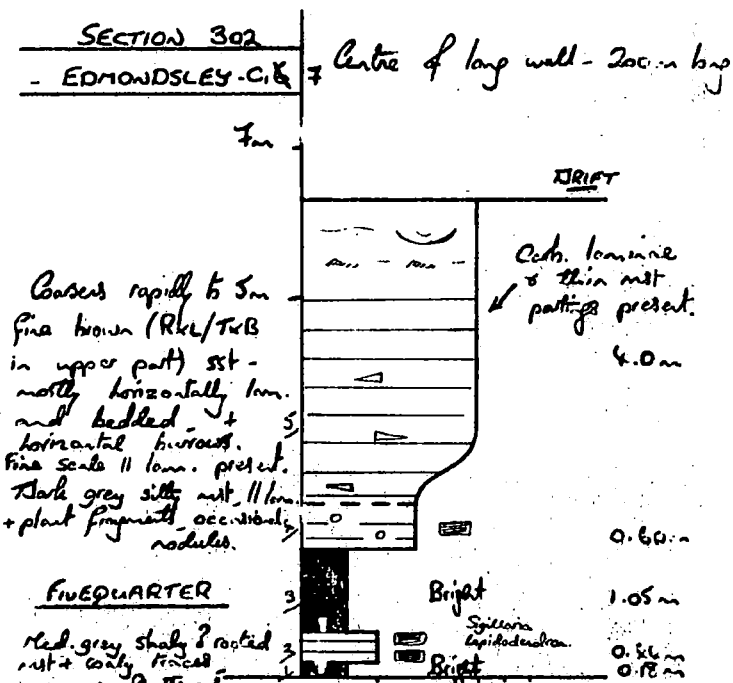
SECTION 301 -
CABIN HOUSE C(E/W)



C.R. FIELDING - 18.2.81.

SECTION 302
- EDMONDSLEY-C.K

Centre of long wall - 200m log



Little lateral variation along ~200m of exposure.

C.R. FIELDING - 18.2.81

(Section 302)

Parting in seam contains abundant flattened stalks - some huge - of Sigillaria, Lepidodendron and other types - all along bedding planes.
Sst - almost entirely // bedded & // laminated, on a very fine scale - with carb. drapes.
Alternating bands of fine sand and dark grey silty mst - 1cm each common.

SECTION 303
- EDMONDSLEY C3 - 8m

Near west end.
9 Total - 20cm long face.

DRIFT

// 1cm. fine white sst with carb. laminae - alternating 1cm bands common. Occasional nodules near base. — 6.0m

Dk. grey crumbly lam. mst coarsening up to fine white // lam. sst. — 0.22m

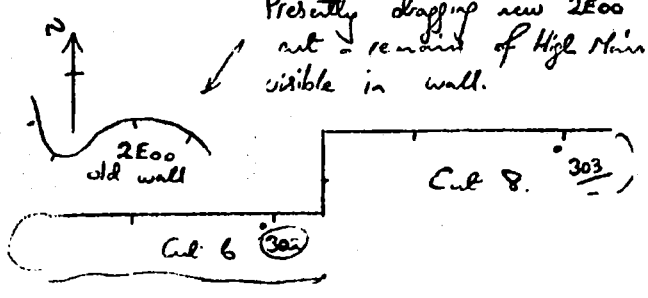
FIVEQUARTER Top leaf. — Bright. — 1.17m

0 — MST — SST — COARSE SST.

Section very similar to rest of exposure - great lateral consistency. Bottom leaf not yet exposed. Note thickening of upper leaf. Drift cutout not as deep. Bottom 3m of sst displays little structure other than // lamination and bedding. Some trough x Bedding in upper part and possible draping in middle of cut.

E — W

Cut plan



C.R. FIELDING - 25.2.81

Area N - Cut 2 - Bar Cut. Trends → 320°. East and south wall.

SECTION 304
- TANNERS HALL 2N

Several small faults present.

12m

DRIFT

TOP BRASS THILL — Bright. — 0.3m
Top rooted.

// lam. med. grey mst + sst bands - as below. — 2.0m

BOTTOM BRASS THILL — Bright. - slaty — 0.1m
Top rooted.

Sst fairly accurate

Med. grey ? carbid flinty lam. mst + bands of fine white massive sst - also thin layers of sand within mst, sandy streaks in places - all // lam. — 6.0m

Bright.
Black coaly shale
Yellow oxidised clayey rooted mst

TOP HUTTON — 0.16m, 0.03m, 0.05m
Top part rooted.

Med. grey blocky partly // lam. mst + dipted plant remains. — 2.06m

BOTTOM HUTTON — Bright — 0.57m

0 — MST — SILT — COARSE SST.

Along cut to west - TBT dies out through coaly shale to mst. Sst bands are laterally extensive - little change in thickness along cut.

SECTION 305.
TANNERS HALL - 2E.

100m north of south end

10m

mst for to T.B.T. →

DRIFT

Med. grey // lam mst. — 1.0m

BOTTOM BRASS THILL — Bright. — 0.1m

Sst quite accurate.

Med. grey lam. slightly flinty mst + fine massive sst bands - nodules near base. — 6.0m

Black coaly shale + coal fines.
Yellow oxidised clayey rooted mst

TOP HUTTON — Bright. — 0.12m, 0.05m, 0.12m
Top rooted -

Med. grey blocky mst - rooted - nodules - lenses of Fe stone. — 1.94m

Close to roof of Bottom Hutton.

0 — MST — SILT — COARSE

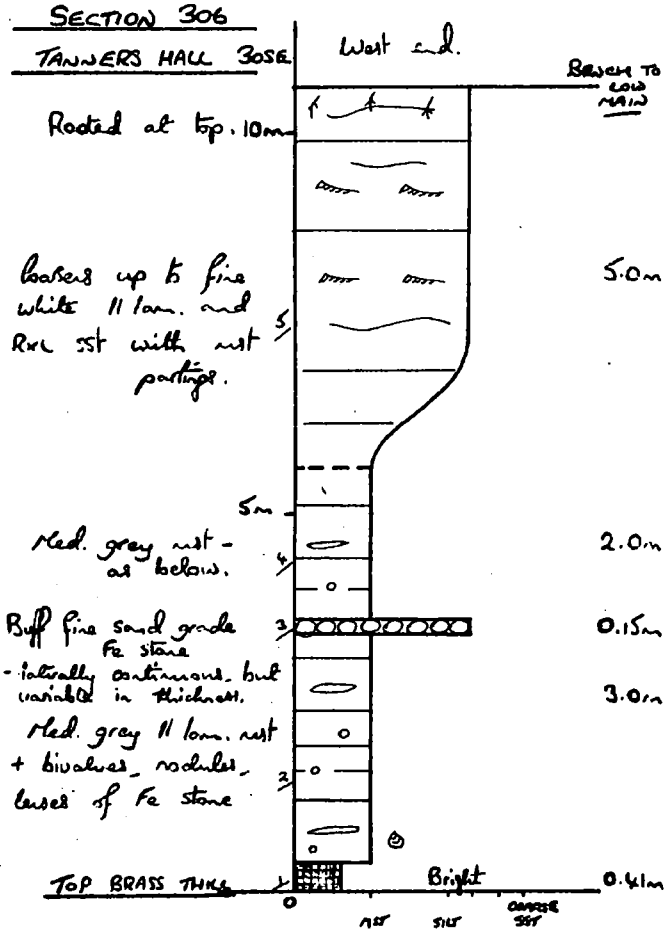
C.R. FIELDING - 25.2.81

Section 305 - previous page - Cut 2E - long cut still dragging - to north - presently ~ 150m up. 1 photo. Sst bands in unit 5 thin and split toward the south. Cut trends → 010°. Lateral variation otherwise negligible. Top Brass Thill worked more or less on outcrop in small cuts to west.

Cut 155 - low Main - on outcrop - just east of farm - low Main with drift above.

SECTION 306

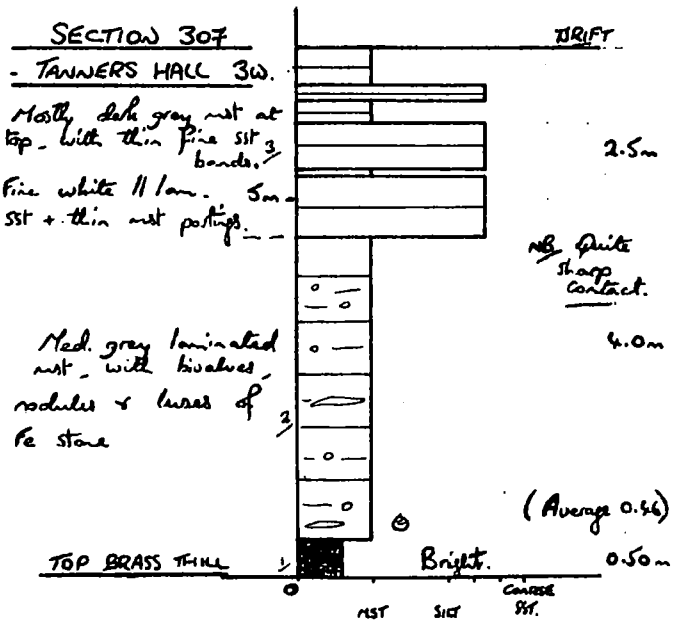
TANNERS HALL 305E



West end of cut - near access road - trends E-W. Still dragging to east. Total ~100m exposure at present. No lateral variation.

SECTION 307

- TANNERS HALL 3W.

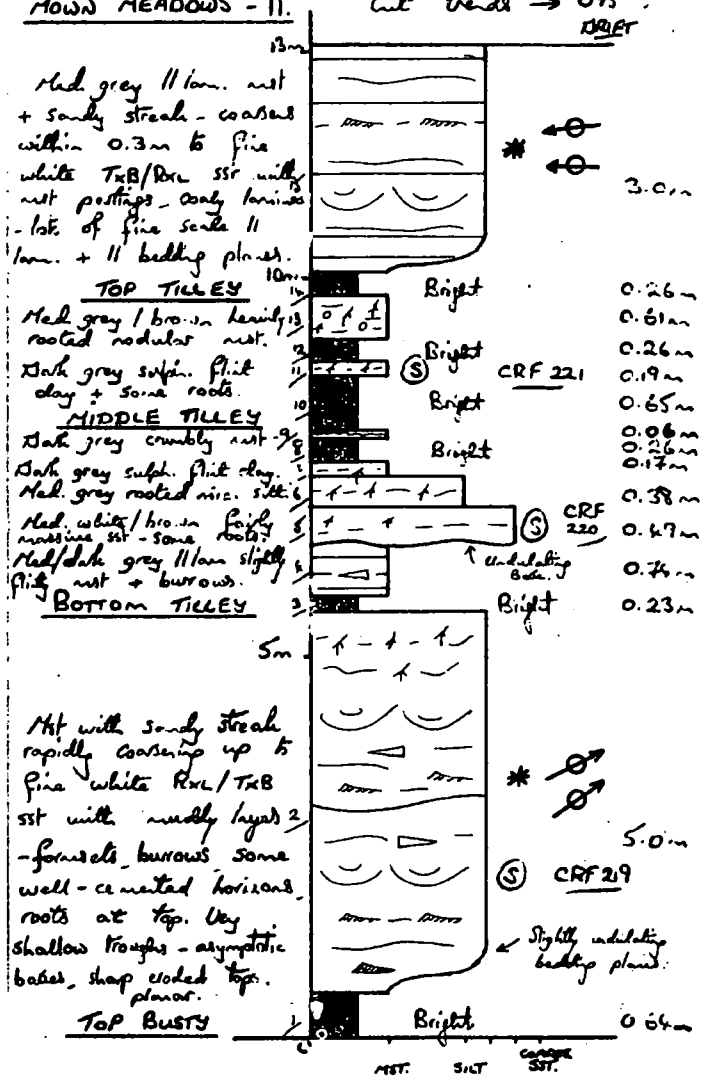


Long N-S Cut - Section by right angle bend in cut. Fault crossed cut at this point - throw 0.17m down to NW.

C.R. FIELDING - 27.2.81

SECTION 308 - MOWN MEADOWS - 11.

Composite Section. Cut trends → 095°.



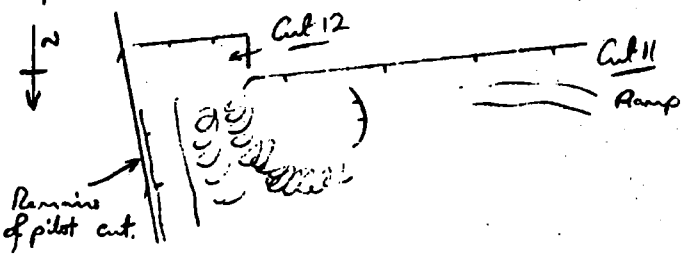
* DIRECTIONAL DATA :-

Unit 15 - RxL → 274° n = 1 (Type A)
Trough × Bedding - 0.1 m / 260° n = 1.

Unit 2 - RxL → 037, 022, 068, 066, 078, 062. n = 6.
Type A-B.

Trough × Bedding (0.1m) → 057°, 035°, 038°. n = 3.

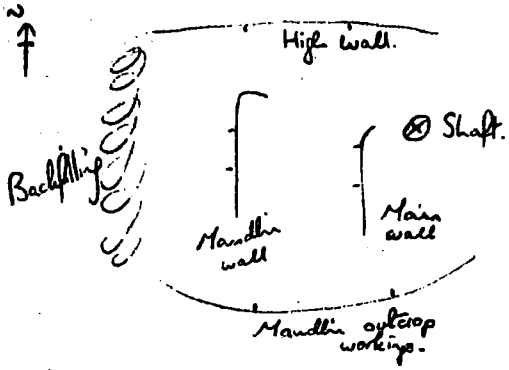
Cut 11 now abandoned - being backfilled - originally went down to Bottom Busty. Total 3 samples. 2 photos.



Little lateral variation visible, but difficult to assess. Cut 12 just starting - coaling P200 at east end, dragging to west. In remains of pilot cut, sst's over P300 thin & grade out to the south - nothing measurable.

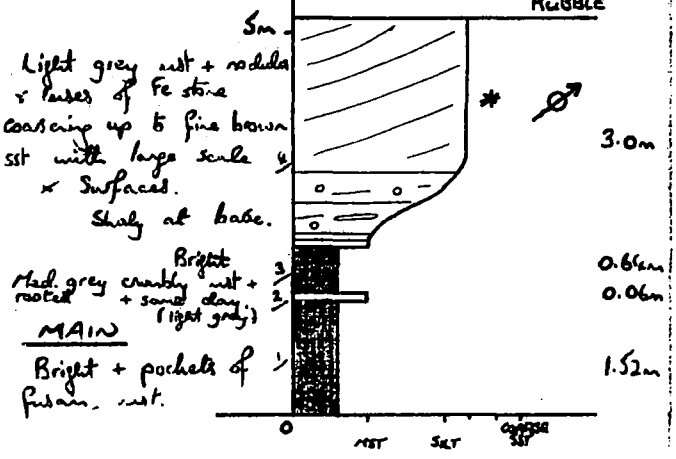
C.R. FIELDING - 3.381

Buckhead - (Area H) Laundry Extension



SECTION 309
- BUCKHEAD - (H) L.E.

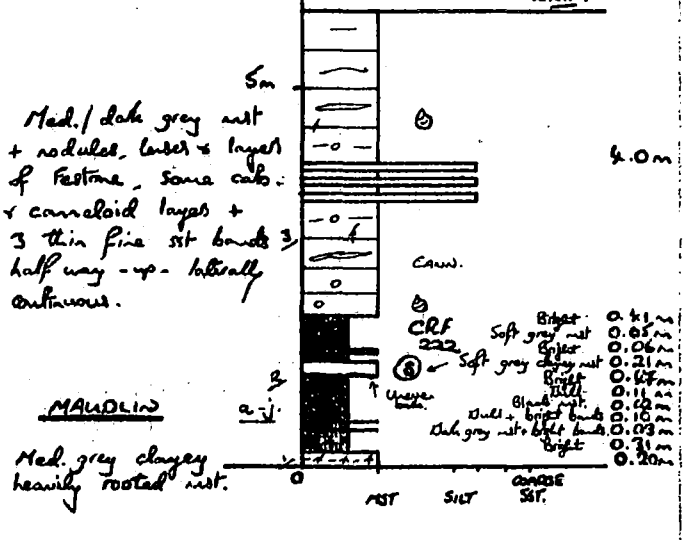
N-S face west of shaft
Tectonic dip 10/018°.



* DIRECTIONAL DATA :- Large scale ✕ surfaced Unit 4
→ 14/050 n = 1

SECTION 310
BUCKHEAD (H) L.E.

Outcrop workings.
Cut trends → 270°.
Section in middle of face.
Tectonic dip 10/358.

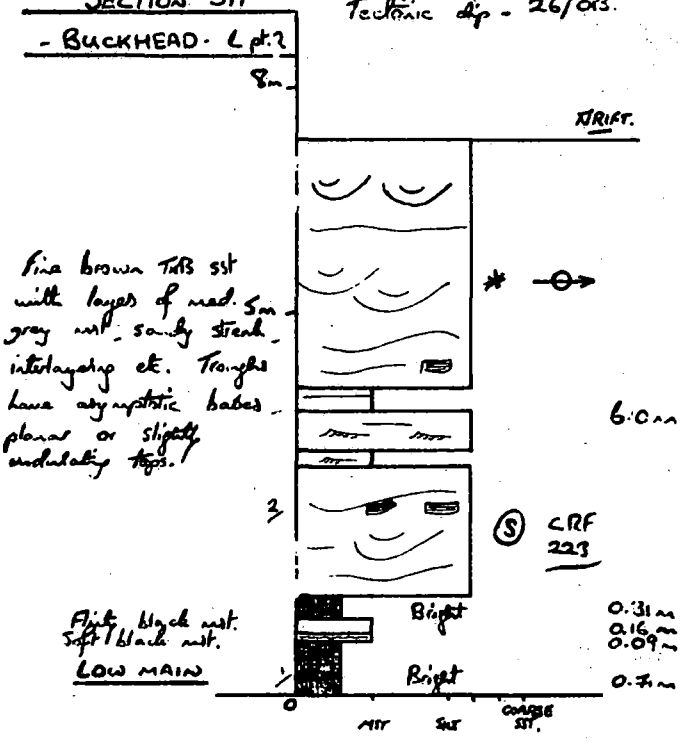


Carbonaceous layers with coaly traces and gypsum crystals - very occasional rooting in light grey blocky mst units. Interfingering of coal & light grey clay at base of top leaf.
2 photos

Exposure of measures above Maudlin in E-W high wall below old shale heaps - consisting upward sequence - thin coal - mst with a few fine sst bands (≤0.3m) - the trace of Fivequarter below drift.

SECTION 311
- BUCKHEAD - L pt. 2

2nd part of Cut -
Tectonic dip - 26/013°.



Working to area limit - but not down to low main yet.

* DIRECTIONAL DATA :- Unit 2 -
Trough ✕ sets 25/0.6m → 084°, 081°, 099°.
n = 3.

Area B - Hutton - still reducing 2nd cut (1 Ex) - presently at level of 1400. Sst in upper part of face have large scale ripple form - A ≤ 2m, λ ≤ 20m - rounded topped - continue along side & back wall - hummocky?

Area C - little further progress - complex faulting revealed at west end of cut. Broad Thill/low Main parting reduced - or possibly tectonically squeezed.

Total 2 samples - 2 photos.

C.R. FIELDING 3.3.81

C.R. FIELDING - 12.3.81

SECTION 312 - DEBORAH Div 40

Side wall - roof down to NE. Tectonic dip 7/047.



* DIRECTIONAL DATA :- Unit 6 - Trough & Rolling 0.4m / 27 / 020° n = 8.

Cut Heads → 050°.

Cut Div 40 - at right angles to 39/30 - long cut trending → 150°. Coaled clays to P200. Sequence V. radular cut. V. light grey sst - clay P300 - sst. light grey mst decreases in thickness at NW end of cut from 2.5m to 1.0m - also decreases toward middle of cut - then constant to S.E. end.

SECTION 313 - DEBORAH Div 9.

Cut Heads → 150°

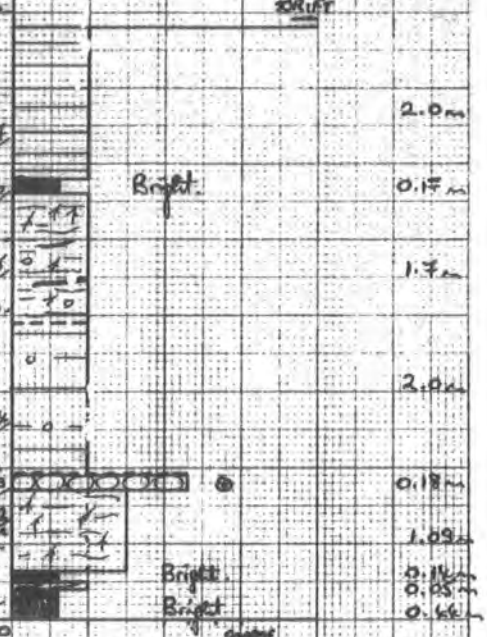


Very little lateral variation.

NB Cut Div 9 also exposed - access difficult strata very similar to previous cuts

SECTION 314 - ROWLEY - HG(N)

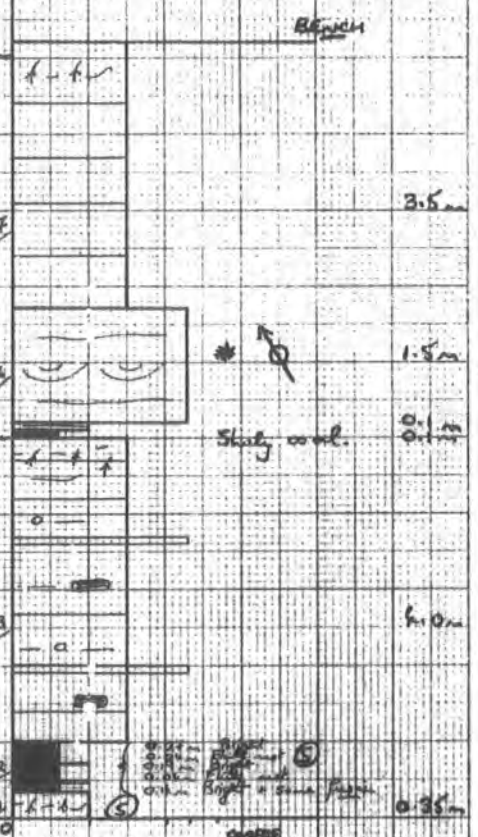
15 metres of south end. Very heavy old workings. Drift channel cuts out Rowley Marine in wall at south end.



Probably dropping ~ 75cm up from south end.

SECTION 315 - ROWLEY A(N)(S)

Corner of sidewall.



* DIRECTIONAL DATA:- Unit 6 - Trough & Rolling - 0.4m / 15 / 301° n = 8.

Notes - See Over.

C.R. FIELDING - 12.3.81

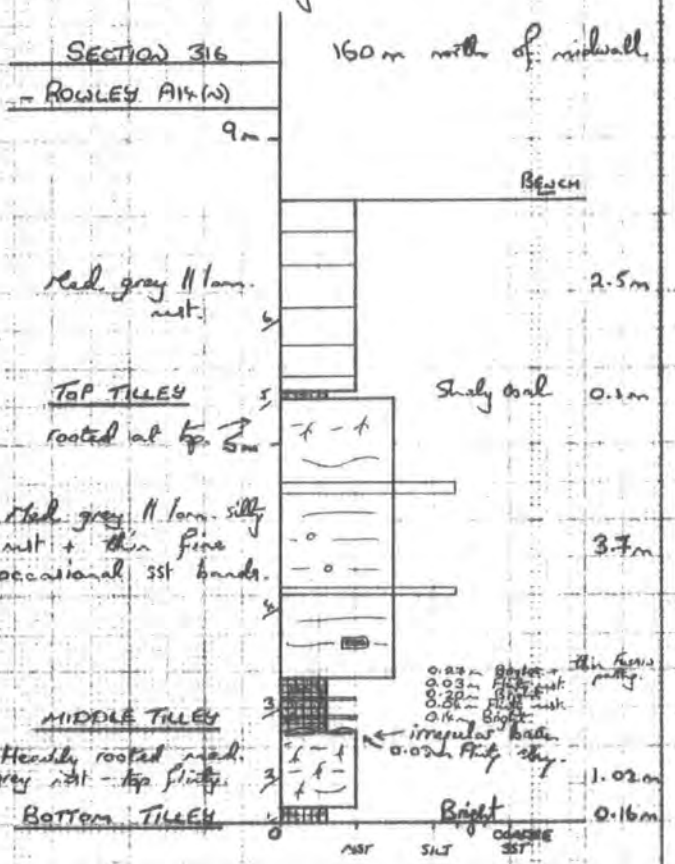
Notes - Section 315 - South end of loop cut gives only partial exposure - little exposure of P200 due to slippage. ~ 4m partly to P300, then ~ 2.5m sst, ~ 2.5m silty mst with sst bands, thin Harvey bench. Some trough x Bedding visible in sst, but mostly // bedding planes. - sst thins to ~ 1.5m on midwall

---

After 60m section completely obscured by tipping. At 150m, exposure starts again. Lithology of over P300 is all med grey mst. At 160m fine white sst starts to come back in, rises up with ? lateral accretion sets. Presently dropping at ~ 230m north. Only another ~ 25m to drag.

SECTION 316 - ROWLEY A14(N)

160m north of midwall



At 160m on, sst starts to come back, rising up face. By 175m, section all sst ~ 2.5m thick - continues this way to the present end of the cut - with drapes & small present all along - ? lateral accretion.

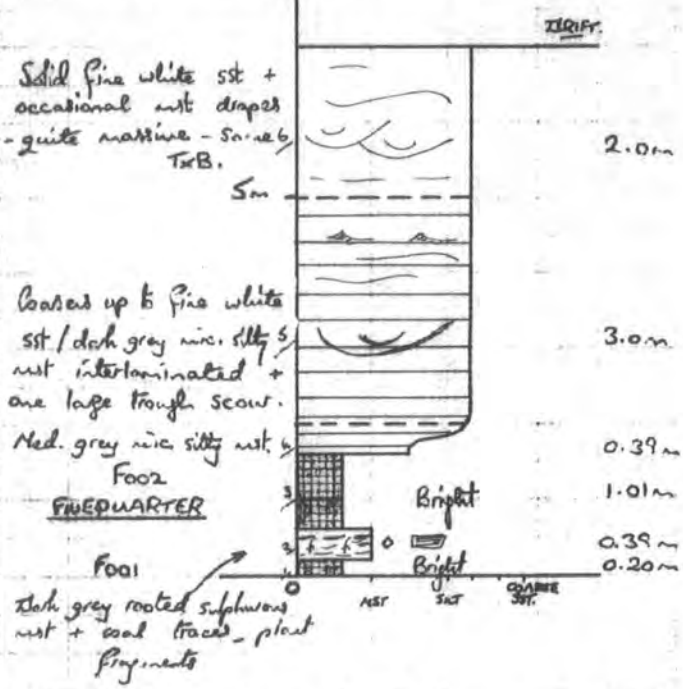
P300 thin shaly coal - persistent right along section. 3 photos. 2 samples.

C.R. FIELDING - 17.3.81

Area C2 (East) - Cut 8

SECTION 317 - EDMONDSLEY C2 8.

50m east of middle access road.

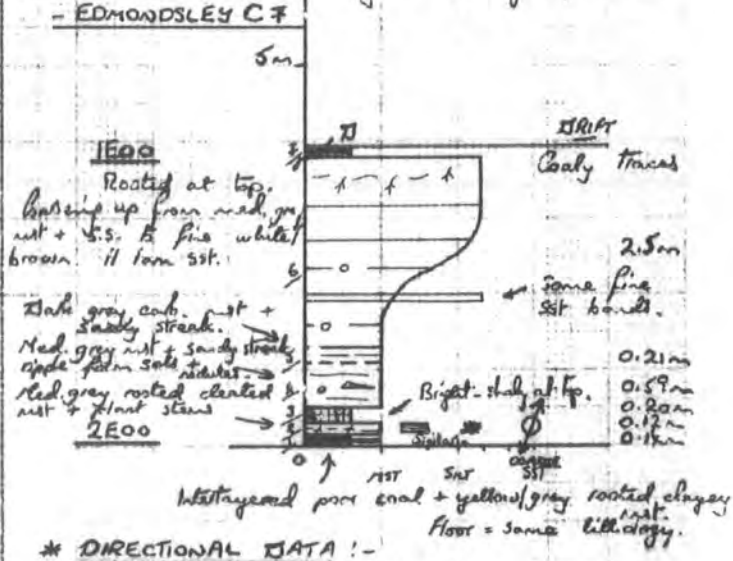


Cut finished coaling - partly filled in - little lateral variation visible.

Interlaminated facies - one trough scours present - direction not determinable - 5m wide, 1m ↑ section. Mostly // lamn. present - some very fine lamination within sst or mst units. General coarsening up - sst units get thicker up, have RxL toward top.

Cut 8 - Side wall - E-W - along southern edge of site.

SECTION 318 - EDMONDSLEY C7



Interlayered poor coal + yellow/grey rooted clayey mst. Floor = same lithology.

* DIRECTIONAL DATA :-

Unit 2 - orientated Sigillaria stems →
208°, 241°, 210°, 180°, 217°, 201° n = 6.

- Plants all flattened impressions on bedding planes.

PLAN

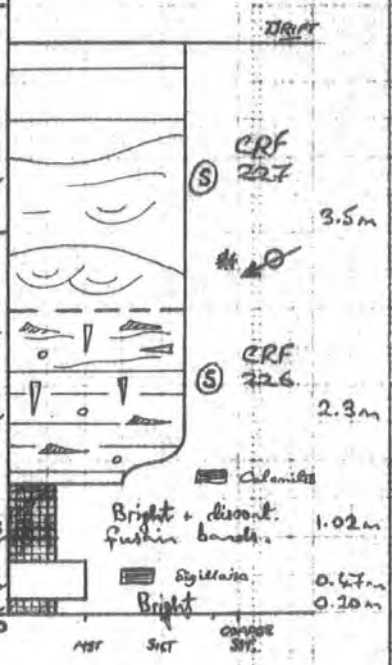


C.R. FIELDING. 17.3.81

SECTION 319 - EDMONDSLEY C310

~100m along from west end of square chunk of Cut 10





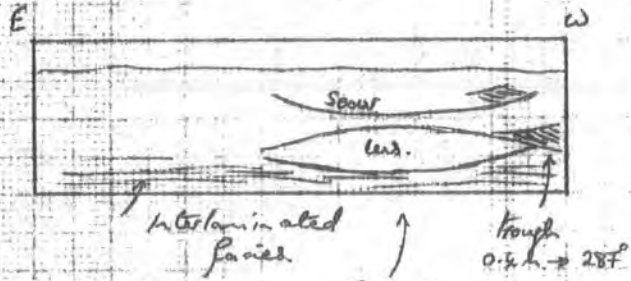
* DIRECTIONAL DATA :- Unit 5.

Trough x Bedding :- 1. 0.6m/15/288° 2. 1.0m/18/280° 3. 0.4m/ / 287°. n = 3.

NB first two from west end of Cut 9.

Interlaminated facies - some ripple form sets - R≥L present - especially near the top of the unit. Horizontal & vertical burrows present. Some very fine interlamination - often uneven.

FIELD SKETCH



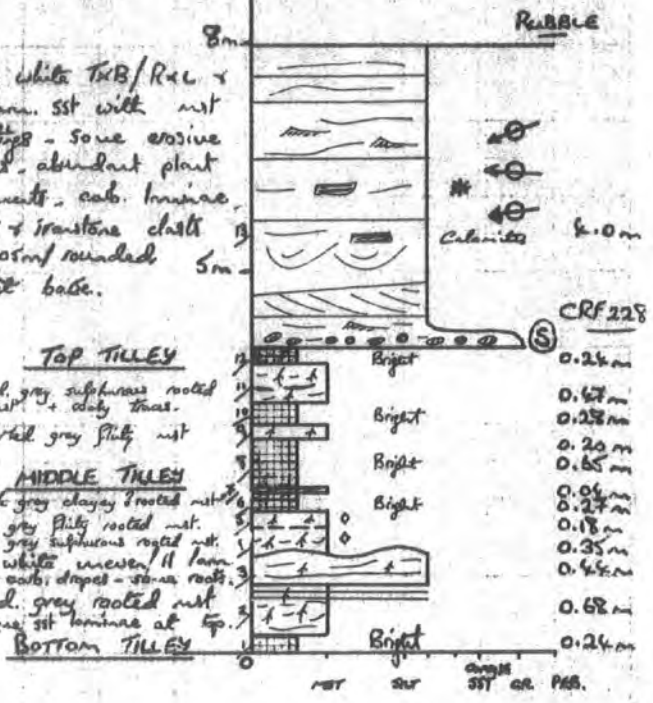
Bar like forms and ? channel scours present in sst.

Cuts still offset - with step in rubble - no new big sections presently exposed.

C.R. FIELDING - 19.3.81

SECTION 320 - MOWN MEADOWS - 12

Cut 12 - 100 west of corner - 2/3 of way along face

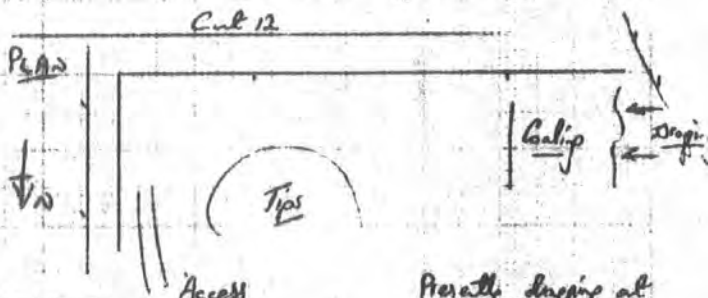


* DIRECTIONAL DATA Unit 13

Trough x Bedding :- 1. 0.35m/ 26/ 214 2. 0.4m/ 27/ 285° n = 2

Ripple x lamination - 1. 288° 2. 283° n=2

Drifted plant remains - 1. 256° n=1 (0.5m long Calamites stalk).



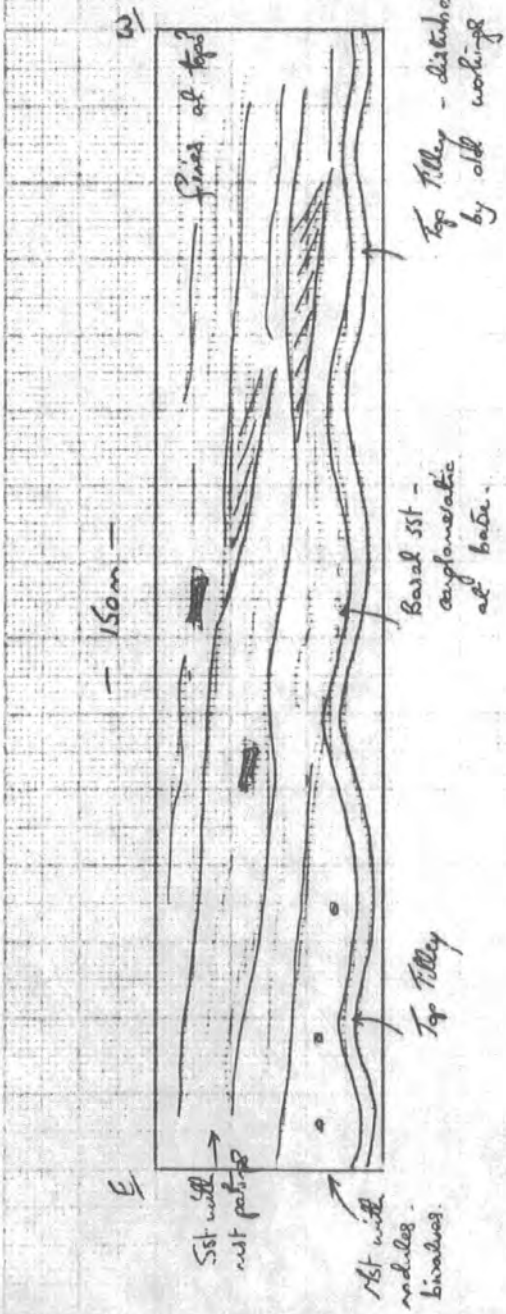
Presently digging at west end of cut - mostly coaled out - near large making site boundary - "Massive sst" appears to directly overlie Top Tilley. Followed by interbedded facies. Cut trends → 260°. At east end of long wall - 1m mst with bivalves and nodules is overlain by interbedded fine sst & mst. By 50m along face, sst lies directly over Top Tilley - and does so for the rest of the section. Sst does not contain many measurable structures - occasional R≥L / T≥B. Some splitting of sst units along face to west. On east face - sst units don't change systematically in thickness - come and go. Sst mostly in units ≤1m thick - separated by med. grey lam. mst partings - often 0.05m or less thick. Mostly 11 lam. or uneven lamination + some R≥L - T≥B. Troughs increase in thickness downcurrent in spoon-shaped scours - have limited longitudinal extent.

C.R. FIELDING - 19.3.81

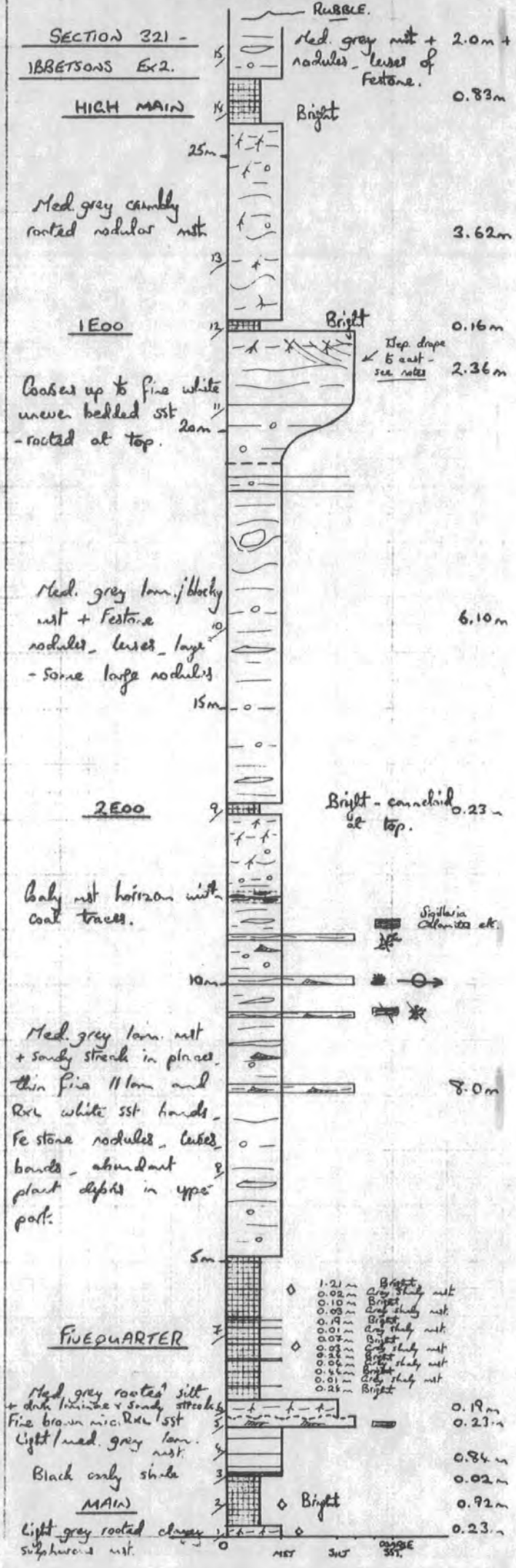
Main Meadows - Cont.

Abundant plant remains present, especially Calamites stems - either preserved as flattened coaly impressions or sand-filled pith casts. Carbonaceous laminae common. Bottom of basal sst is conglomeratic - containing partly rounded clasts ≤0.06m of mst + ironstone. Abrupt top to conglomeratic layer. Matrix of this layer is med./coarse sand grade. Bedding planes flat or undulating. Sst cuts into mst, but not into sst.

SKETCH OF FACE - CUT 12.



C.R. FIELDING - 23.3.81



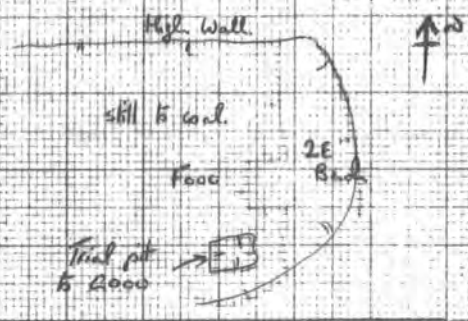
C.R. FIELDING - 23.3.81

C.R. FIELDING 27.3.81. CABIN HOUSE

Observations - Section 321 - continued

Section 321 is composite. See Plan.

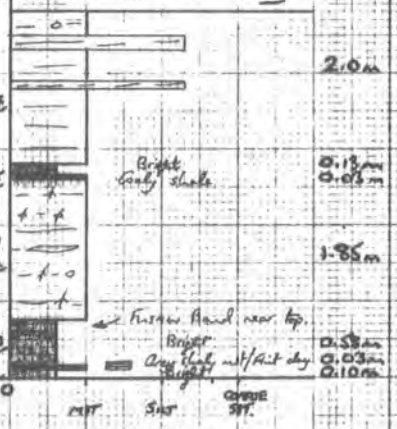
PLAN OF WORKINGS



* DIRECTIONAL DATA :- Unit 8
Rake → 100° n = 1

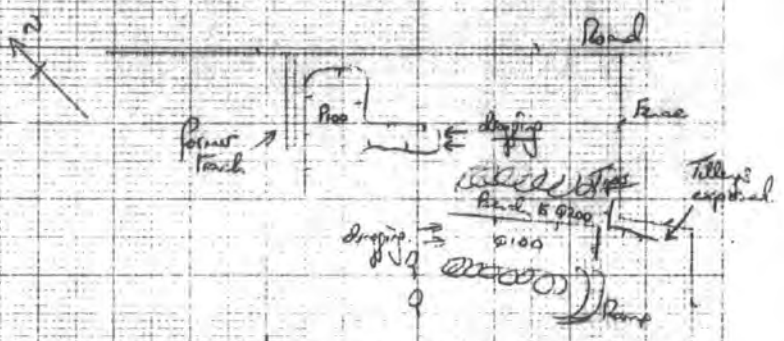
Thin sst units in Unit 8 contain lenticular bedding and Rpl - often very low angle. At top of section, High Main part cannel in with abrupt contact, but section is obscured by rubble. Sst below 1E00 dipping down to east at east end of High wall - 1m asymptotic sst. 2 plates of Main exposure.

SECTION 322 North end of Cut 2E.
- TRAWLERS HAUL - 2E.



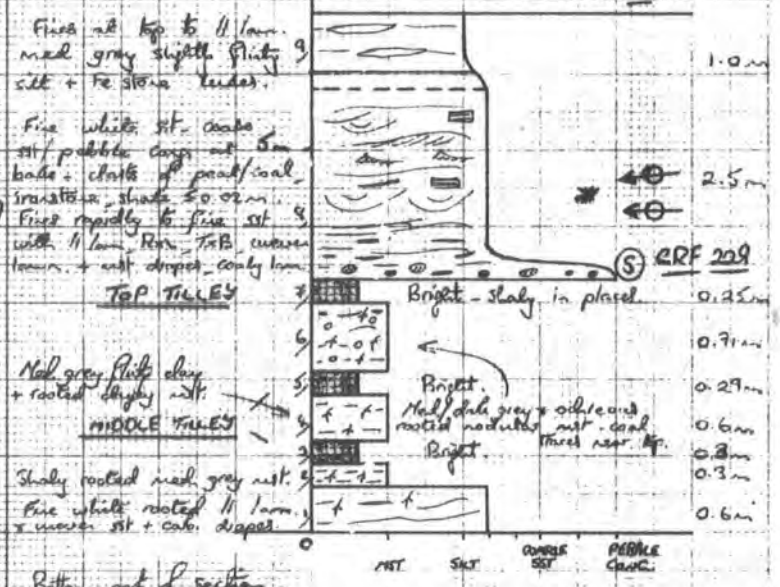
No lateral variation visible except thickness of Top Hutton - undulating. Bottom leaf of Bottom Hutton varies from 0.05 - 0.15m - and also varied in quality. Band varied from shaly grey mst to grey/brown flint clay. + often coaly.

Cut 2E now finished - Cut 3E just started at south end. Situation otherwise exactly as per last visit - Cut 4W just starting.



SECTION 323
CABIN HOUSE - B(S)

Tilley cut by fence - partly flooded. Area to north completely backfilled. Cut TE 15



Bottom part of section disturbed by old workings.

* DIRECTIONAL DATA :- Unit 8.
Trough x Bedding - 0.2m/29/273° n = 1
Ripple x lamination - 229°, 231°, 298°, 274° n = 4
Some very low angle x sets present.
Some evidence of overall dip to west in sst.
In Unit 8, plenty of coaly laminae & traces in basal part, carbonaceous drapes further up.

C.R. FIELDING 27.3.81

7.4.81

NB Out of Sequence

SECTION 328
CABIN HOUSE - CH1

Cut BBB

Same one

Our cut further than last visit. Dragline at west end

Take as 0.5m gap.

BUBBLE

Bed - next bed of Top Bustry.

Red grey ll lam silt + plant debris.

Bright - 1020

Fine white Rm/FsB sst + some massive bedding silt partings with abundant plant debris, thin coal seam near top

Roof not visible →

Bottom Bustry

Bright - not measured ?

CRB 250

5.0m

6.0m

2.0m

0 MST SST COARSE SST

DIRECTIONAL DATA :-

Unit 2 - Trough x Bedding - 0.4m/17/161
0.3m/20/173°

Very wide shallow troughs - almost like planar asymptotic x sets?

Unit 2 - Ripple x lamination → 151° 160° 136°
153° 146° 170° 131° 153° 144° 182° 156° 153°
134° 142° 152°. n = 15.

Rxl of 3 types - 1. Cosets of Type A ripples ≤ 0.03m Lth.

(climbing rippled)

2. Mutually cross cutting ripples, some stoss-side preservation.

3. Very low angle ripples

Very little coal present - heavily worked. Silt partings in sst - often rooted. Sst has abundant carb. shapes - also red Fe-O rich laminae in Rxl - weathering. Some fine grey mst shapes also. Some sst beds "structureless" - well cemented. Beds ≤ 1m thick - mostly less.

At corner of fence, east end of Bottom Bustry cut, barbwire exposure of Tilleys still visible, though badly slumped and heavily worked. Sequence - Bottom Tilley, shales, sst, shales, Middle Tilley - 2 layers with upper one - Seam - the shales + rubble. Section down to Top Bustry mostly obscured

Total 2 samples
5 photos.

SECTION 329
DEBORAH Dn 83.84

Section at NW end of cut.

Cut trends → 330°.

DRIFT

13m

10m

13

12

11

10

9

8

7

6

5

4

3

2

1

0

Fine buff fragile x Bedded sst + coaly plant debris

Bright

Red grey rooted mst

Bright

TOP TILLEY

Hard brown/grey flinty rooted mst.

as below but rooted. Seam

Well cemented in places. - May have been sst originally.

Light grey rooted clayey mst - may have been silt

Carbonaceous up to uneven lam of very fine sst.

Red. grey mst + common fossil

11 lam med. grey silt + sandy streak

Coarsening up to fine white micaceous lam sst.

Red grey blocky/lam. mst + nodules

MIDDLE TILLEY

Bright

MST SST COARSE SST.

5.0m

0.18m
0.45m
0.36m
0.03m

1.60m

0.70m

0.60m

0.45m

0.74m

0.42m

1.86m

0.19m

DIRECTIONAL DATA.

Unit 13 - Trough x Bedding

1. 0.5m/15/339
2. 0.3m/9/139
3. 0.6m/22/006
4. 0.2m/24/025°

n = 4

Little lateral variation in facies.

3 photos.

C.R. FIELDING - 7.4.81.

SECTION 326 - BUCKHEAD - C2



Buckhead unit - although unit well exposed and well bedded/laminated

Fine buff silt - well-consolidated - mostly homogeneous - occasional shell debris in beds. Sporadic development of pelitic coquina (coarse) at base.

Med. grey hard flaky & rooted silt - some only traces

Coq. - composed of shale & mudstone clasts, some well-rounded - 5-0.05m across - only distal preserved also. Matrix supported, though high clast concentration. No internal organisation - abrupt top.

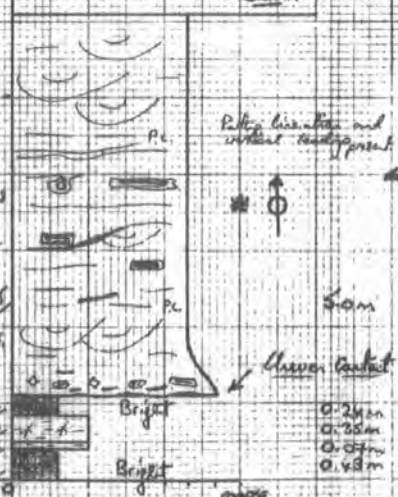
Few stringers in lower homogeneous unit.



2 photos.

SECTION 328 - DEBORAH Xiv N.

Cut track → 330°
SE End



Fine white/buff silt - frequent rooting & Buckhead homogeneous unit - centre of bed.

Abund. shell debris and pyrite blebs & early plant casts.

Mm-cm scale pottage in places. Some rough lag casts.

Red grey rooted silt - early stages

Light grey clay

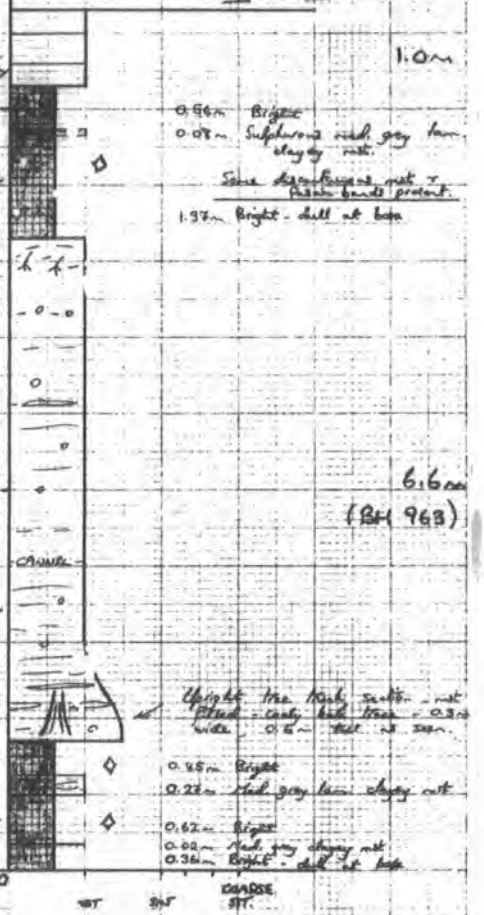
Pelitic lineation and current ripples present

Uneven contact

SECTION 327 - BUCKHEAD (L.E.)

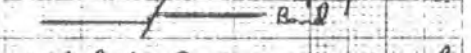
3 photos





NB Maudlin & Main pelite appear to be decreasing to east. Confirmed by borehole. Section above Main disturbed by faulting.

Maudlin - bands laterally variable and discontinuous - typ synsedimentary faults - particularly near top of seam, affecting top band



Working becoming very disturbed by faulting at north end of area. Fingerpost being worked at outcrop - under pc layer on northern wall. Coarsening up sequence over Main still present, but no lags forecast present.

2F00 is ~ 0.3m thick.

* DIRECTIONAL DATA

Unit 5 - F18 - 0.3m / 15/352°. n=1

NB Little lateral variation visible - only 50m measured so far.

General direction of flow → N.E. Pelitic lineation present. Block of 5ft under dogline still.

2 Desiccation cracks on mst slope - east.

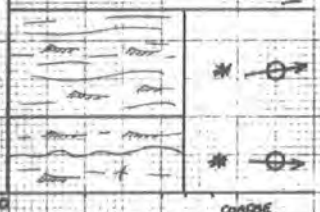
Spread left - due to vertical loading.

SECTION 329 - SEE BEFORE 325

CRF - 8.6.81.

SECTION 330
- WEAR GORGE (a)

Outcrop a - see map - South of Prebends Bridge on west bank of Wear.

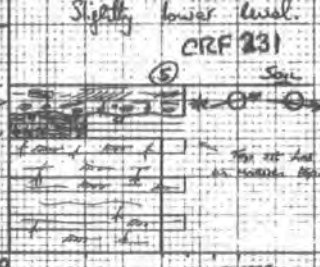


* DIRECTIONAL DATA :-
Unit 2 - Rml → 097° n=1
Unit 1 - Rml → 069°, 100°, 132° n=3

Position 20' from top of bank. Probably top of Seam ssk body exposed above Prebends bridge.

SECTION 331
- WEAR GORGE (g)

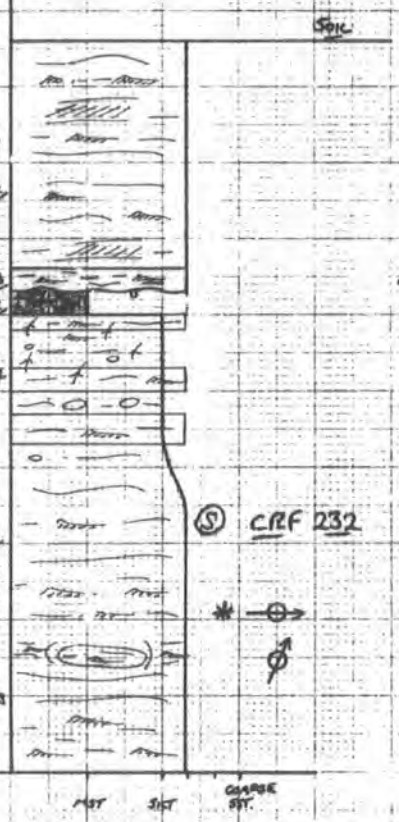
Half way up bank, 20m South of 330 - just above path. Slightly lower level.



* DIRECTIONAL DATA :-
Unit 3 - plant casts (clipped) → 067° n=1
Unit 3 - Tabular x set 027/19°/100°. n=1.

SECTION 332
- WEAR GORGE (h)

West side of 3rd re-entrant large a.a carrying small stream. Upper half of bank.



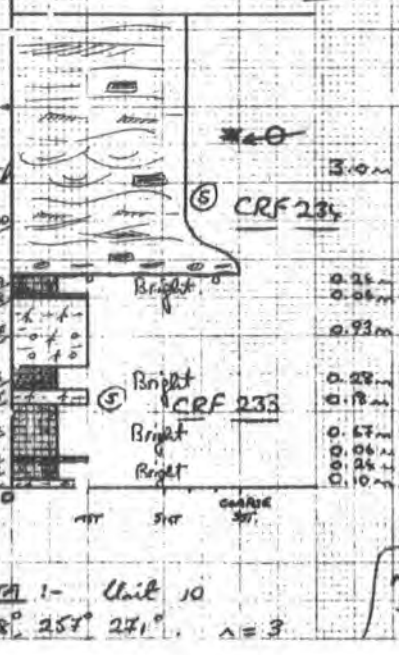
* DIRECTIONAL DATA :-
Unit 1 - Rml - 099° 063 096 074 086 106° 050 088 035 n=9
Unit 1 - Rml - in "cretionary" layers - 031 353 345 019° n=4.

CRF 9.6.81

SECTION 333
- ASHES MEADOWS-13

East end of Cut 13.

Badly disturbed by old workings.



Unit 6 - Coal seam locally thickened by lens of dense pyritic ssk in middle of bed + small cementations also there.

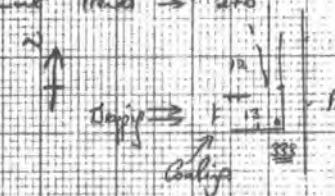
* DIRECTIONAL DATA :- Unit 10
Rml → 228°, 257°, 271°. n=3

NOTES - SEE OVER

CRF 9.4.81

Mows Meadows - Notes

Cut 13 - prin. dip/az 30m west of east end Cut Mark → 270°

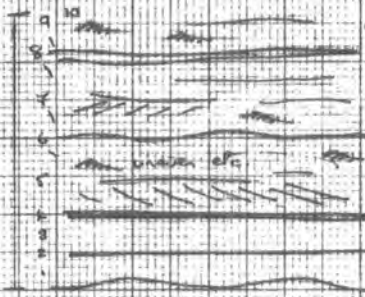


SSt lies directly over P300 - exes at east end of cut. Visit present 30m along access road to north.

Flint nods appear to have more brown material - bulbs - near top of cut more grey crab matter downward (also are flint).

Top Tilley post - common plant stems. Shale clasts + coaly laminae at base of SSt. plant casts - all through. Low angle x lamination + x Bedding predominates - flow toward west. Slightly folded rock to SSt directly over coal - undulating slightly erosive contact.

eg Detailed vertical sequence



Units mostly tabular laterally - but disturbed by old scourings. Layers between mtst drapes commonly ~ 10 cm.

* DIRECTIONAL DATA:-

SECTION 334

Unit 5 - Tabular x Sets 0.2m/18/182 0.6m/8/048
CAXS 0.15m/2/03)°
Rxc → 043 092 042 071 031 017 033 085 088 040 028 152 050 040 028.

Unit 3 Rxc → 038 042.

Unit 1 Rxc → 044 030 015 081 046 029 049 042 051 030 035 067 056 021 085 040 063 026 023 029 007 018 008.

SECTION 335

Unit 4 - Plant axes (drifted) → 183°
Trough x sets 0.3m/21/162. 0.4m/15/139

Unit 1 - Trough x Set 0.6m/23/144°

SEE REPORT.

CRF 10.4.81

Composite Section - St. Oswalds Well Locality M

SECTION 334 - WEAR GORGE.

Fine brown Tab 10m xB/Rxc sst: both thin bedded + well cemented types present. Ripples - types as for 1, but longer. (resets 60.05m)

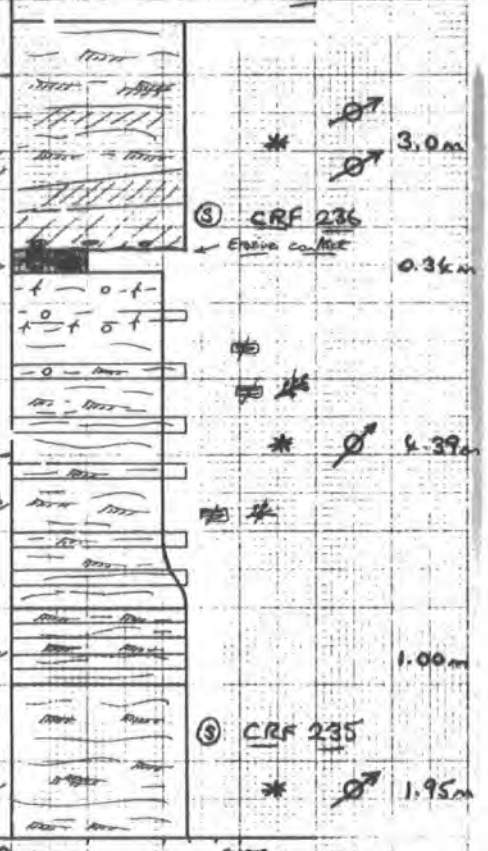
Coaly x coaly shale 4

Nodules x roots towards top.

Interbedded Fine 5m brown Rxc sst x med. grey silt - all thin 3 laminated + sandy streak

As below but very thinly bedded.

Fine brown Rxc sst + mostly well cemented Rx's - Type A mutually interfering x low angle - dish cavities 0.02m both Innings - or alternations of this type.



SECTION 335 - WEAR GORGE.

Sayda south of Kingsgate Bridge - Locality A.

Med brown TxB sst + coaly mass + plant fragments.

10m

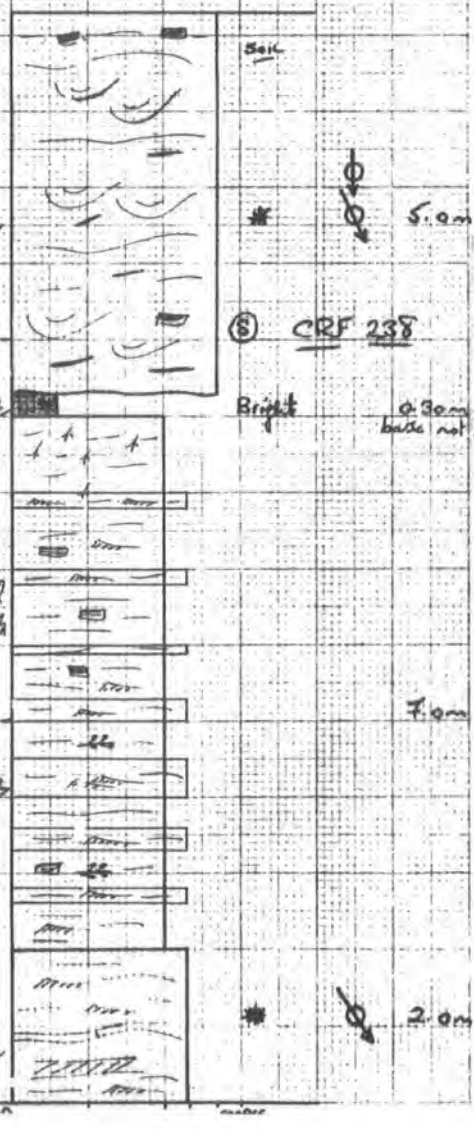
COAL SEAM

Top rooted.

Med grey Rxc silt + sandy streak, occasional fine thin Rxc sst beds - more sst downward

Well preserved plant 5m remains in silt layers.

Fine/med. TxB/Rxc sst with med grey silt partings



CRF E 15.4.81

CRF 27.4.81.

SECTION 336 - WOOLEY A3.

Cut 3 - 2oyds south of NW end - east trends → 124°.



Fine/med buff x bedded sst - wavy bed. 5m

Med. grey silty mst

Fine buff sst

Med. grey silty mst + sandy streaky

Fine buff Rxc sst + calc. lenticles

Med. grey lam. silty mst

Massive fine buff sst

Med grey lam mst + lenticles

Med. grey + buff sandy flasers

Med grey clayey rooted mst

Cut is ~ 70m long. Sst bands laterally continuous and were at least constant in thickness along the cut. Cuts 1 & 2 were largely on outcrop and badly disturbed.

SECTION 337 - WOOLEY A3

25m further E SE - 20m from SE end of cut - nearly completed dogging.



Buff fine/med. TxB sst - weathered 5m

Med grey silty mst + sandy streaky - wavy bed. 12

Fine white mottled sst. 19

Med. grey silty mst - sandy streaky

Mottled buff fine sst. 8

Med. grey silty mst + sandy streaky

Fine white mottled sst 5

Med. grey lam. mst - dish + sandy lenses

Med grey silty mst + coal flasers

Med grey clayey rooted mst 3

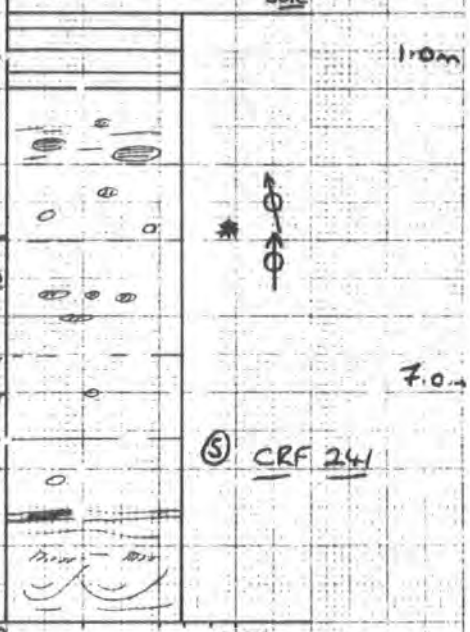
Note - Section 339 lots of low angle x surfaces present - low amplitude wide troughs probably → undulose bedding observed on weathered outcrop.

Units logged change in character x thickness laterally very rapidly. Some similarity to thick micaceous bedded strata exposed at Elland Edge - though more SST. Some normally graded thin sst units present.

SECTION 338 - LANGLEY WEST QUARRY

Hoiron - Horsey Post. Tectonic dip 9/034

As below but wall badded (11).



Fine buff sst - mostly homogeneous - some 5m - faint lamination - much spheroidal weathering - some TxB and RxL near base, abundant shale clasts - some rounded SST clasts near top. Some small patchy, wavy laminae, nodules.

⑤ CRF 241

SEE REPORT

DIRECTIONAL DATA

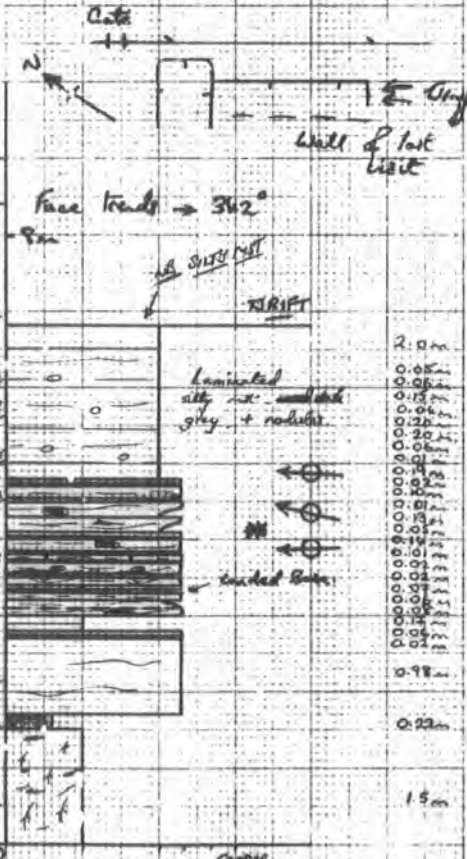
Trough x set - 0.3m / 24 / 338. n = 1.

RxL - 320°, 020°, 011°, n = 3.

CRF 29.4.81

CLK T.17

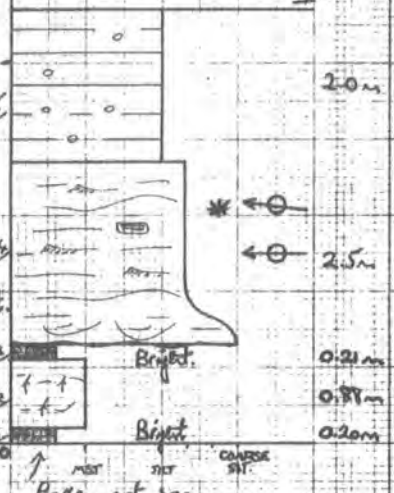
SECTION 339 - CABIN HOUSE B(S)


Cut 11
N
Dogging
Wall of last night
Face trends → 342°
8m
NB SILTY MST
DRIFT
2.0m
0.05m
0.06m
0.13m
0.04m
0.02m
0.02m
0.01m
0.01m
0.03m
0.01m
0.01m
0.01

CRF - 29.4.81

SECTION 340
- MOOR MEADOWS - 13.

Cut 13 troughs → 282°.
Presently 80m along - section half way along.

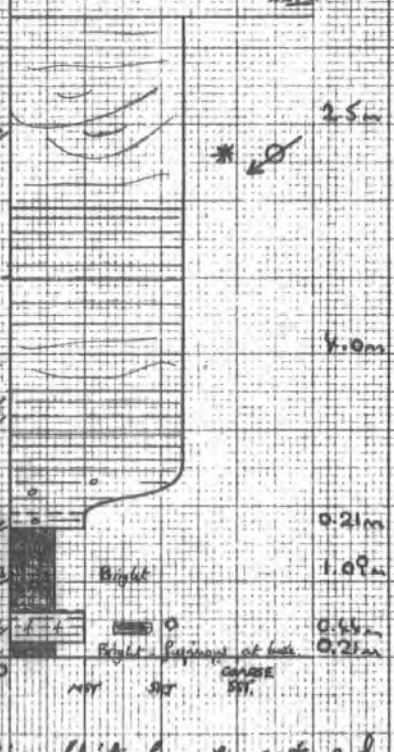


* DIRECTIONAL DATA :-
Trough x Set - 0.2m / 31 / 288. n = 1.
Ripple x lamination - 267°. n = 1.
NB In eastern corner of cut, draping effect of sst layers down to south - oblique to flow direction.
Lateral variability impossible to assess.

CRF 30.4.81

SECTION 341 -
EDMONDSLEY C310

10m 50m from west end of cut. Cut finished.



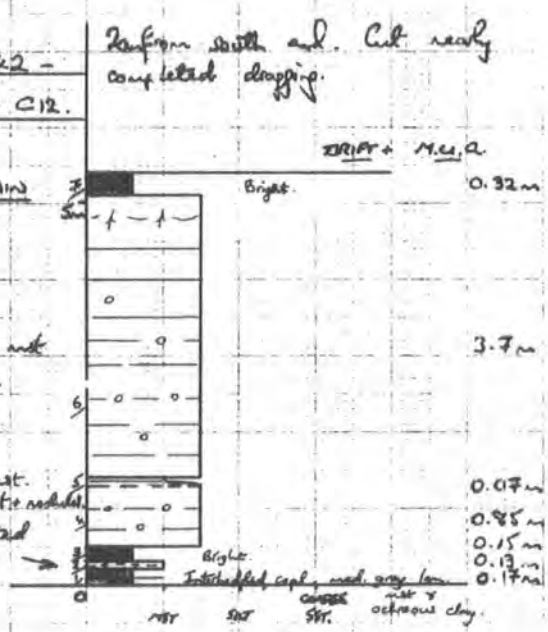
DIRECTIONAL DATA - Unit 6 at east end of cut - Trough x set 2m / * / 231°.
? 20m wide.

CRF 30.4.81

At east end of cut several large ≤ 20m wide troughs ≤ 2m deep, in the upper solid sst facies - direction difficult to assess - very oblique to face, one → 231°. Underneath, in interlaminated facies, trough-like scours also occur, with the upper parts infilled by solid sst, and occasionally overlain by more interlaminated sediment - 2m upward - major trough mentioned above. Basal parts of erosive units Rrl and chaotically bedded.

SECTION 342 -
EDMONDSLEY - C12.

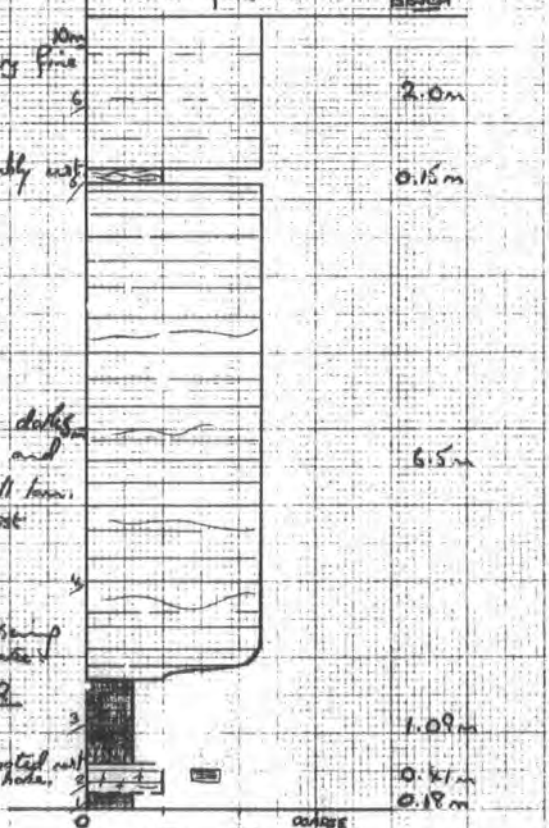
Dip from south end. Cut nearly completed dipping.



Ochreous yellow clay floor.
Sharp dip outcrop at south end of cut.

SECTION 343 -
EDMONDSLEY C29

Near east end (20m away) cut finished.

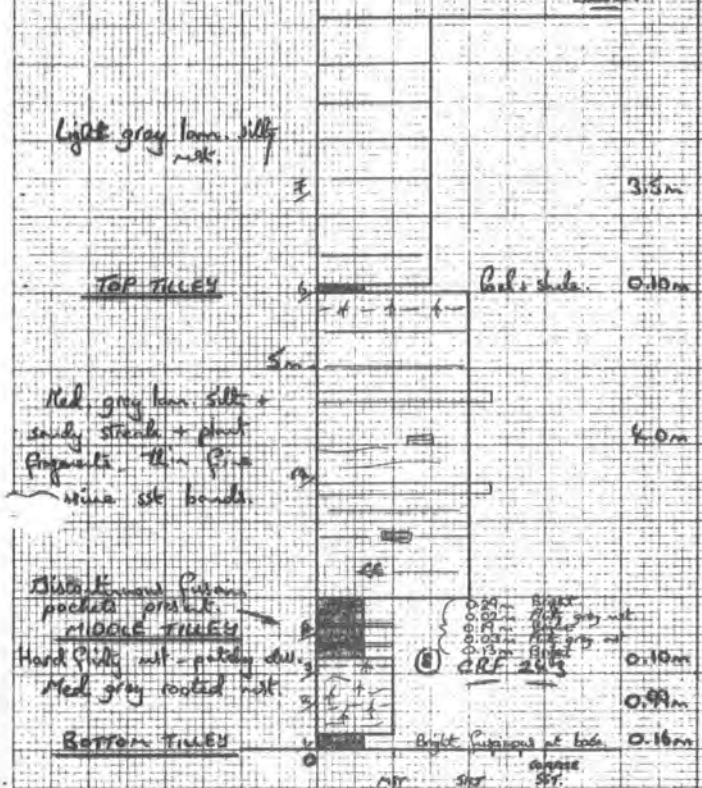


(CRF 342 - Wetter Hill)

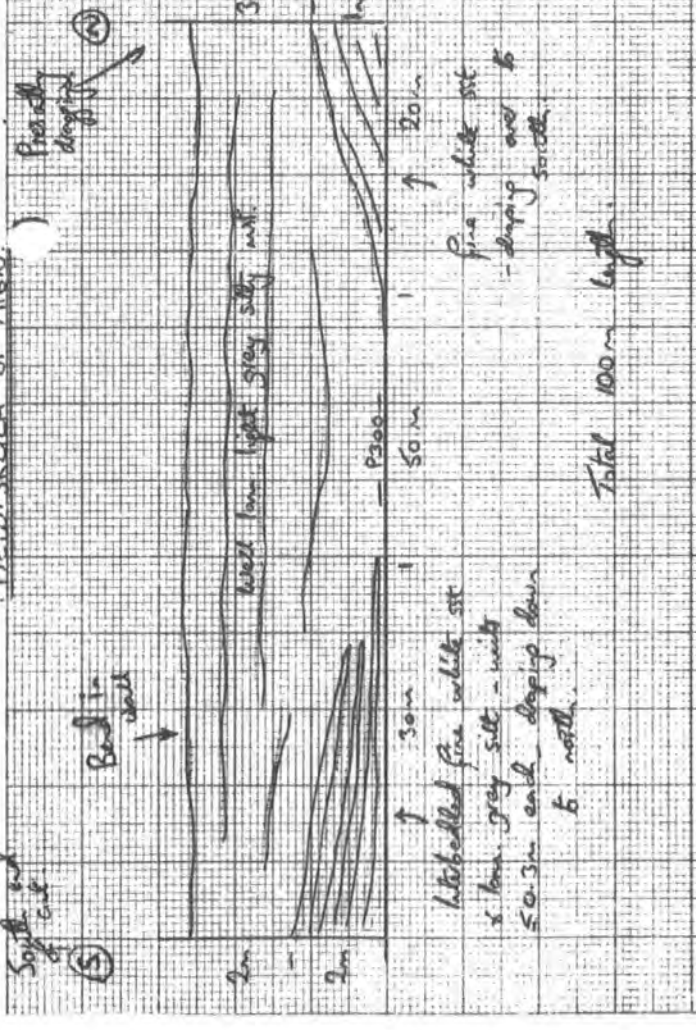
CRF 6.5.81

SECTION 344 - ROWLEY AIGN.

Cut AIGN - Final Tilley cut 50m north of south end. Another 50m to grey. Finally 100m dragged.



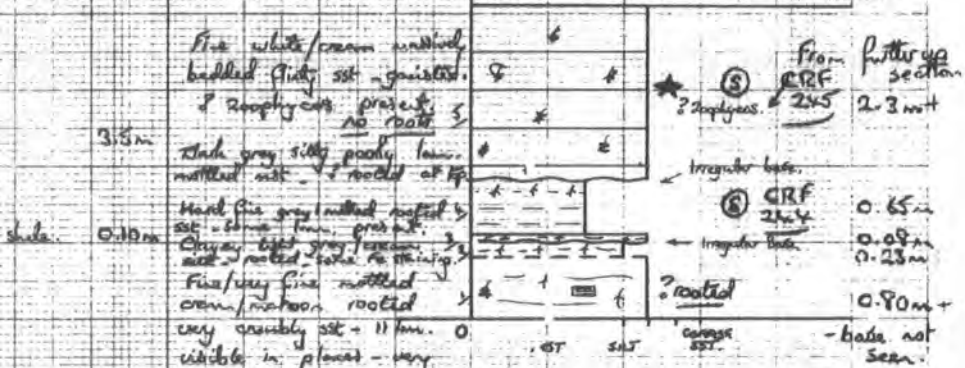
Units in P300 variable in thickness



CRF 13.5.81

Heavily weathered streambank section. GR NZ 096647. Just south of bridge on minor road. Ho 20m - below Kays Lea MB = LISTERI STREAM.

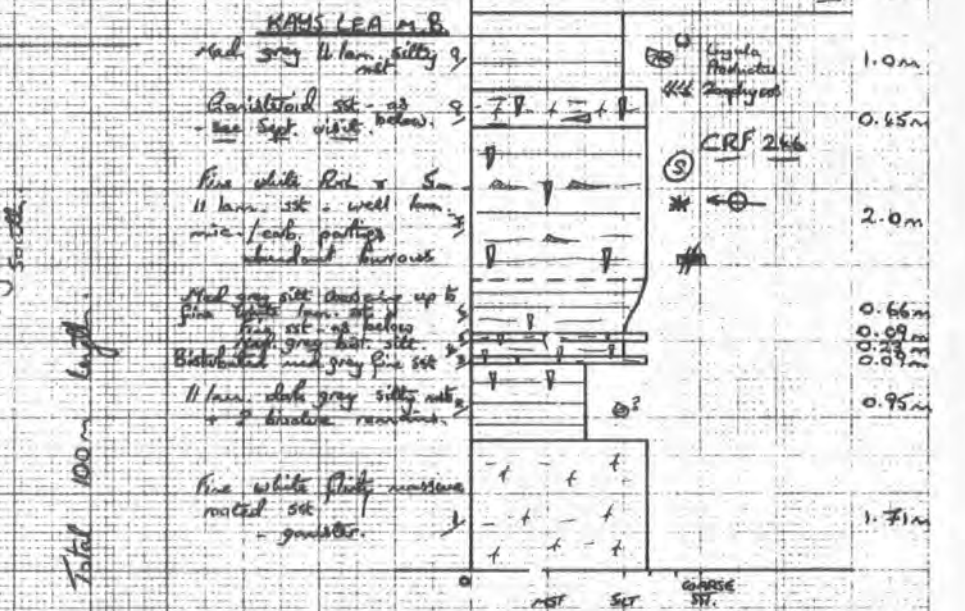
SECTION 345 - WEST BLAISFIELD QUARRIES



Units laterally continuous over ~ 30m.

SECTION 346 - WEST BLAISFIELD QUARRIES

East end of main quarry - used as canal rubbish tip.



* DIRECTIONAL DATA:- Unit 7. Ripple x lamination → 297° 263° 296° x = 3.

Unit traceable with ~ constant thickness along quarry face for ~ 200m. Unit 7 interbedded with shales to East. 200m further east along old linear quarry - sinuous feeding traces in silt - trough x Bedding in sst (Unit 7)

* 0.25m/24/183 0.15/23/190 0.2m/19/192 x = 3

Sst med grained - fine. Top part of underlying V sequence contains smooth-topped wave-influenced ripples striking 292° 0.02m Λ ≤0.05m λ. Top gritstone 0.7m thick underlain by a thin cream coloured clay with ferruginous nodules. Kays Lea MB = LISTERI.

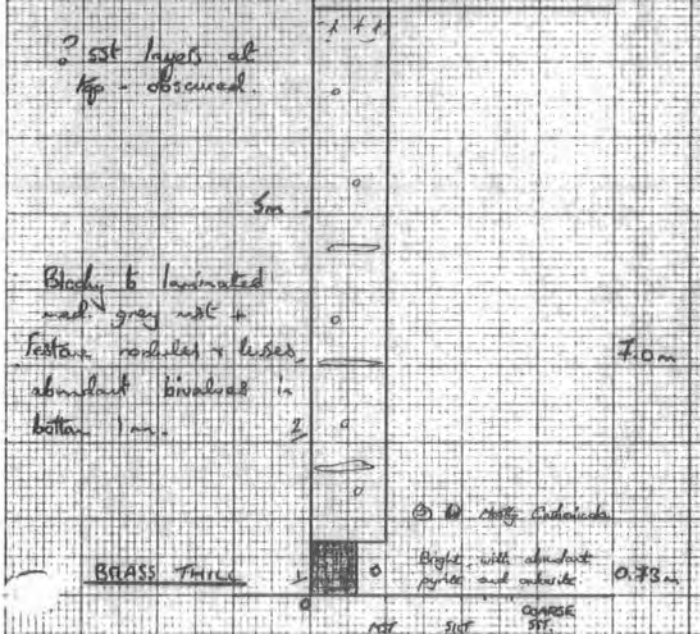
CRF 14.5.81

SECTION 347

BUCKHEAD C(2)

Second part of Area C!

RUBBLE - BENCH TO LOW MAIN



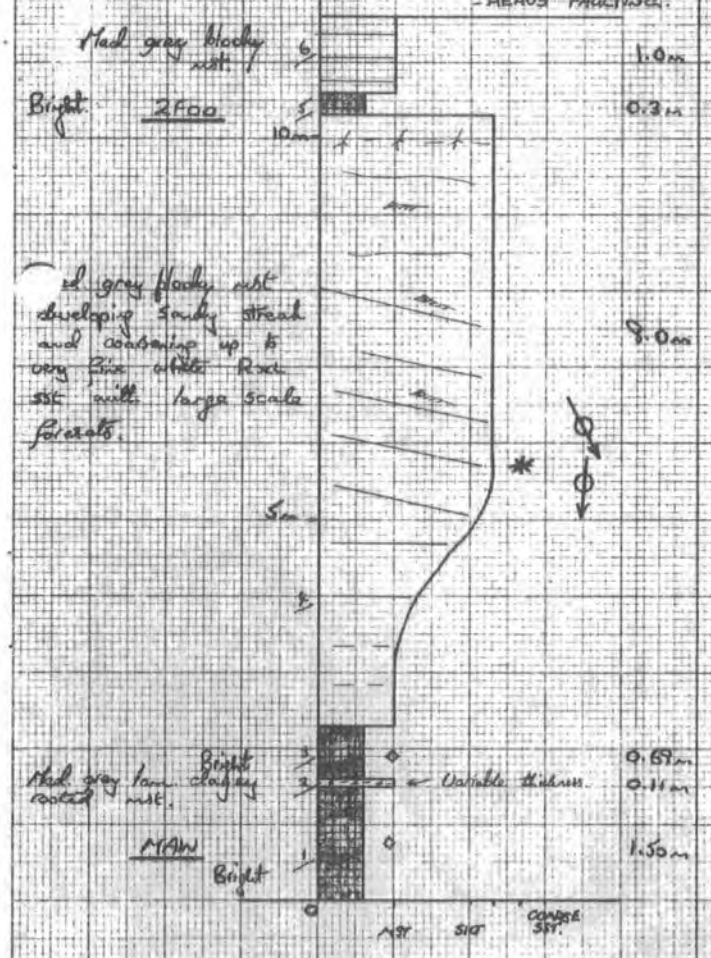
Bivalves - some in life (burrowing position) - some clapped - majority disarticulated.

SECTION 348

BUCKHEAD (L.E.)

Sidewall of Laundry Extension → 348° - toward east end of pit heaps.

SECTION CONTINUES - HEAVY FAULTING.



DIRECTIONAL DATA :- Section 348.

Unit 4 - Large scale foresets → 152°. n = 1

Unit 4 - Rxl → 183°, 220°, 229°, 180°. n = 4.

Exposure does not permit detailed observation of sequence above 2F00, but sst developed the 1F00 mst & disturbed five quarter under old pit heaps.

CRF 16.5.81 PEMBROKESHIRE. C.R. SN 186072 to 174072.

SECTION 349 – TECRYN PT. → AMROTH

TOP OF SECTION.

NB 10.0m exposure.

Total – 48.6m section.

CONTINUED.

Coarse & med. grey silty mst – some large conc.-like coal siderite concretions – horizontal spacing quite regular – circular or oval in plan – 4in across

9.0m

Med./dark grey mst. finely in places, with rare very thin sst and plant fragments – some burrowed mdstn.

20m

Plant debris mostly Calamites stems.

Fine/v. fine dark grey silty mst with gradational contact

SUBGREYATTIAN M.B.

Bright

Coal in upper part + sphaerosiderite

Med. grey silt with Type C ripples – almost structureless

4.0m

as below.

Well cemented sst horizon.

Sst fine to v. fine grey silt with sinking ripple x lamination – injection pipes of sst. load casts and slumped deformation structures with chaotic bedding CRXL Type B x C commonly 0.05m A, 0.40m λ, about 10m from top of unit – Structureless Type C – A = 0.10m, λ = 0.50m

Slumped structures concentrated in base of CRXL unit

Fine grey sst with sinking x laminations – uniform direction

0.70m

CRF 247

4.0m

Fine grey sst with ripple x lamination – Type A cross laminations – wavy flaser type – wavy, strong lipped ripple basal A = 0.01m–0.02m, λ = 0.10m – small trough forms ≤ 0.10m wide with variable directions in ripples

FAREWELL ROCK

Fine grey sst with irregular bedding – ripple x lamination (Type A)

Variable directions in ripples

4.0m

BASE OF SECTION.

0 mst sst co. Base not seen.

Tectonic dip 14/215 but variable

4.5m

Fine brown x bedded sst – ≤0.03m silt chasts, ≤0.10m silt chasts and large log casts at base only. 40m – some root partings

Sst is well bedded fine to flat base. Large scale x bedding with smaller low angle sets within.

10.0m

Dark grey coaly shale + abundant plant fragments, occasional nodules, colour a bit lighter up

Bright sheared coal

Fine at top, colour darker.

Heavily rooted very fine grey sst + goethite filled cracks, sphaerid. coal, in roots at base, rare at top.

Silt coarse silt + roots, goethite filled cracks, tops of many dykes.

Med. grey rooted silt + sphaerosiderite – cracks filled with goethite + silt filled dykes. Coarsens up into coarse silt with Ra. (Type B) x (bar)flow. 35m16

Ripples near base) sandy near top.

Dark grey shale with plant fragments

Light grey bioturbated and rooted silt with Fe stained nodules – originally well form. – coarsens up to very fine grey rippled sst.

Black coaly rooted coal mst

Fine to med. grey silt becomes rooted

Med. grey / brown fine sst with ripple x furrow. In lower part + large calcareous concretions – Type A ripple x laminated. Better up. – mutually cross cutting sets. Some loading esp. in silty bottoms.

30cm

Fine grey sst with silt pebble shape ripped contents – sst base bedded (undulating)

Load casts and detached load balls of sst in a silt matrix – no consistent closure direction – series of loaded units.

Convoluted horizon overlain by flat lam. silt with basal Fe stone layer.

Coarsens to med. grey sst with festoon nodules x bases – some convolute lamination.

25m

CRF 248

CRF 249

Calamites

Load balls ≤ 0.50m across.

1.30m

0.12m

0.80m

0.15m

0.70m

0.75m

0.40m

1.75m

0.27m

1.0m

3.0m

0.7m

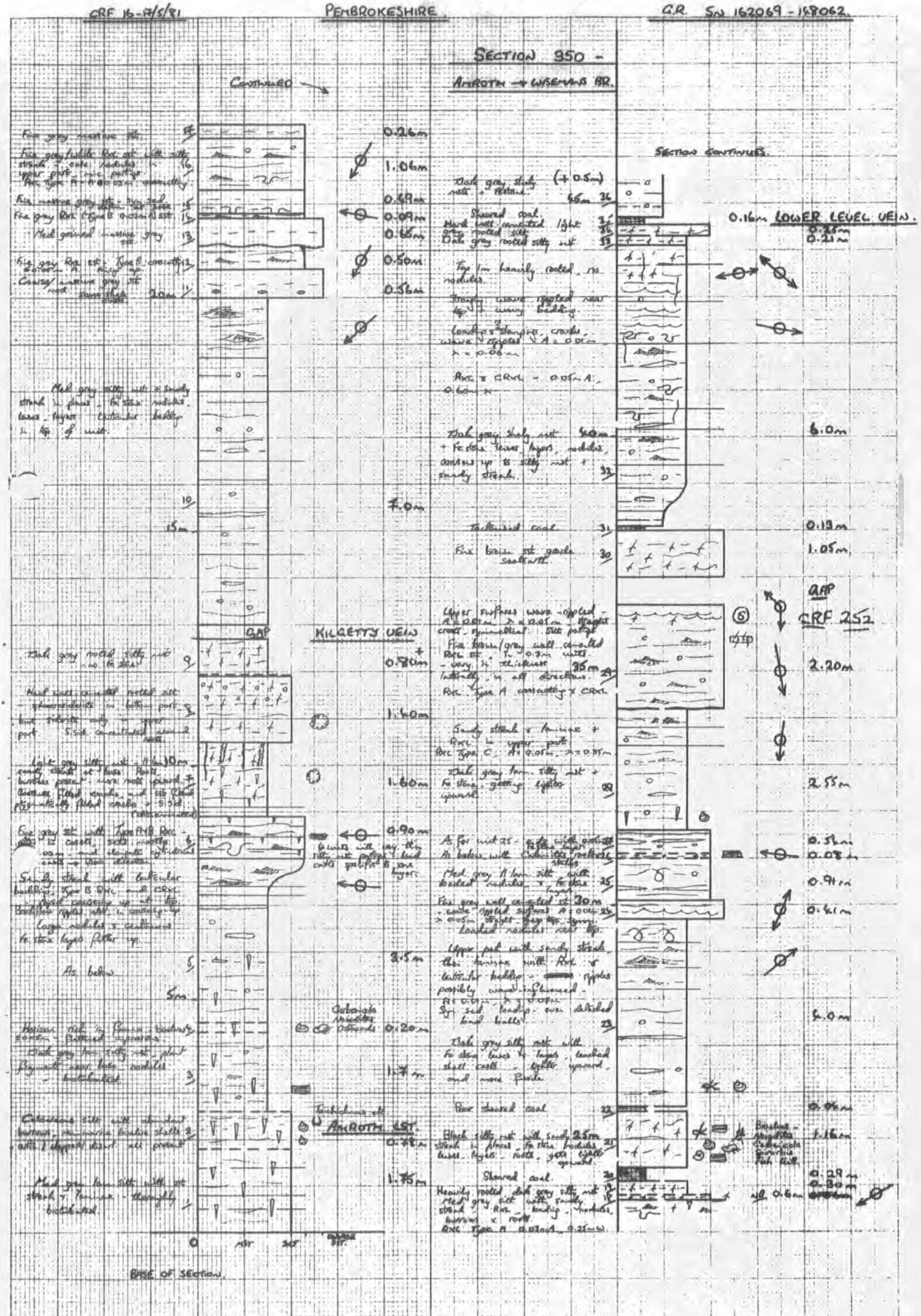
1.0m

(9.0m)

CRF 16-7/5/81 PEMBROKESHIRE G.R. SM 162069 - 168062.

SECTION 350 -

AMROTH → WISEMANS BR.



C.R.F. 18/5/81 — PEMBROKESHIRE — G.R. SM 855188.

See Written Description

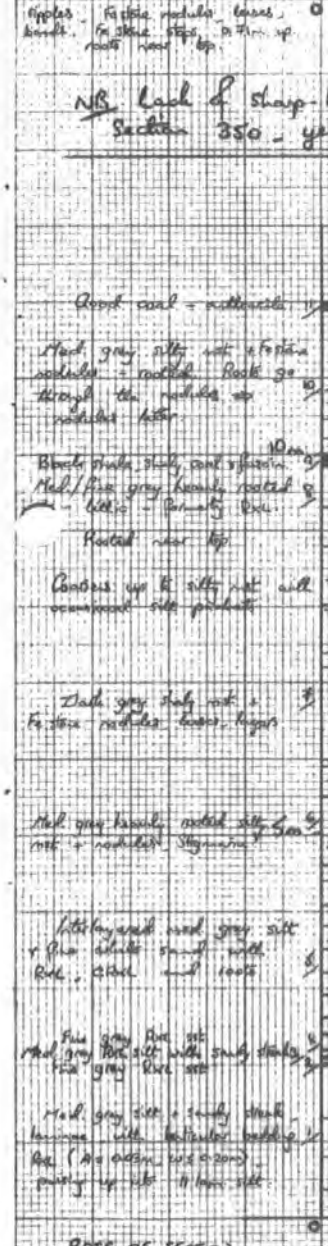
Isolated unbalanced expansion of Kilgetty Vein seatearth in fault block.

SECTION 351 –

200m WEST OF AMROTH C.P.

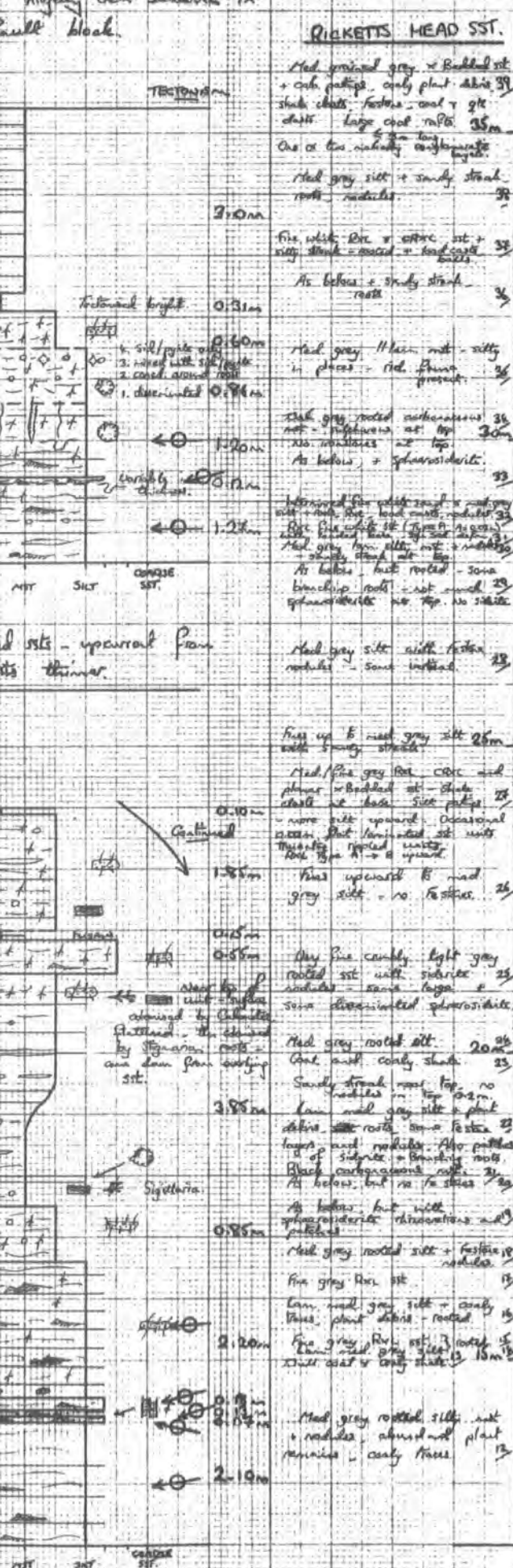


NB Lack of sharp-based sts - upcurrent from Section 350 - yet sts thinner.



SECTION 352 :-

RICKETTS HEAD SOUTH



10m + Bedded sst
4m Sst + silt with TAB + chaotic bedding
3. Mst + U/Bedded sst. Some scour
2m. silt with clastic bedding
?m + Bedded with coaly, lough - coal rafts

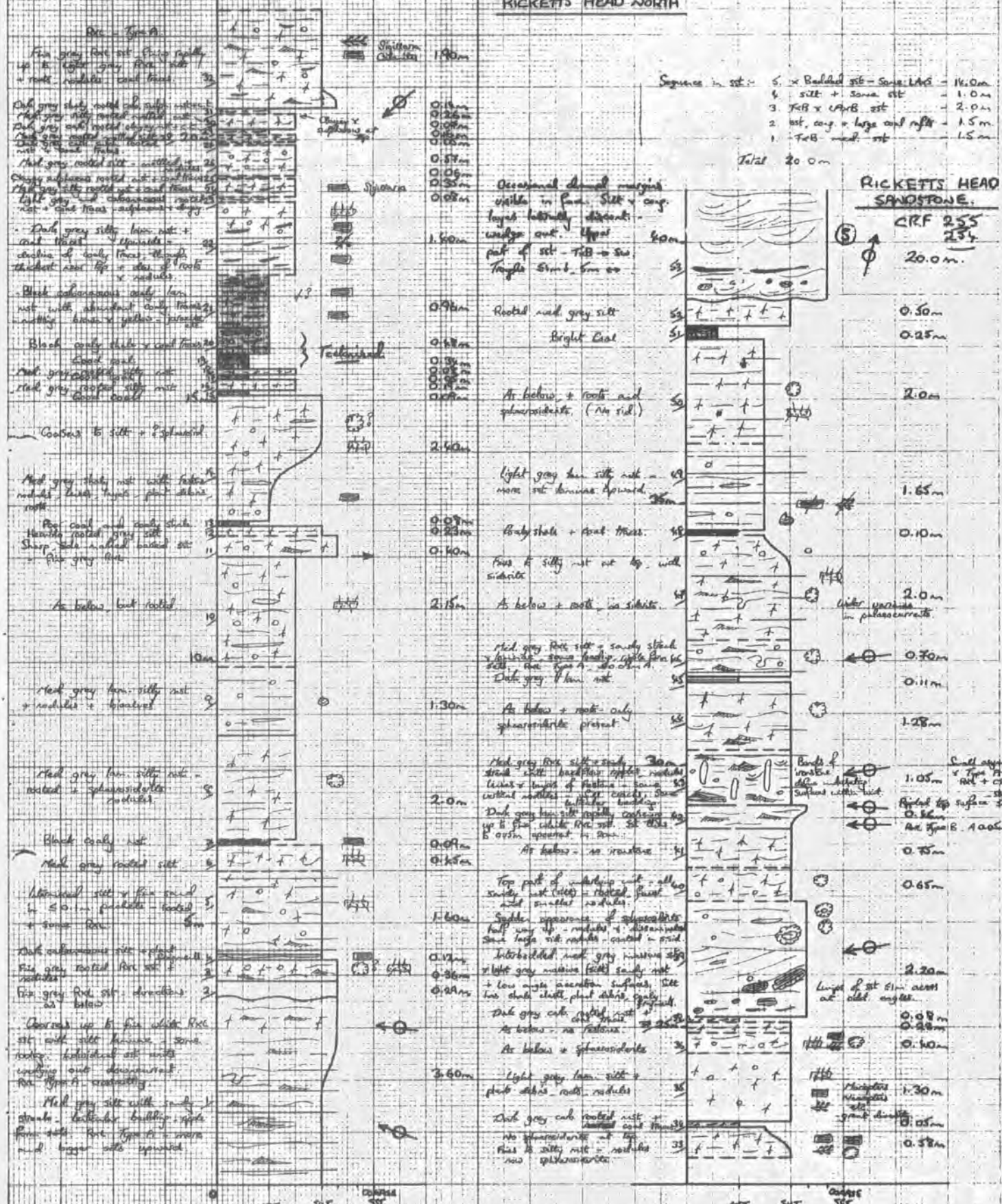
NB 22.0m of Silt

22m
1.30m
0.62m
1.07m
1.60m
0.30m
1.10m
0.72m
0.06m
0.16m
0.90m
1.90m
Rox soil dip all colours discurrent
Individual sst units thicken discurrent
1.97m
1.22m
1.80m
0.47m
0.10m
1.70m
0.07m
0.13m
0.90m
0.55m
0.30m
0.83m
0.18m
0.10m
0.105m
3.00m

?

C.R.F. R-A/5/81 PEMBROKESHIRE. G.R. SM855192.

SECTION 353 - RICKETTS HEAD NORTH



CRF 20.5.81 LANCASHIRE.

SECTION 354 - BILLINGE HILL QUARRY

North end of main quarry.

Tectonic dip 16/100.

Soil

Flaggy dark grey shales. 10m

? PASTURE MINE m.B

Fine buff RXL/TXB sst. - some loading. 2.0m

Well lam. dark grey silty mst 0.50m

CEMETERY MINE 0.22m

Mostly silt grit top. Bright Lower lam. fine buff sst + silt partings + lenticular - rooted 2.03m

Dark grey shale, mst + plants Lighter grey 0.18m

Bright grey clayey/silt mst/sst 0.95m

Buff fine RXL + 1 lam sst + med. grey silt partings 0.12m 1.3m

? CRUTCHMAN SST.

Buff fine TXB sst - also RXL. Plant lam. + P.R. - burrows - thin silt partings ? xylaroid trunks. 2.8m

CRF 257 258

0 MST SST COARSE SST.

SECTION 355 - BILLINGE HILL QUARRY.

9m

Soil

Dark grey shaly mst + occasional lenses fissile mudstone

3.0m

Dark grey flaky laminated mudstone silt + flaser beds.

? PASTURE MINE m.B

Planolites 0.19m

sst as below, but softer weathering + heavily rooted. 0.4m

Fine buff RXL sst. 2.1m

Dark + light grey silt + thin sst beds. 3

CEMETERY MINE 0.14m 0.16m

Heavily rooted fine white RXL sst + silt partings. 8.0m

0 MST SST COARSE SST.

NB Section 354 does not have accurate datum at top of sequence - refer to Section 355.

ROUGH SECTION - COMPOSITE.

Tectonic dip 6/105.

SECTION 356 - APPLEY BRIDGE EAST.

25m

Soil

Fine buff flat bedded sst. 2.0m

2m

Dark grey shaly silty mst + thin sst beds. 3.0m

Fine buff RXL sst - variable in thickness 0.5m

Dark grey shales + some thin fine sst bands. 15m 6.0m

Rooted and bioturbated at top. Planolites Arenicolites Rhizocorallium JF

10m

Interbedded fine grey lam. sst + dark grey silty mst partings - RXL, CRXL, ripple x furrow, wave ripples, rippled ripples, interference ripples. Some channel forms. Some very plant-rich surfaces. 4.0m

CRF 260 261 262

5m

OLD LAWRENCE ROCK 7.0m

Solid massively bedded TXB/RXL sst. occasional very thin dark mst drapes - pastry + stramin lineation, large fossiliferous concretions. Some interference ripples near top. CRF 259 256

P.L. x S.C.

Base not seen.

0 MST SST COARSE SST.

C.R.F. 21.5.81. S. YORKSHIRE.

SECTION 357 - RUSHAW LANE (Longstt)

Old gannister workings - composite section - see Section 188.

5m

Soil

Dark grey shaly sandy silty mst + sandy bands + rootlets / grey shaly silty mst upwards

2.0m

(Alton) LISTERI n.b.

Cauliflower bed. Dunbarella.

HALIFAX HARD BED

Bright

? 0.85m

Hard flinty fine grey rooted massive silt

SHEFFIELD BLUE CLAY

Irregular top. Variable thickness 0.69 / Irregular base passes laterally into 0.23 m / 0.15 m+

Green/brown clayey rooty mst: passes into fissile clayey mst: thin sandy cuttings / heavily weathered silt: - mst / heavily rooted.

0 MST SILT COARSE SST.

SECTION 358 CAR HOLE, JACKSON BR

G.R. SE 175075 - composite section.

Soil

Fine brown thinly bedded sst + flute casts at base. Abundant shale clasts.

1.0m

10m

"Flaggy" thinly bedded Rxl, fine sst, fining upwards to silty mst + sandy streak.

3.0m

* Bedded fine brown sst - channel fill - single asymptotic bedset forset + parting lineation. 11 lam. within + shale clasts.

Rc.

2.0m

* thin bedded 5cm very fine sst - some Rxl - surface with abundant shale clasts - ? wave ripples.

GREENMOOR ROCK

Fine, mainly bedded sst - some scour present.

4.0m

0 MST SILT COARSE SST.

SECTION 359 - APPLETON QUARRIES (LANE HEAD) (G.R. SE 194087)

Composite section - see Description for lateral variations etc.

5cm

Med grey silty mst - heavily weathered. 2cm

5.0m

Rooted top. Fine brown weathered ? Rxl sst. Many lands at top.

Some oil-shaped spiral burrows.

1.20m

Med grey silty mst + sandy streak, coarsening up - Rxl

0.70m

Fine brown sst with occasional med grey silt partings - all Rxl + sandy streak, some ? HCS. Parallel burrows. Some landing. Silt partings coarsen upwards.

⑤ CRF 264

2.90m

BEDDER BED.

Parallel Protovirgularia

Bright

0.05m

10m

Light grey/blue silty mst - 11 lam., rooted in upper part. Occasional nodules.

7.0m

n.b. Total Section 9.5m

Two thin fine Rxl sst bands present - lower one rooted.

5m

Fine grey Rxl sst - very well cemented.

5.0m

GREENMOOR ROCK

⑤ CRF 263

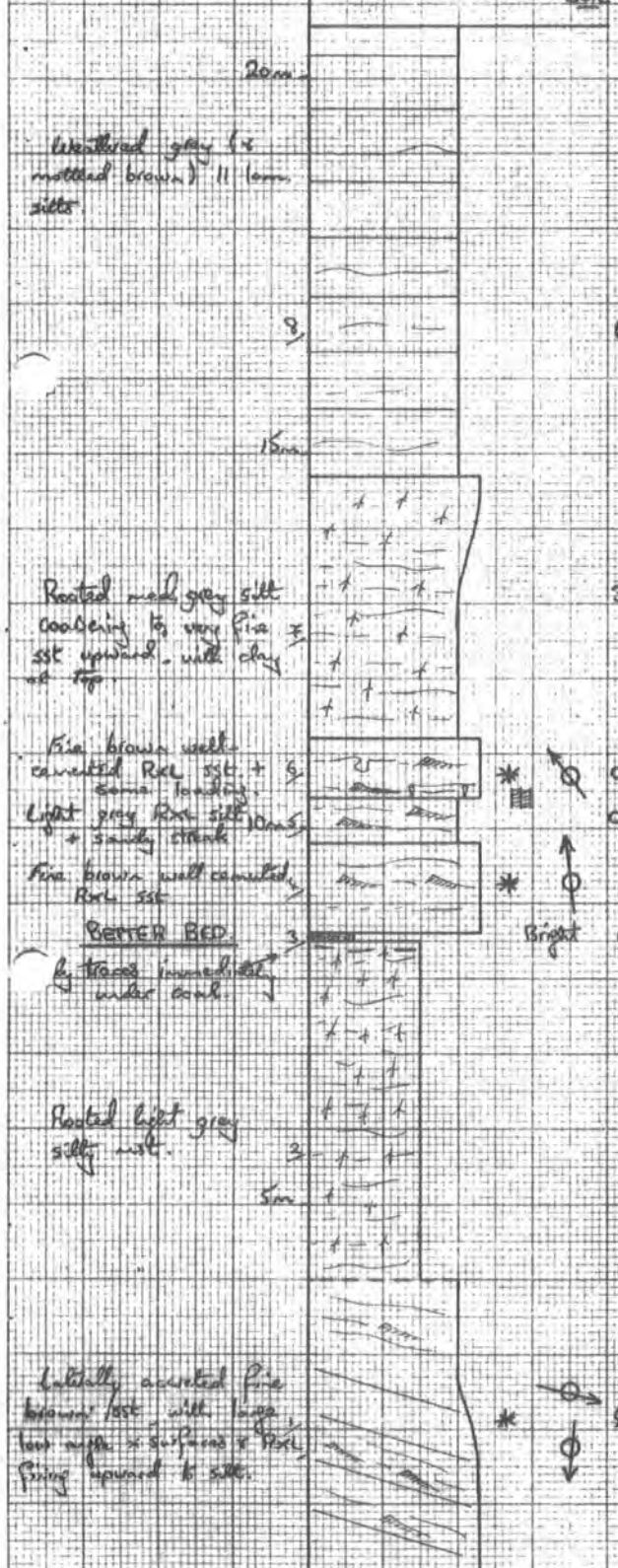
0 MST SILT COARSE SST.

Composite section taken from exposures at 3 "outcrops" on/near (old quarries).

S YORKS. - CRF 21.5.81.

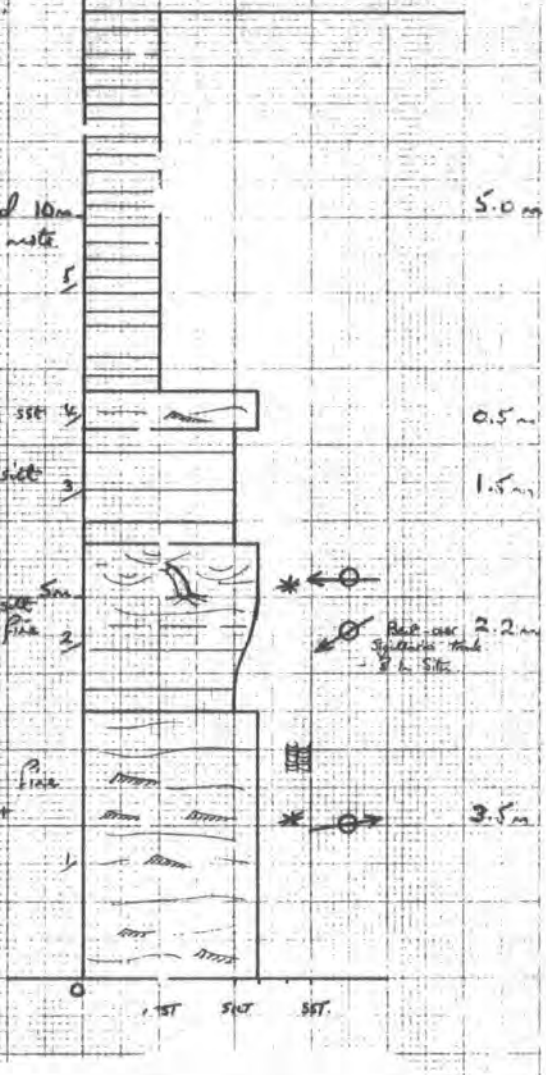
SECTION 360 - SHEPLEY SOUTH QUARRY (GR SE 197088)

Section at east end of quarry - see Description for lateral variations



SECTION 361 - SHEPLEY NORTH QUARRY (GR SE 197088).

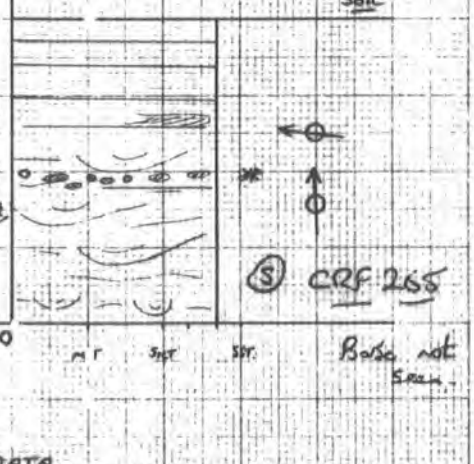
Section along South face - see Description for lateral variations



SECTION 362 - BRUSSELTON WOOD QU.

GR NZ 202251.

Opposite section from several small exposures. Foreshore dip - 14/350.



* DIRECTIONAL DATA.

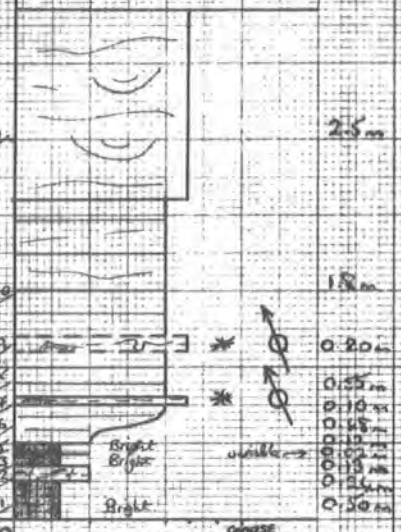
① Trough x Beddings - 0.5m / 25 / 284° n = 1

② Narrow trough-like scour → 355° n = 1

CRF - 27.5.81

SECTION 363
WOOLEY - CUT 9.

Cut 9 - NW end.
Trends → 298°



* DIRECTIONAL DATA :-

Unit 9 - RxL → 322, 328, 323, 337, 327, 341°
n = 6

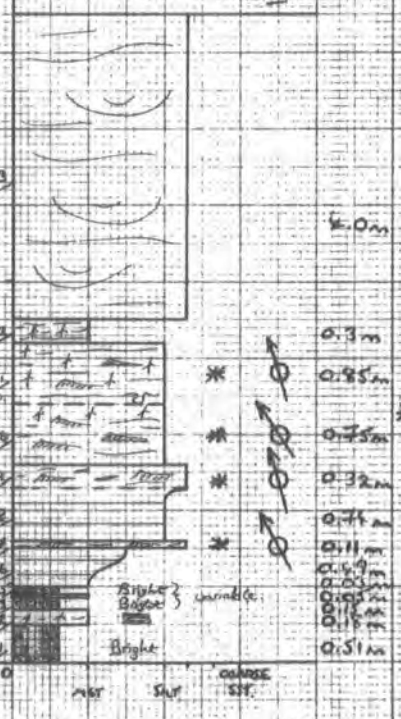
Unit 7 - RxL → 323° n = 1

RxL ≤ 0.02m sets, crosscutting.

Still digging at SE end - 100m exposure presently. Little horizontal variation except in top leaf thicknesses, which vary randomly.

SECTION 364
- WOOLEY - CUT 8.

Cut 8 - 100m from SE end
Cut Trends → 300°



* DIRECTIONAL DATA :-

* DIRECTIONAL DATA :- Section 364

RxL - crosscutting sets Type A, ≤0.02m A.

Unit 11 - RxL → 335° n = 1.

Unit 10 - RxL → 328° n = 1.

ripple form sets → 342° n = 1.

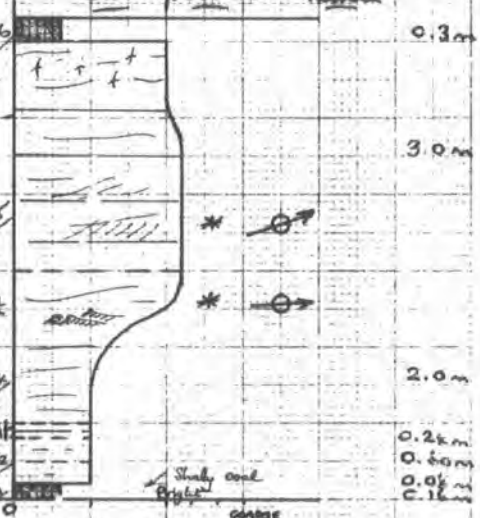
Unit 9 - RxL → 330, 354, 350, 348, 337. n = 5.

Unit 7 - RxL → 327° n = 1

Further to NW, a thin 0.05m coal appears in the wall above the dark grey shaly horizon - level of Top Hutton? Several small faults offset the rocks to the SE - towards the end of the cut. Facies very similar in character & thickness.

Western extension of Cut 3 on 2600 - 80m east of Foss Cut ends.

SECTION 365
- EDMONDSLEY - 26/3



* DIRECTIONAL DATA :-

Unit 5 - Low Angle x set 020 - 060° n = 1

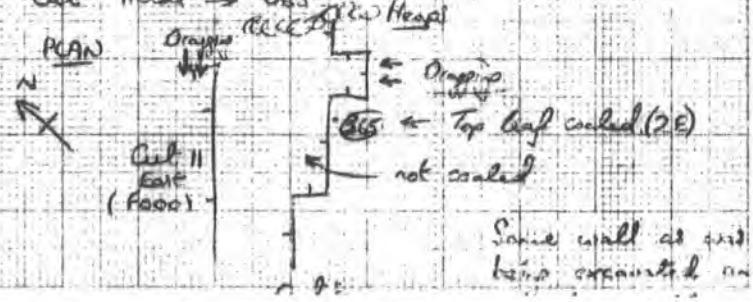
Unit 4 - CRxL with backflow ripples → 080 - 085° n = 2

20m West - over thin mst roof & coal is fine white RxL sst with silty streak - thickness makin...

* RxL Type A - A = c.0.01m → 252° n = 1

Thin mst above. Thickness of sst & total extent not ascertainable - fine plant debris on bedding planes

Cut Trends → 048°



EDMONDSLEY - 27.5.81 a.l

CRF - 4.6.81.

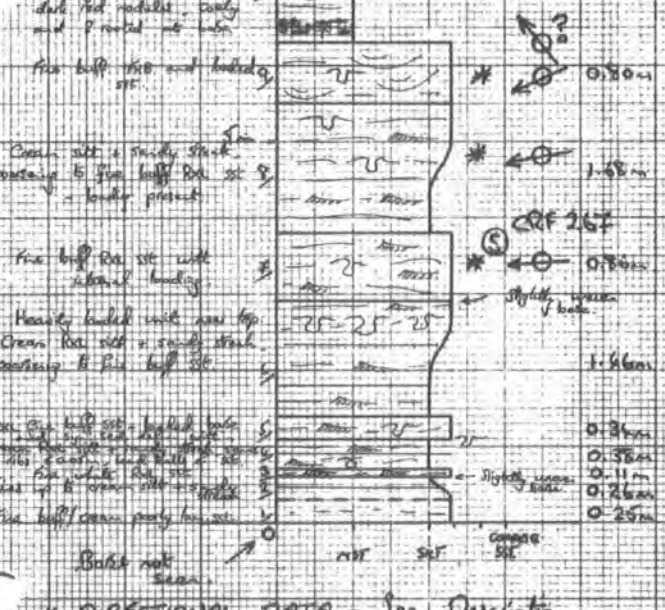
(CRF 266 - Bishopdale

Cut 11 East - exposure of Faddo and overlying sediments - true thickness of slump not determinable due to heavy pitching. Over - rapid coarsening up from mst to rhythmically alternating silty mst & fine white sst - all 11 Lam. Abundant large Syllavia pinnacle present in sst layers. Section - ~ 5.5m interlaminated fines. 2m dk sst thin crumbly mst. 2m fine brown sst → birch. Sequence slightly different in upper part at west end of cut. Not heavily weathered and drift disturbed.

CRF - 1.6.81.

SECTION 366 - ELDON HILL QUARRY

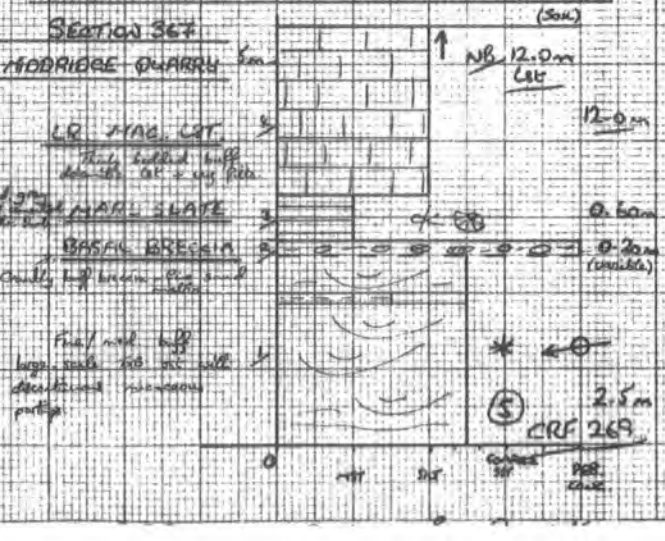
NW face - composite section. Main probably not far below base of section.



* DIRECTIONAL DATA - See Description.

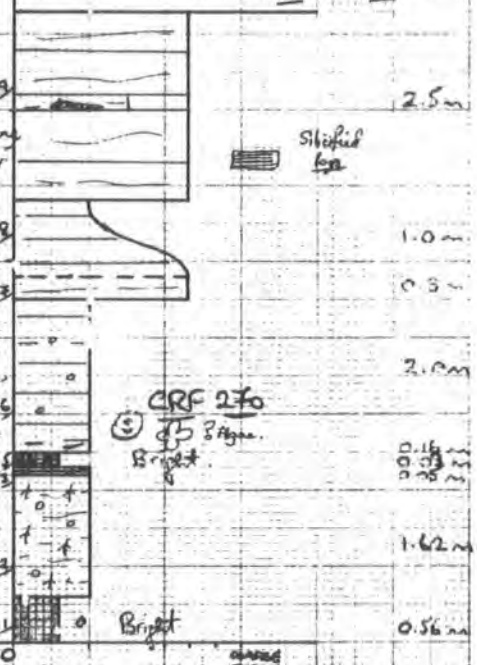
NB A unit of silt → fine sst upward wedges in below the dark shales at the south end of the face - ? rooted - with Type B Rds ≤ 0.03 m A → 010°, with high directional variance. Reaches 0.7m thickness at south end.

SECTION 367 - HODRIDGE QUARRY



SECTION 368 - TANNERS HALL (Ew)

Several small faults. Well-preserved old workings.



bk sst continues along face to SE with - constant thickness - another one starts to wedge in (above) appears 50m along - thickens to ~ 0.3m by 100m further - mix simple thinning - canal and goaf. Also thin (0.01m) discontinuous dev. of early shale above Top Hutton. 1 photo.

SE end - ~ 2.5m sst overlain by mst for 0.5m - then dark horizon - Bottom Brass Thill probably. Two sst still present - but section above second one is mostly mst in lower part. Several occurrences of bent-over tree stumps in roof of Bottom Hutton. 0.05m ochreous mst dev. on Top Hutton roof at east end, as well as in floor.

Cut SE proudly exposing Top & Bottom Hutton, 5w x 3w above Brass Thill. 5w just started - only 30m exposure - dipping S. South.

All cut 3w open - coal removed but standing in bays. At boundary of two cuts, small step fault.

Cut 3w heads → 020° for first 150m - then swings round to east. Little / local variation visible - seam apparently thicker in this cut than elsewhere. Thin well-cemented sst previously present 2m up is no longer - Several thin (~ 0.05m) Fe stone bands occur.

Section 369 - OVER

CRF - 4.6.81

SECTION 369 - TANNERS HALL 3m

10m north of south end

9m

DRIFT

Contains up to 5% white Rst + mainly fine sst + silt partings with 3 horizons at top - 2 thin V. contains interlaminated sand.

2.5m

5m

Med. grey blocky mst - bioturbated at base. Pistane nodules, faint, larger throughout.

5.0m

TOP BRASS THILL

Bright

0.5m

MST SST COARSE SST.

SECTION 370 - TANNERS HALL SE.

10m slag from north end.

BENCH - TOP BRASS THILL

10m

Dark grey slinky mst.

2.0m

BOTTOM BRASS THILL

Bright

0.1m

Med. grey ll lam. rooted silts

1.8m

SST

0.15m

As Below

5cm

mst

2.0m

SST

0.5m

Med grey fine mst. Fine white poorly lam. sst.

0.7m

0.22m

Med grey silty lam. mst.

1.89m

TOP HUTTON

Bright

0.15m

MST SST COARSE SST.

Bottom sst. wedges in 100m slag from north end - thickens to 0.7m by 150m slag then constant - all other sst is constant. Total = 300m end length.

Cut oriented N-S. Probably reducing Top →

Bottom Hutton at South end

CRF - 16.6.81

SECTION 371 - CUMLEY PARK BURN

2cm

Composite Section. See description.

5cm

1. Cobbled fine sst - as below - mod med. grey silt + sandy streak - Rst + flat lam. 7

4.5m

Prominent sst ribs near base, but mostly silt above.

Fine brown/white well cemented sst + Rst some uneven bedding 10cm

- Some thin silt drapes overlain by erosional surfaces with ≤0.1m relief.

(8) CRF 277

6.5m

(1600) METAL

Bright

0.16m

Rooted nodular med grey silty mst - as below.

1.65m

Fine grey poorly lam. sst 5cm

0.21m

3.50m

Fines to silty mst As below but rooted nodular.

Med. grey/brown Rst silt / v. fine sst. Some uneven bedding present

1.60m

0

MST SST COARSE SST.

(CRF 276 - Newbottle)

CRF 17.681.

Cut Div12.

SECTION 372 - DEBORAH Div12

15m Cut trend - 348° Little lateral variation.



* DIRECTIONAL DATA :-

Unit 7 - Trough x Bedding

0.8m/360 0.5m/342 0.4m/314 1.0m/306

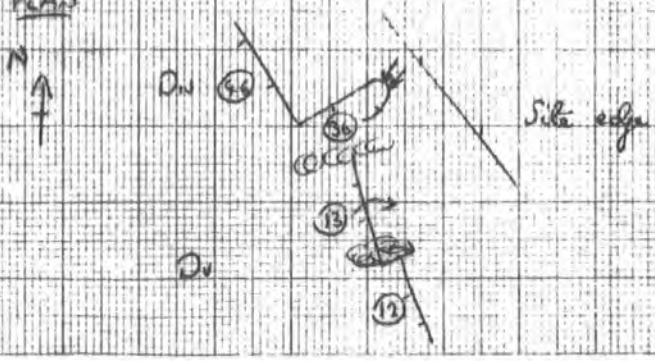
Fairly large scale TxB present.

50m north in Cut Div13 (only down to P300) TxB -

* 1.0m/333, 0.7m/339, 0.8m/330

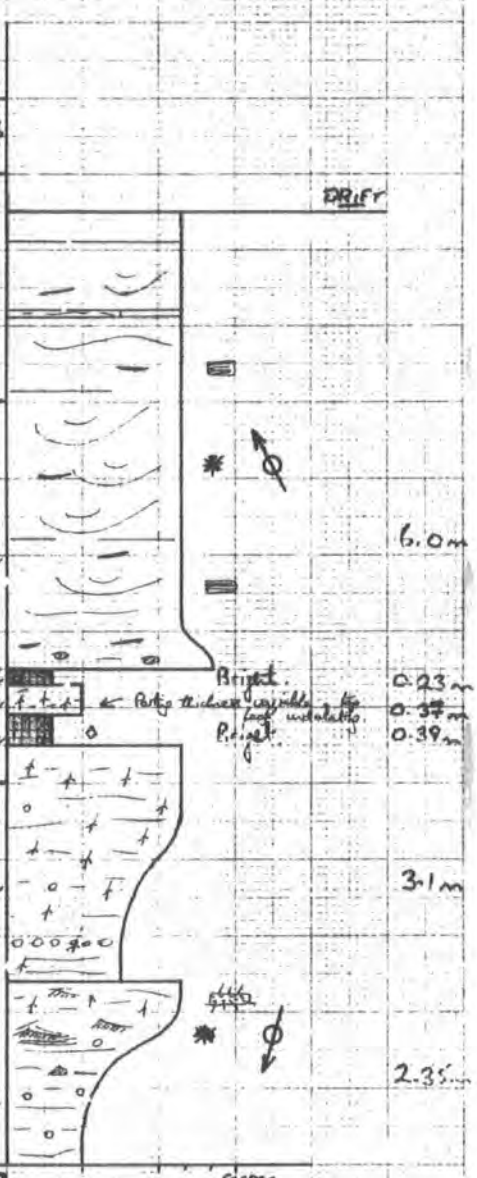
Presently working - Div12-13, Div36 & 46, Area C west end.

PLAN



Cut Div36 - presently dropping + not much exposure. Along Cut 46 - Walls → 322°. Section 60m along from SE end.

SECTION 373 - DEBORAH - Div46



* DIRECTIONAL DATA :-

Unit 6 - Trough x bedding -

0.3m/346, 0.5m/333, 0.4m/307 ~ 3

Unit 1 - RxL, Type :, A: 0.01-2m often low angle → 40, 213, 223, 185. ~ 4

Top SSt is massive in places, but commonly well bedded - more so than in area Div. - abundant TxB in both areas. Little lateral variation.

Area B/C Extension - under power lines - presently exposure of Tilleys - some P300 exposed at north, but by south wall (main) level of drift is down to 1m above P200.

Site now only working Tilleys in Area D, apart from B/C Extension above.

CRF - 25.6.81. STAINMORE.

CRF - 29.6.81. CUMBRIA.

SECTION 374
ARGILL BECK
(GR. NY 835134)

Level - Below Swinstone Band = ? Cancellation.
Yoredale. Soil

Fine cream heavily bioturbated sst. 10 — 3.10m

F

Dk grey well laminated silty mst to ? fine - medium laminated sst. 5m — 1.06m

Clayey dk grey lam. mst + fine ? light grey/cream lam. heavily bioturbated sst. 3 — 0.11m

★ 1?

Buff/grey mic clayey lam. & silty mst. 3 — 0.66m

0.47m

F

Fault plane inclined steeply E west

Fine buff lam. sst + dk grey shale 3 — 0.21m

Dk grey lam. silty mst + coaly streaks. Coarsening up to fine buff lam. sst + shale. 3 — 0.15m

Fe lam + abundant shell fragments along bedding planes + cleavage? — 0.10m

0.27m

Med/dk grey bioturbated laminated micaceous silty mst — 2.0m

0 mst sst coarse sst.

Crinoid bank 1 stem diam 1cm bioturbation.

★ Fine fossil assemblage in dk/st ? Cruziana - ① Hormosiphon ? 1cm wide burrow ② Horizontal branching burrows 0.003m wide ③ Horizontal ? Amphycoa ④ ? Planolites burrows.

SECTION 375
ARGILL BECK
(GR. NY 837135)

Soil

10m

CRF 278 — 5.0m

Med. brown weathering sst. - beds sometimes horizontal trough and plane cross.

Shaly coal + black shale + dk grey rooted mst - some lam. - more clayey near top. — 0.04m — 0.02m

CRF 279 like ★ — 1.75m

Light grey/cream/red mottled carbonated rooted silt - no lam. 5m

Calcite burst not ccr - cemented

Med grey ? lam. rooted silty. 2 — 2.0m

Mottled cream/red & med. grained sst. — 3.0m

0 mst sst coarse sst.

Sst body above Swinstone Top ME = SUBCREVASSE - ? Bridal Crag Member?

SECTION 376
WHITEHAVEN BEACH SOUTH

North end of section - car park and cliff path.

Soil

Medium and coarse grained red/purple sst, granular in places, with purple silt pebbles - ? lam + Rox in bottom part, more ? B further up. Shale + mudstone clasts common. — 5.0m

Hard dark grey/purple silty mst - well lam. - turns & gradually purple upward. — 1.38m

Coal - 1ft 3in →

2AP - 6.0m — 6.0m

Rox red. grey silt. 5 — 1.0m

Fine buff rooted weathered sst - fines up to silt. 10m — 1.20m

Fines to dk grey shaly nodular mst. 3 — 4.00m

Coal ? not exposed →

CROW

Clayey rooted buff 5cm 3 ochre fine sst. — 2.00m

Fine/med. grey/buff trough + bedded and Rox sst. — 4.0m

0 mst sst coarse sst.

CRF 280 - Sst from Crag House Cliff
CRF 281 - Striegill Grit
CRF 282 - sst over Pseudorabdota bed
CRF 283 - sst from Argill Beck.

CRF 1.7.81. CUMBRIA.

Barngill House.

SECTION 377 - REDNESS POINT (NTH)

(C.R. NX 975197)

Boulder Pit Sst

Soil

CRF (S) 286

10.0m

Erosive-based med grained buff x bedded sst - markedly conglomeratic at base - 3/ shale chstl(x pt) ≤ 0.1m. occ. rounded beds on base. Lots of L.A. x belly some TxB

Flute Casts

Relief on bed surface not certain - at least 1m

As below but with sandy streak - laminae - variable proportion of sst present. Some coaly plant debris. Rare 10m. 2/

7.0m

Light grey 11 fem. silt + abundant well preserved plant remains - occ. thin fine sst/ironstone bands. 1/

7.0m

Calamites very abundant Neuropteris Annularia

No. 4 coal of Whitehaven Brickworks

0 MST SST COARSE SST.

Position - Cliffs above railway - ~100m south of end of bed in railway by signal and bridge in sea wall - unaffected vertical section. South end of old quarry - probably marked fossil locality - by old hills.

SEE DESCRIPTION

(CRF 286 - W.S.S. - Redness Point
CRF 285 - Bannock Band Rock - Parton Bay (S))

CRF 287 - Shales - } Siabro Cliff
CRF 288 - Biot silt }
CRF 289 - Hensingham pit from

SECTION 378 - BARNGILL QUARRY.

(C.R. NX 998218.)

N

A595

Tectonics dip 10/135.

Main face Trends → 17.°

South end

Soil

? rooted light grey silts + feature nodules etc. 9/

1.0m

Bright.

Rooted at top. 8/

0.23m

Dark grey 11 lam. fissile shaly silt + some sandy bands. 7/

2.50m

Erosive-based fine grey sst 6/ - x bedded + mica/coal partings.

0.77m

← Base commonly marked with bedding!

Light grey silt - 11 lam. dev. sandy streaks up + Rare form sets. 5/

1.40m

Bright. 4/

Dark grey shaly mst.

0.09m
0.06m

Light grey rooted clayey silt - more rooted up. 3/

0.72m

Med. grained ulitic x bedded hut markedly bedded sst

4.97m

5/4 ROCK

0 MST SST COARSE SST.

CRF 2.7.81

SECTION 379 - CUNNIWA POINT

(C.R. NX 978229)

10m

Soil

Hard flinty fine rooted gritstr sst. Knobbly top. Well-cemented. 3/

CRF (S) 290 1.0m

(HARRINGTON) 4 FOOT ROCK (Upper Part)

7.0m

Fine brown Dol/TxBs sst + sets becoming smaller and changing direction in upper part. Well-cemented. 2/

Med. grey mic. shaly very fissile mst + plant debris - occ. thin fine sst bands - develops sandy streak near top with ripple form sets x

2.0m

CRF 2/7/81 - CUMBRIA.

CRF - 3.7.81 - CUMBRIA.

SECTION 380

ANDREW'S ~~GROSSERA~~ GILL

(G.R. NX 980227)

Section taken on both sides of the stream 50m upstream from bottom fence (above railway).

Scale

Dark grey shaly mst 15m + Festiona nodules, fossils.

3.0m

UPPER 3/4 Bright

Dark grey carbonaceous mst + shaly fissile. 0.10m 0.09m 0.16m

Bright

Pale clayey near top.

As below + fine SSt bands - all sharp based some loaded, sharp or transitional top. Rare Dav. burrowing rooted upward. Some nodules.

4.3m

Coarsening upward fine SSt with Sandy streak

5.0m

Med. grey lam. silty mst

MICKLAM FIRECLAY SEAM

Dark grey shaly + sandy mst. 0.25m

Interbanded fine SSt/silt with varying proportions - a distinct ripple cross-lamination, some soft sediment faults.

1.98m

Dark grey well lam. silt + abund. Festiona.

0.21m

Light grey well lam. silty + sandy streak, plant fossils, roots in upper part.

0.96m

Little lateral variation via hole.

SECTION 381

= CAT GILL.

Foreshore → narrow ravine of Cal Gill about railway - GR. NX 982237.

Tectonic dip - 5/050.

CONTINUED OVER.

Long, dark grey mst. Black flaky cannaloid mst

UPPER 3/4

0.26m 0.11m

Bright.

0.53m

Fining through silt to silty mst, lam. but rooted, some upward + dow. of nodules.

3.05m

20m

Fine white Rvl SSt.

1.30m

Med. grey, mst + Festiona nodules etc.

1.0m

GAP - 0.5m?

Med. grey shaly mst + Festiona nodules etc.

0.34m

Dark grey shaly mst + plant debris

0.26m

Small coal + coaly shale. Bright

0.22m

MICKLAM FIRECLAY SEAM.

0.19m

Light grey crumbly rooted mst.

0.70m

Dark grey rooted silty mst 15m

0.26m

As below, but rooted + fulled SSt cracks.

1.10m

Interbanded med. grey silty mst + Rvl. fine SSt + Hematite sparks

0.74m

Fine white/buff Rvl/TkB SSt - Roughs in upper part.

1.03m

Interbanded fine SSt + silty mst - Rvl. loading, convolute lam. Some soft sed., vertical burrows.

1.21m

As below + Sandy streak + lenticular.

1.75m

10m

Med. grey lam. silty mst + Festiona nodules, burrows.

1.9m

Dark grey rooted silty mst + coaly streak

0.25m

Med. grey lam. silty + sandy streak Festiona nodules, SSt filled cracks, occasional 2.0-3cm SSt beds.

Becoming rooted upward.

1.30m

Dav. Festiona mst/top of top. Interbanded fine white SSt + med. grey silty mst - layer 2-4.0cm + Rvl. loading.

Some upward convolution

0.77m

5m

Fine white Rvl SSt + red mst streak. Some loading.

1.35m

Med. grey lam. mst + fine Some silt. Rapid fining up fine white Rvl SSt + sandy streaks.

Fine white/buff Rvl SSt + red mst laminae, lenticular TkB upward (Top bottom 0.7m only R/L)

1.40m

Rapid coarsening up to fine white Rvl SSt.

0.38m

Med. grey shaly mst + nodules, leaves, fragments of Festiona.

1.70m

Base not seen

NOT SHS COARSE SST.

CRF 3.7.81. CUMBRIA.

CRF 8.7.81

SECTION 381 (CONT.)

CAT GILL

TOP OF SECTION

Stopped logging at force over stream. Complete section visible despite some faulting.

SOIL.

Fine white RxL/TxB sst + mst laminae pattings, 3% marked plants.

1.77m

Med. grey well lam. silt mst + festoria nodules etc.

1.34m

Bright

0.84m

As below. Ginge to silty mst + festoria nodules etc. - roots

2.73m

Light grey RxL sst

2.0m

Light grey sandy mst

0.10m

CONTINUED FROM BELOW

MST SST CONGLOMERATE SST

SECTION 382

HARRINGTON SHORE (SHS)

"? CLIFF ROCK"

Situation - NNW of Swallow Pit - GR NX 986243 - on shoreline.

Tectonic dip 18/243.

Top not seen. SHORELINE

Med. grey well lam. silt mst + festoria nodules etc.

2.0m

Impure light grey flinky silt-grade sandst.

Carp 0.3m

CRF 283 0.15m

As below but no ? Skol. or festoria.

Bright strip 0.6m

As below but + rooted + nodular ? S. sil. other hyps. calc. nodules (+ a little pebbly/ash S. sil.)

CRF 281 nodular + some pebbly/ash

0.8m

Light grey lam. silty mst developing patchy mud distortion/bed splitting towards upward + occasional rootlets.

2.0m

Base not seen.

MST SST CONGLOMERATE SST

SECTION 383

- WOOLEY - 13.

North end of Cut 13 - face heads → 035°. (End Wall)

DRIFT

5m

Fine buff TxB sst.

2.0m

Med. grey silty mic. well lam. mst.

2.3m

Fine massive buff sst.

0.10m

Dark + med. grey well lam. mst + plant debris throughout.

0.50m

Bright.

0.12m

Dark silty - clayey mst + black sandy rooted layer with black sandy mst

0.14m

0.01m

Light grey/mottled

BOTTOM HUTTON

Bright - Resinous at base.

0.42m

0.05m

Black sandy/clayey rooted mst

MST SST CONGLOMERATE SST

Facies appears laterally persistent, though some variation likely around seam. Base of top sst is erosive - channels level along face. Int. main wall of cut - heads 125°. Base of sst more persistent in level. Wall higher.

SECTION 384

- WOOLEY - 13.

100m along wall from northern 10m wall. Prevailing dip 160° from northern corner.

RUBBLE.

Fine buff TxB sst.

4.5m

3

5m

Becomes dark at top.

Med. grey lam. silt + sandy streaks, some fine sst bands + laminae - ripples form sets.

3.0m

Med. grey lam. mst → fine white RxL sst upward.

0.74m

Fine white RxL sst.

0.10m

Dark - med. grey well lam. mst

0.51m

Med. grey clayey rooted mst.

Bright

0.05m

BOTTOM HUTTON ROOF

MST SST CONGLOMERATE SST

* DIRECTIONAL DATA :-

Unit 6 - Ripple form sets → 301° n = 1.

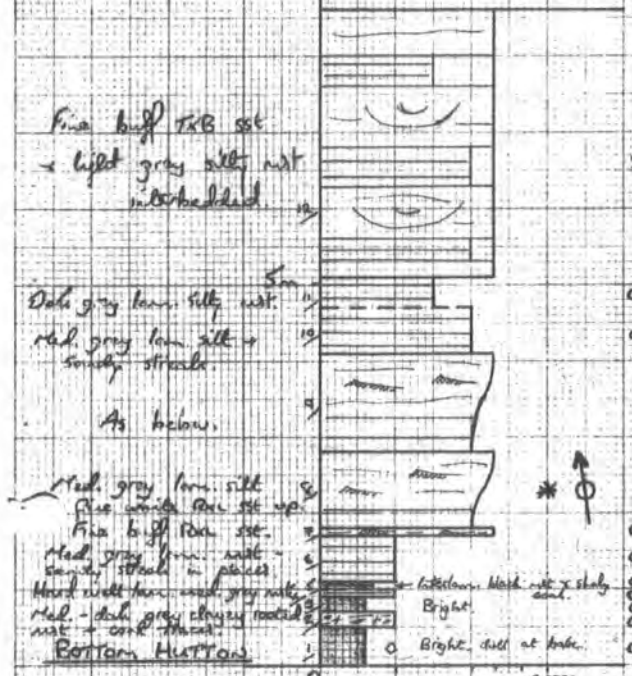
Unit 5 - RxL - Type A, 50.05m A → 319°, 318°, 328°, 315° n = 5

Unit 4 - RxL - A = 50.05m → 330°, 318°. n = 2.

CRF 8.7.81.

SECTION 385 - WOOLEY - 12

Cut 12 approx. 120 m north of south end. Cut trends → 30°? - about ¼ way along length of cut.



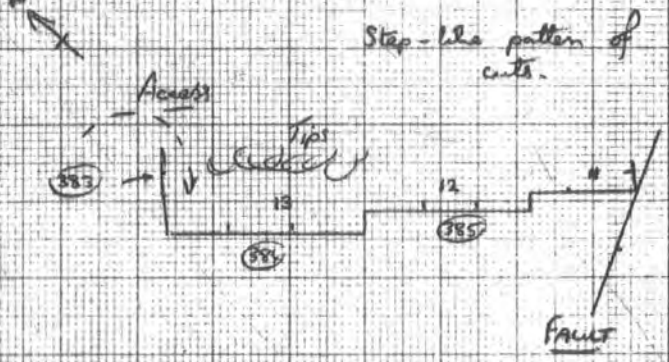
* DIRECTIONAL DATA :- Unit 8 -

Rxl → 348°. n = 1.

Fracs very persistent laterally + uniform - upper bedding-up unit picked out well.

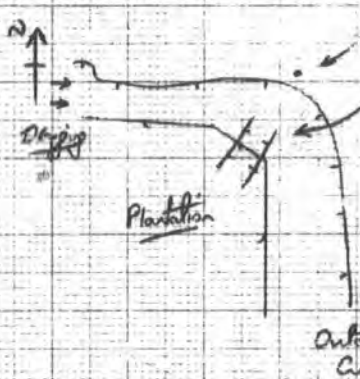
Top sst - may actually be composed at least 50% of silt mst - / exposure difficult to assess; 2 photos from extreme south end. Exposure in Cut 11 now masked by tipping.

PLAN Working cuts 12 + 13. Cut 11 cored out + being backfilled.



LANGLEY - 1st visit. (See Site Plan).

Site recently started working. Presently working Main (C 000) at western edge of site - on outcrop cut - Area A, Cut 1. - runs parallel to site boundary - just outside a drift washout.



Base of Main is apparently 0.10 m shaly coal - before bright starts. Formerly a cannel band exposed at this level - now not present. Main is overlain by a thick sst at this level - though at this point is somewhat disturbed by drift cover. Old workings present - and occasional small faults.

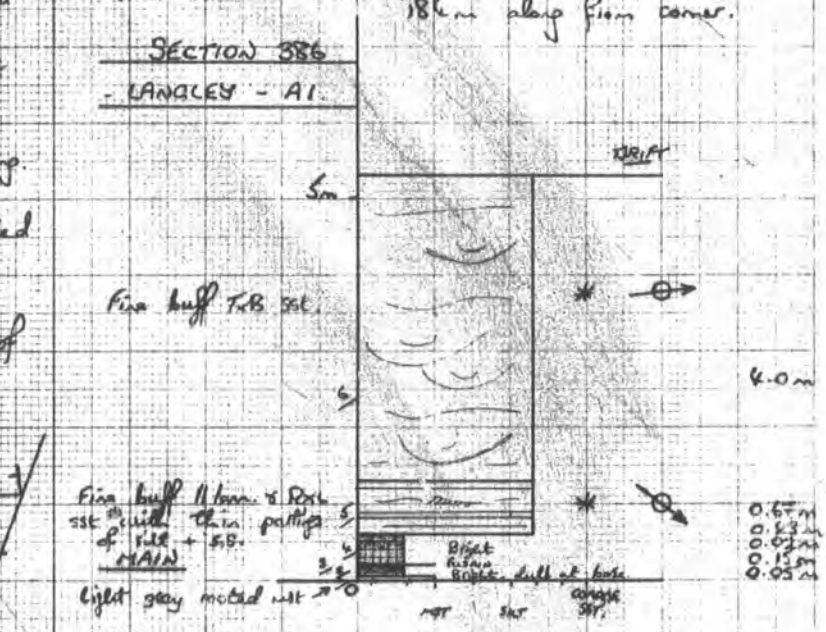
To west - Coal is overlain by 0.6 m interbedded ? bioturbated fine white sst + med. grey silt + sandy streaks - then ≤ 5 m buff fine TxB sst. (Rxl present also)

* DIRECTIONAL DATA :- Trough + bedding

0.5m/21/101°, 0.7m/21/060°. n = 2.

Outcrop wall trending → 126° - sst outcrop increased to 6 m over coal 18 m along from corner.

SECTION 386 - LANGLEY - A1.



* DIRECTIONAL DATA

Unit 6 - Trough + bedding - 1.0m/16/078. n = 1.

Unit 5 - Ripple + lamination - Type A, ≤ 0.02 m A → 130°. n = 1.

Lateral variation difficult to assess - heavy old workings and proximity to drift cover.

Section continues for another 200 m + to SE.

CRF 296 Butterwell 4/11/81

CRF 10.7.81

CRF 16.7.81

SECTION 387 -

KNITSLEY BRIDGE QUARRY

Thinly bedded fine buff sst - some trough x bedding continuous coal partings occasional scours.

6.0m

(Marshall Green post)

Strongly trough x bedded fine & med grained sst - FxB often in coats of sets 5cm each

7.0m

Single laterally continuous large x set in med & buff sst - forms base of quarry at south end

2.0m

Base not seen

CARBS SST.

SECTION 388

- CROSS U. CANAL QUARRY

NZ 002447

CRF 15.7.81

Minor faun - half way along face Mode → 062°

3rd CRIT

Med. with buff x bedded sst - thinly bedded, & RxL. wit laminae, rarely ripples & ripple surfaces current lineation - shale chips - small intraval erosion

3.5m

Brick up to shaly silt & occasional very thin fine sst bands. Bioturbation & sandy streak present

Sandy lam. fine brown biot. sst & plant debris.

2.0m

Med & dark grey shaly silty mst - occasional plant debris

1.90m

LEVEL OF C. SUBCRENATUM NB.

Base not seen

SECTION 389 - Composite Log - Cut 2 - See notes.

BUCKHEAD - B2.

Med. grey lam. silty mst.

3.0m

NB Lateral variation - see notes

Fine buff FxB sst. thin partings of grey silty mst.

2.0m

2K00

Bright

0.04m

Rooted in top half - sst bright x lamina 60.05m thick. Fe stains (roots) etc present - occasional coaly traces.

4.5m

Med. grey silty mst - lt lam. developing sandy streak & laminae up - more sst upward, sst bright, some ferruginous 2K00

Bright

0.15m

Oolitic & clayey at top.

Med grey lam. rooted mst & nodules etc. of Festona

2.77m

C200 2K00

Bright

0.07m

Variable thickness Variable thickness - almost humocky at top of unit

0.3m

Med. grey clayey rooted mst.

Fine to silt at top, bioturbated clayey fine buff well-cemented FxB/RxL sst - muddy streaks in places. Upper half rooted

3.0m

Light grey lam. mst + nodules etc. of Festona & several continuous 5cm Festona bands.

2.0m

Dark grey biot. lam. mst + Festona nodules etc. Some horizons rich in coaly traces. Fine

2.0m

Coarsens up to silt + sandy streak - heavily bioturbated in middle. Rare sets. RxL. deformed bedding present. RxL A = 0.04m

1.10m

Ripples variously intersected. Several lines of wave - formed ripples present also - A = 0.01m - λ = 0.01m

Light grey lam. mst + Festona nodules etc. Several 5cm continuous Festona bands present. Med. grey crumbly biot. mst + roberts.

2.8m

Bright

0.06m

Coal drill at base, pyrite & siderite mineralisation present up. near top.

1.09m

HUTTON (Seam) C100

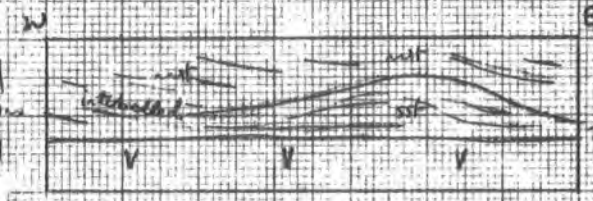
0 mst SST CARBS SST

300 - Millett - 8.80

CRF 16.7.81 - Notes on Section 389.

Section 389 taken in two parts - lower half near south end of cut - and upper half near north end - working benches. Lower section taken for upper part - at northern end of west wall - upper most sst is 2.0m followed by 3.0m silty mst - but thickness very undulating top & sst. The sst also thins markedly on the E-W north wall - and displays an undulating top - as a huge rippled surface. The mst under the top coal appears to contain a solid fine sst along this wall for 0.5m, then 0.3m mst, then coal.

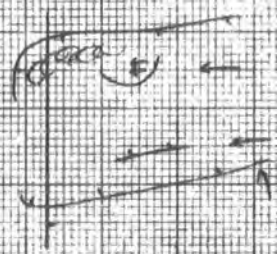
Sketch of north wall



~ 60m ~

Mst over sst dipping → East.
Cut walls trend → 007° & 090°.

Area C - still working low Main & Brass Thill - little continuous exposure.



Wigglesworth Fault

In Sec 390 north of fault section exposed complete. ~ 8m parting between B.T & L.M.
0.3m sst under coal then 0.6m mst + thin sst layers - then mst down to Brass Thill.
100m back to east - 0.3m/0.6m light grey mst of over low Main - below sst - more or less continuous. sst appears to be very massive with - little structure displayed except some 11 low / bedding - no Sp. Long bedrock not present.

Area C.E. - presently working at east end of old coaling bays - about to drop a cut to east, obs. Hamsterley outcrop. At north end bottom of Lde Hamsterley is badly disturbed - Main is as normal but several faults occur. Little channel exposure.

CRF 18.7.81.

Rough Composite Log.

SECTION 390
PHOENIX QUARRY

DRIFT

Erosion-based fine buff Rxc ≈ 4ft with mic/carb. laminae & partings. CRF 305 ⑤ ≈ 5.0m
Cut out and completely in place.
* Rxc → 040°.

BOTTOM BENCH THICK

Bright coal - lower half dotched. 1.40m
Med. grey silty mst & silt - lam. & well-preserved plant remains, especially in festive no fucus. Rooted at top. ? 10m
Rooted horizon also present ~ ⅓ of way up the section. One upright tree stump present visible - low down here.
Bright coal 0.51m
Light grey clayey rooted silty mst 0.06m 0.05m
Bright coal 0.76m 0.78m
Mst grade sandstone with low thin coal seams. 1.5m

* DIRECTIONAL DATA - Unit 7 - Rxc → 040°. n = 1.

Bottom leaf of ? Hutton contains thin discontinuous clayey mst & fine sst bands. The floor contains flattened large Sigillaria stalks, oriented in all directions.
In main silt unit - diverse flora (+ some logs present) includes Lepidodendron, Sigillaria, Bothrodendron, Alethopteris, Neuropteris, Sphenophyllum, also. Disturbance in lower part of Brass Thill attributable to glacial pull - movement possibly along intra-seam clay partings.

Cliffs by old kiln ~ 100m east of main rock.
See Description.

SECTION 391
CARKEHEIGH ROAD

Sunderland (CR NZ 362 545) 5m

Red grey low. mst with marine fossils passing up into light grey low. silty mst. Occasionally small festive bands.

4.0m

CRF 306
(⊗) ⑨ ⑩ ⑪

DOGGER HILL N.B.

Dk grey clayey mst, silty mst & Heavily bioturbated & rooted pale white sst. 0.05m
Fine white Rxc bed 0.3m
sst - mic/carb partings 0.7m
& thin mst partings

Dovehill NB = Top = CAMBRIENSE MB.

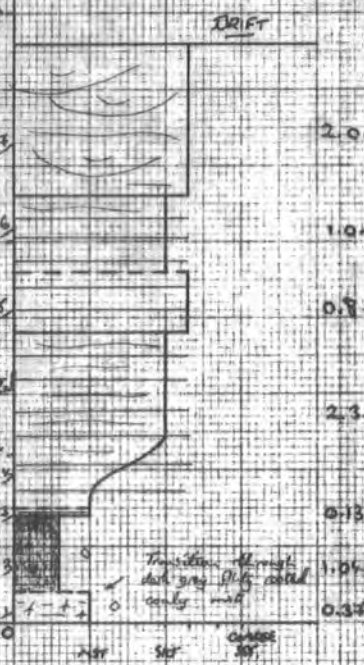
Quarry Wood Quarry

CRF 23.7.81.

SECTION 392

EDMONDSLEY C(b) Pit

Area C west - Cut 1½ 20 m from west end.

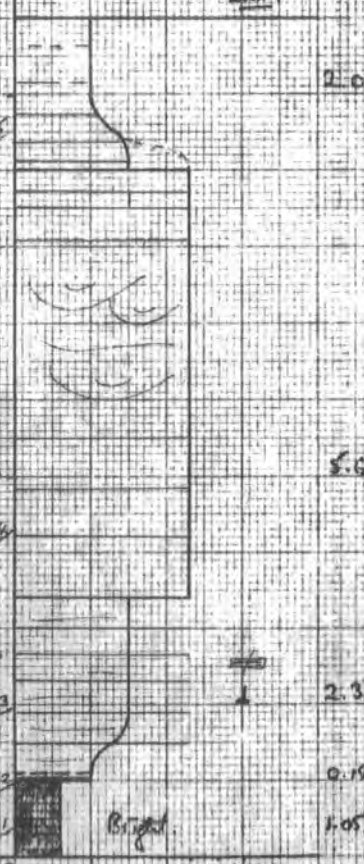


Bottom Coal not visible.

SECTION 393

EDMONDSLEY C&D Pit

Area C west - Cut 1½ 120 m from west end.



NB Section 393 - Top to major sst, but some intercalation with silty mst in uppermost 1 m.

Interlaminated facies - silty mst partings are often dark grey + highly carbonaceous, and contain very abundant fine plant debris - also quite micaceous.

Drift cover - thin - close to outcrop of 2E00 - Cut 1 west presently being excavated above.



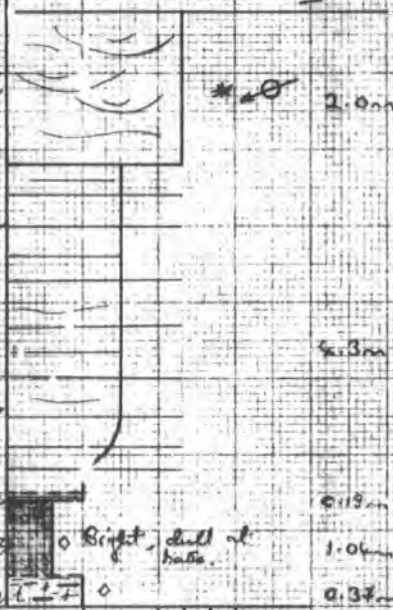
SECTION 394

EDMONDSLEY - B1(1)

Outcrop Cut

~70 m from NW end, Cut trends → 320°. Near BH 252.

? 1.0m to next bench



* DIRECTIONAL DATA :- Unit 5 -

Trough x bedding - 0.5 m / 245° n = 1.

SECTION 395

EDMONDSLEY B1(2E)

Outcrop Cut

Cut trends 330°, ~70 m from NW end - near B.H. 601.



* DIRECTIONAL DATA :- Unit 5.

Trough x Bedding : 0.1 m / 304 n = 2.

0.1 m / 274

Θ = 293° n = 2

CRF 23.7.81.

Notes. Section 396. Area B 2E00 Cut is one step ahead — & above F000 cut - also Wanding → wis - will probably work back in sequence.

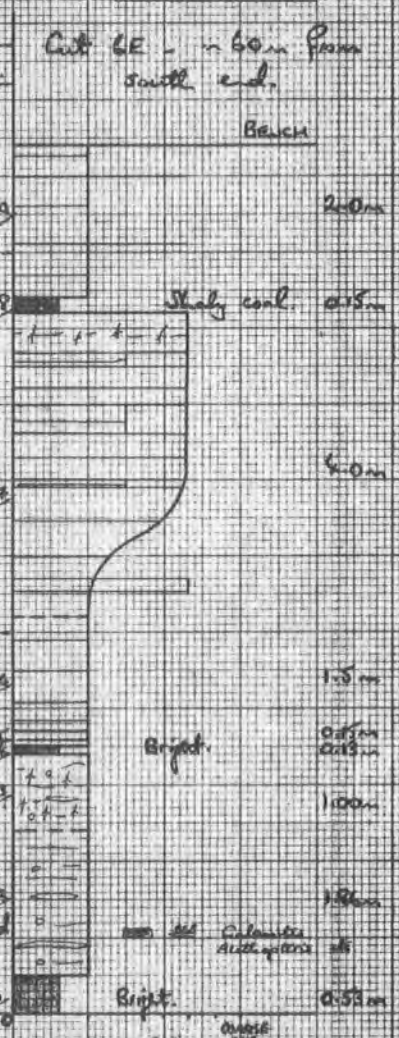
Also exposed but not examined in detail - 2E00 Area C Cut ½ East - 1 west.

BRETSONS. Still working Main + five quarter - now close to site boundary at east end. Worked out High Main 2E00 × 1E00 benches close to east end - and five quarters (pillars only) - 50m from boundary. Exposure poorly - no detailed observation. Facies appear very similar to previous cuts.

CRF 19.8.81.

SECTION 396 TANNERS HALL - 6E.

Cut 6E - in 60m from south end.

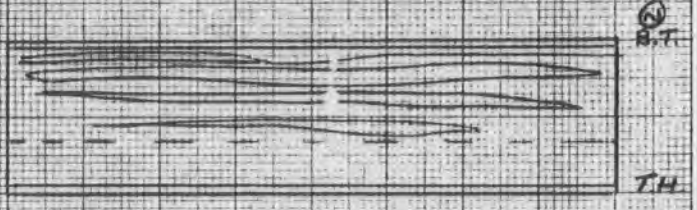


Long north - south cut - coal above Hutton seam reaches a maximum in the middle of the cut - decreasing on either side.

50m from north end similar facies and thicknesses - sst lens in and out. Lowest level of sst in middle of face - come in progressively higher to north and south.

CRF 19.8.81.

(Cut 6E)

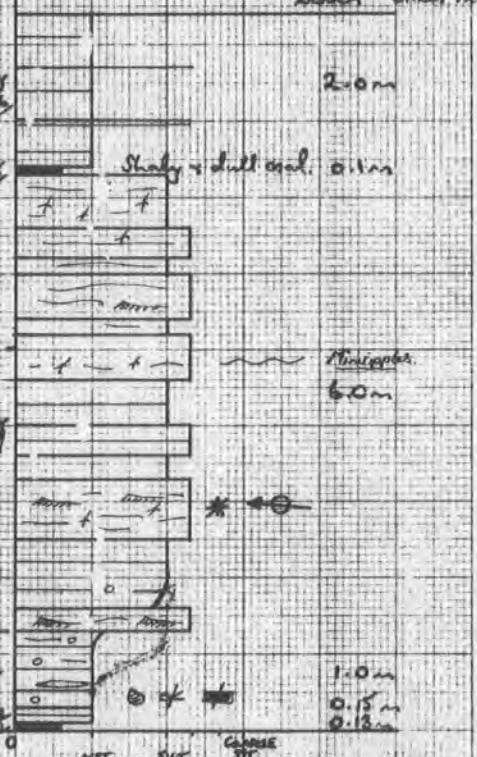


Sst lens wedge in and out along the face ⇒ transport ⊥ east or west. Facies otherwise display little lateral variation. 2 cross photos.

Drift cut down to level of Bottom Hutton at extreme north end of cut. (Drift washout also still present at extreme south end).

SECTION 397 TANNERS HALL - 6W

100m west of east end - before start of step faulting.



* DIRECTIONAL DATA :- RIPPLE - Type A - A = 0.01/2m axis. single set.

→ 280, 283, 272, 308, 266°. n = 5.

Θ = 282° ζ = 9°? n = 5

NB At east end of Cut 6W - by curve in face - sst over TH appears to come in after only 1m. 50m along - mst is dark coloured over TH. 100m along - before start of step faulting - mdst dark splinty and hard again. 1m mst to lst sst - but mst contains somewhat up to 4ft sst + silty mst - some horizons rooted. Rippled surface to one loose sst block. At 200m west - past start of step faulting - drag-line presently working.

Sst units appear more persistent laterally - although exposure does not allow continuous observation.

CRF 308 | Vicarage Hill Area - Rainshill

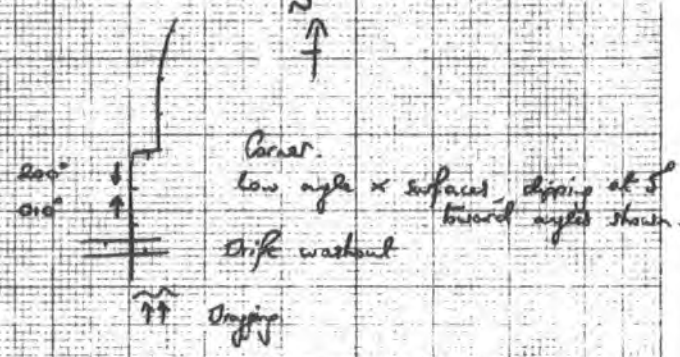
CRF A.8.81.

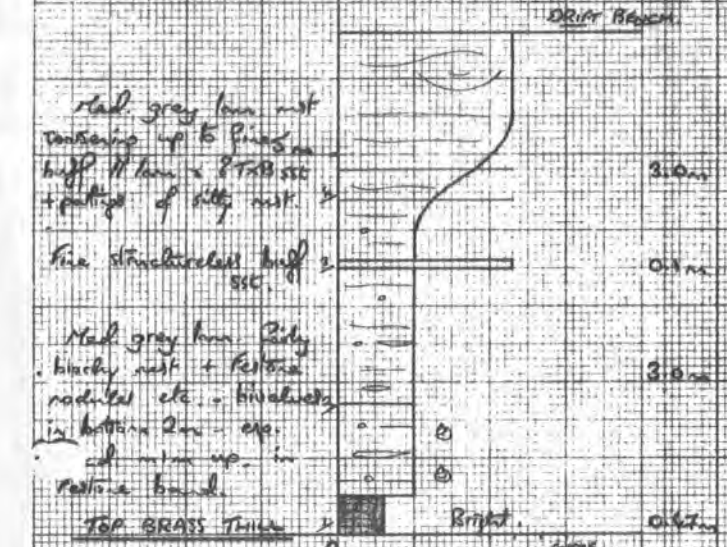
SECTION 398 –
TAWNERS HALL SW(BT)

200 m from east end – level with draglie and edge of plantation to north. Bench above Hutton cut.

PLAN – Cut 6W

2 colour photos.





Low angle false bedding has a domed-like form when viewed from a distance – appears fairly symmetrical in the face – ~ 50 m wide, 2-3 m high – dip/dip dirs consistent right across the feature – no change at all little lateral variation otherwise.

NB Areas south and south-east / SW are completely planted and infilled.

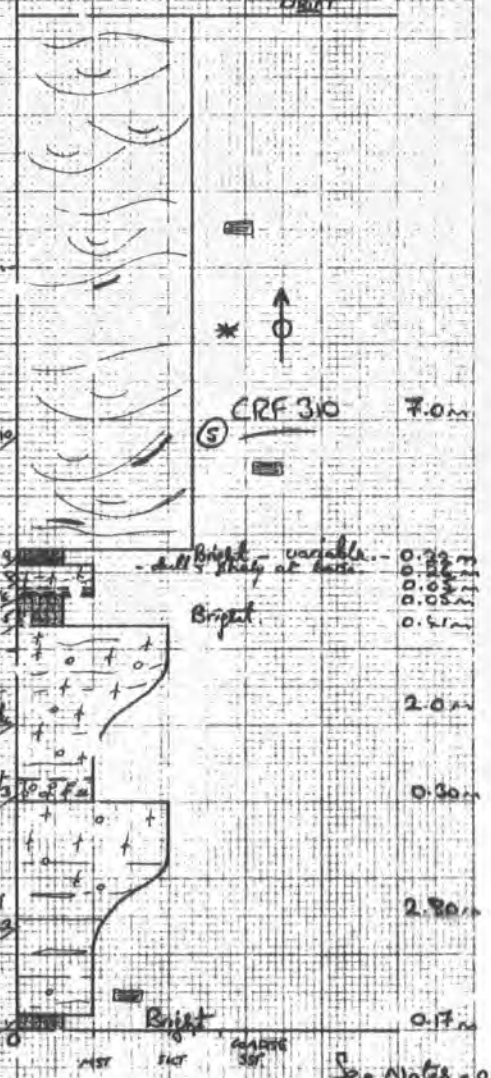
The thin sst thins along the face to the west (100 m further exposure), and also slightly to the east. These long E-W cuts will eventually extend across to the NW edge of the site-boundary with Milne opencast.

CRF – 25.8.81.

Cut D5-16 – Composite section.

Long cut – 352°.

SECTION 400
DEBORAH DRIFT

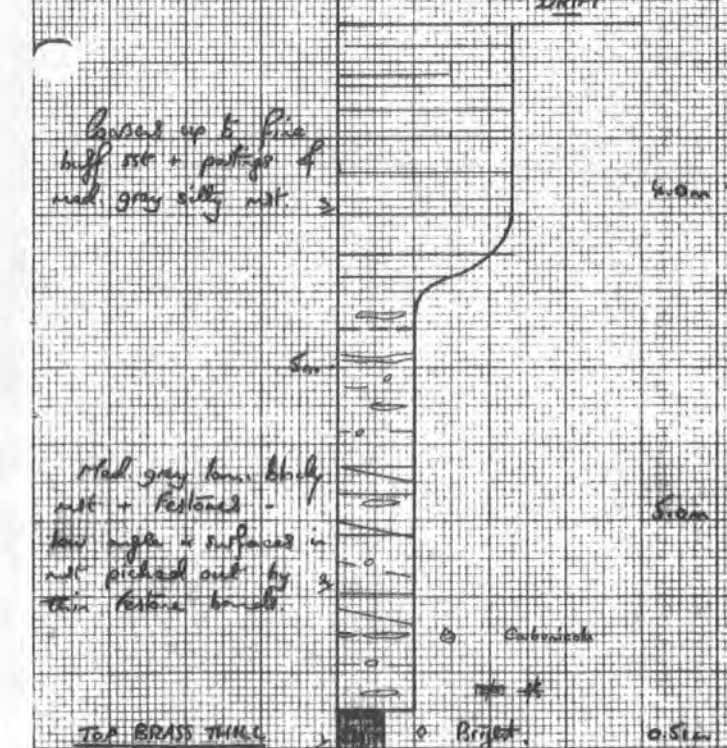


SECTION 399 –
TAWNERS HALL – 6W

Cut 6W north

80 m from present face (ie ~150 m from south end.

North-south cut.



See Notes – over

* DIRECTIONAL DATA – Unit 10 – trough x bedding
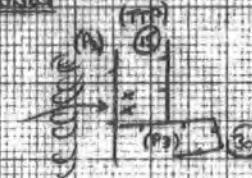
0.6m/355, 1.0m/010, 1.4m/018, 1.3m/347, 0.7m/342. n = 5.

CRF 25.8.81

Deborah 25.8.81

Section 400 - Notes - Section 400 is a composite - bottom part exposed near south end of cut, upper part near north end and middle.
TxB in T.P. is wide but angle troughs - probably often truncated bases of troughs. Set of planes common dark carbonaceous laminae - N low. and low angle x-cutting within troughs.
Lateral variation in cut is limited to some undulation in P302 level - under 40ft.

PLAN OF WORKINGS

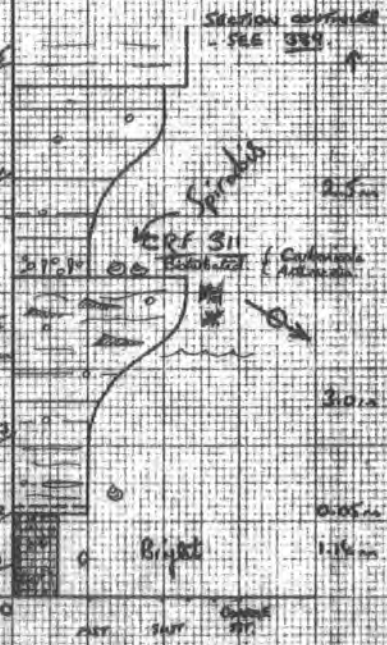




Generally working
Cuts Dip 15 x 30
Dip 14.

Generally reducing to P300 - set heavily fractured due to blasting - accurate not possible. Set 1-2m thick - beds - thin - 2m units known of 7 Harvey just below drift. 1 calcite slide.

SECTION 401
- BUCKHEAD - B2



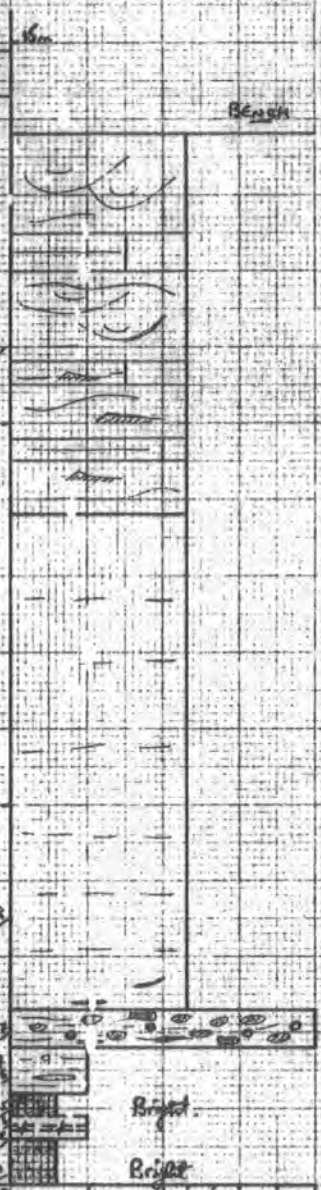
* DIRECTIONAL DATA:- Unit 3 -
- Rel - Type A, A = 0.01 ms.
→ 118° - 136° n = 2. Θ = 127° - n = 2

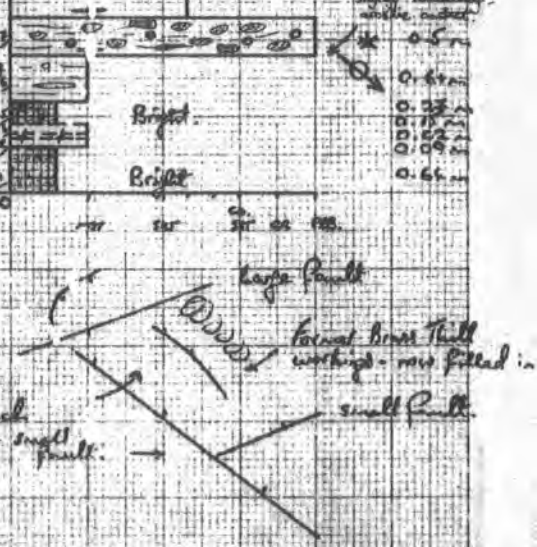
Area B - situation similar & but visit - one more long cut & Hutton → 360° + sand absent.



Section 301 - Wave ripples only imperfectly developed - isolated wave-influenced form sets - mostly. Occurrence of ?foraminifera or spirorbis in beds of Unit 4 also bioturbated + rib in bivalves.
2 photos.

SECTIONS 402
BUCKHEAD - C3





Area C - Plan

Notes - Conglomerate - pebbles ≤ c.10cm of mst + mudstone all well rounded - supported in a matrix of fine buff sst - some clasts rounded - well rounded - mostly only partly rounded. Conglomerate layers is discontinuous - commonly lens shaped.



* DIRECTIONAL DATA
Cradle stratification of pebbles - imbricated dips → 326°
in westerly

CRF 25.8.81

Buckhead Area C continued.

Under level of low Main, two thin sst occur - structures within mainly 11s uneven laminations with muddy streak - disturbed by rooting - no RHL visible. 2 photos.

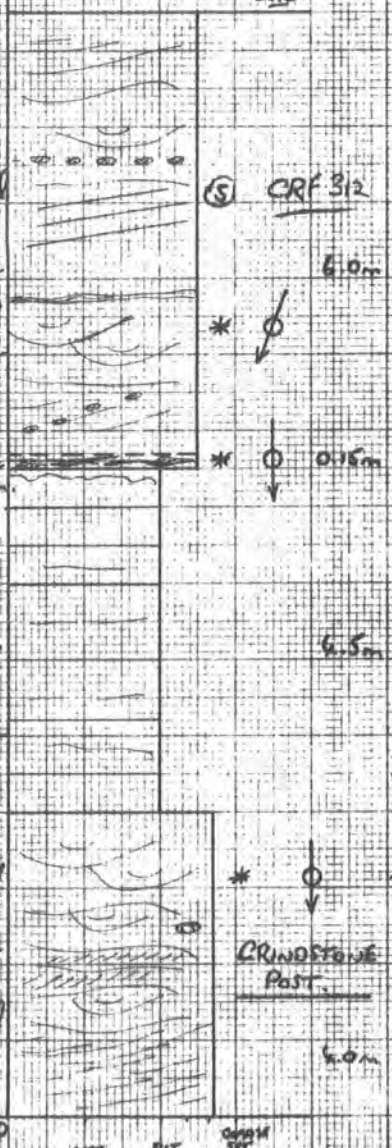
Area LE - Headline at bottom of hole now cleared out - at north end of collapse tip: - being backfilled. Presently working on Main - half way down ramp - fingerpainting exposure.

At top - top E-W cut into Area J along Headline outcrop - presently 10m along from west end. No exposure at present.

Examination of Tadlow cracks over Area C.

CRF 26.8.81.

SECTION 403 (Pashley) - Composite section
- BARNWELL QUARRY. - C.R. NZ 32654O.
See Description



Fine/med buff weathered sst with horizons containing abundant & shale clips ≤0.05m Occasional coal parting.

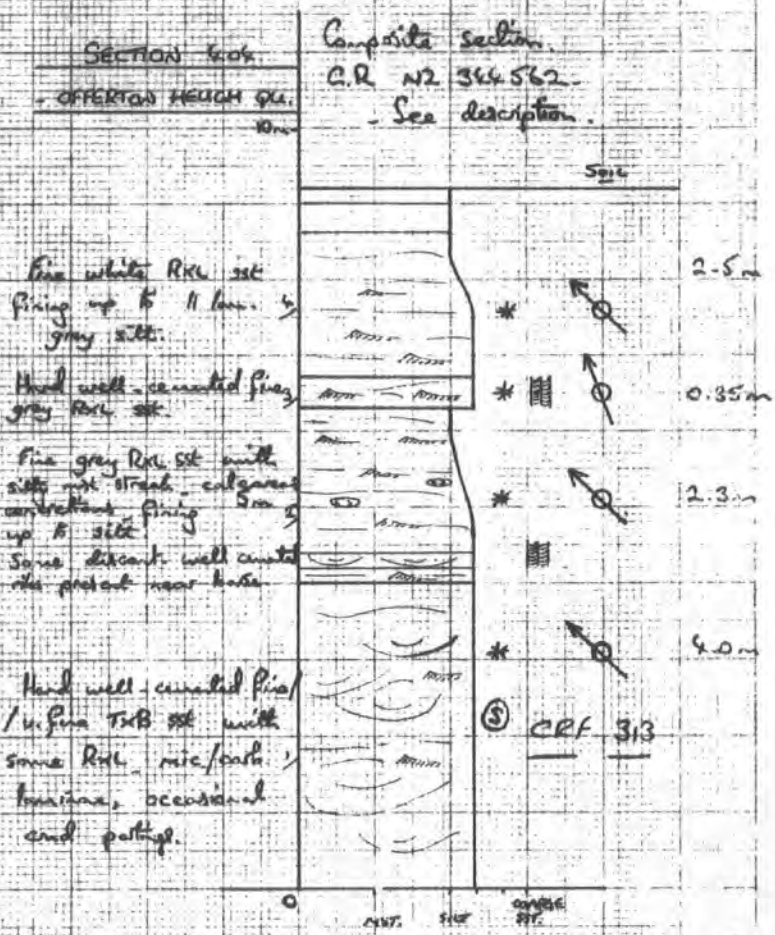
Hard white sst with abundant mic./carb. laminae ≤0.005m - 11cm. wavy lam. & RHL.

Hard grey 11 lam. silts - heavily weathered at top.

Hard well-cemented med buff sst - TxB, low angle & bedding - commonly in cracks - largest x sets exposed near base.

Horizon - between Rylope MB & Ellsworth Coal.

SECTION 404
- OFFERTON HEUGH QU.



Fine white RHL sst fining up to 11 lam. & grey silt.

Hard well-cemented fine grey RHL sst.

Fine grey RHL sst with silty mst streak - calcareous cementation fining up to silt. Some discont. well cemented mst present near base.

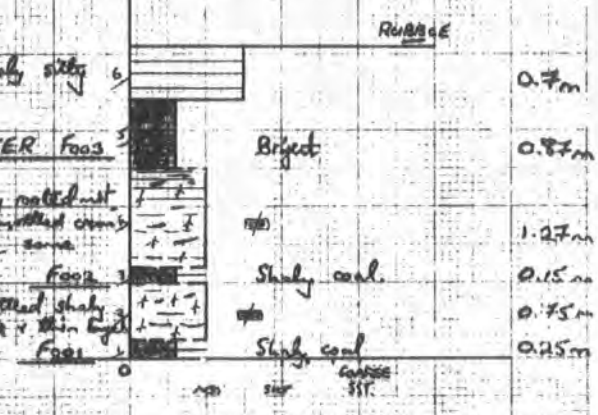
Hard well-cemented fine/v.fine TxB sst with some RHL mic/carb. laminae, occasional coal partings.

Composite section.
C.R. NZ 344562.
- See description.

Above Bottom Hebburn Fell Coal.
Horizon - between Wearmouth & Coquilla MBs.

CRF 2.9.81.

SECTION 406 Fivequarter outcrop cut.
LANGLEY A1 (Foss)



Hard grey shaly silty mst.

FIVEQUARTER Foss

Hard - dk grey mottled mst shaky near top - mottled crumb & other in places - some carb. fossil.

Foss

Pedal grey & mottled shaky mst & coal bands & thin lyrs - shaly coal mottled colour in places.

Foss

Outcrop cut - worked in two benches - bottom 2 leaves in 1st bench - then top one. Coal thicknesses probably reduced - coal quality also due to proximity to outcrop. & Top leaf becomes heavily worked away from outcrop. Worked on bench above Main coals. NB 3 leaf? pattern to coal.

EDMONDSLEY 2.9.81 - CRF.

CRF 9.9.81

Area C - small island of 1E00 x E000 left - 0.40m Bight → 0.95m light grey clay mottled olive & red in places → 0.70m pulverised coal & shale fragments. - Lithology probably partly due to glacial movement. Limited exposure - 20m long "face" trending → 315°

Above Cut C16 west. 2E00 beige worked ? almost at outcrop - overlain by 8m light grey silt & sandy streaks.

Cut 16 west - F000 not presently exposed - but section above.

SECTION 605 - EDMONDSLEY C16W.

BENCH TO 2E.

Rooted nodular 10m - silty mst. 2.0m

grey loam. dark grey mst 0.10m

Rapid fining to light grey silty mst + nodules? Some silt filled trough forms. 2.0m

Solid buff cross-bedded fine sst with 5m large scale TxB. 3.5m

Interlaminated fine white sst & dark grey silty mst - mostly 1" lam. - some current lam + bioturbated placed. FAT laminae less common upward. May be thin mst at base. 3.2m

roof of FIVEQUARTER

NOT NOT COARSE SST.

SECTION 409 - QUICKBURN QUARRY. 10m Face 2 - composite log - See Description.

SOIL

Grey fine II lam, Rac & TxB thinly bedded mic. sst. 3

Coarsens to silt at top. Dark grey lam. mst. 11

Hard rooted fine white sst - rarely well bedded 5m 10

Dark grey rooted silt 9

coal 8

Rooted med. grey silt - dark at top. 7

Hard white rooted sst - CAVISTER. 6

Med. grey rooted silt 5

Rac rooted fine - med. white sst 4

Fines to med. grey silt + S.S. 3

Med grey rooted lam silt + sandy streak - Rac fine white sst. 2

Fine buff low angle TxB sst - micaceous. 1

Undulating top - unit 2 3 is thicker where 1 is thinner.

S CRF 318

2.0m 0.71m 0.52m 0.80m 0.11m

CRF 317

0.70m 0.68m 0.34m 0.28m 0.07m 0.60m 1.84m

See Below Planolites

0 mst sst COARSE SST.

NB Unit 2 & 3 only 0.32m together in places where Unit 1 is thicker in topographic high.

Base of Unit 6 is knobbly and displays some irregular trails - hypichnia on base

SECTION 410 SALTERS GATE QUARRY.

Face 4 - southern end of quarry. See Description

SOIL

Fine/very fine II lam mica lam + fine thinly bedded sst. 4

Shaly silty mst. 5m - 3

Coal 2

Hard white rooted fine sst - CAVISTER - heavily bioturbated in places. 1

Red/fine white TxB sst - extensive rooted upward. 3

red grey silt + sandy streak, some trails 2

Hard well cemented fine white TxB sst. 1

0.7m 1.9m 0.1m 0.50m 0.80m 0.80m 2.0m

Planolites

0 mst sst COARSE SST.

DIRECTIONAL DATA :- Unit 2 - TxB

0.9/220 . 1.0/209 . 0.7m/233 . 0.3m/202°

$\hat{n} = \zeta$. $\Theta = 211°$ $L = 972$ $n = \zeta$

Unit 2 - Rac Type A . A = 0.01m → 275. $\lambda = 1$. $\Theta = 275$

Level of sst base varies along cut but old working plant → difficult to assess relief on contact.

Sst (Unit 2) has thin coal/mic. laminae with comminuted plant remains - almost interlam in places & in infills of some small troughs.

In fining unit - some silt-filled trough forms present. Thin mst near top of section is laterally persistent. 2E00 coal lies on bench above top of section.

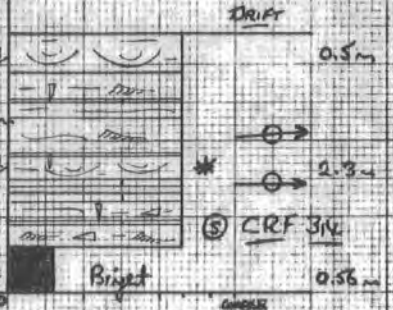
Area B cuts as per last visit. Area C middle and east under restoration.

(CRF 316 - major sst - Salters Gate)

CRF 2.9.81.

SECTION 607
LANGLEY A 84 EAST

5m East end cut - just below sinuous outcrop line - trends → 223°. (SE end of long cut).



Solid fine buff TxB sst. Interbedded/laterlaminated fine white RxC, lt's mauve brn sst + dark grey carb. silty mst - locally bioturbated in places. Some small low angle x sets.

Floor - light grey clayey rooted mst.

* DIRECTIONAL DATA :-

Unit 2 - TxB - 0.1m/080°. n=1 θ = 080°

Unit 2 - RxC - A=0.01m → 106, 131, 072, 073, n=4.

θ = 095°

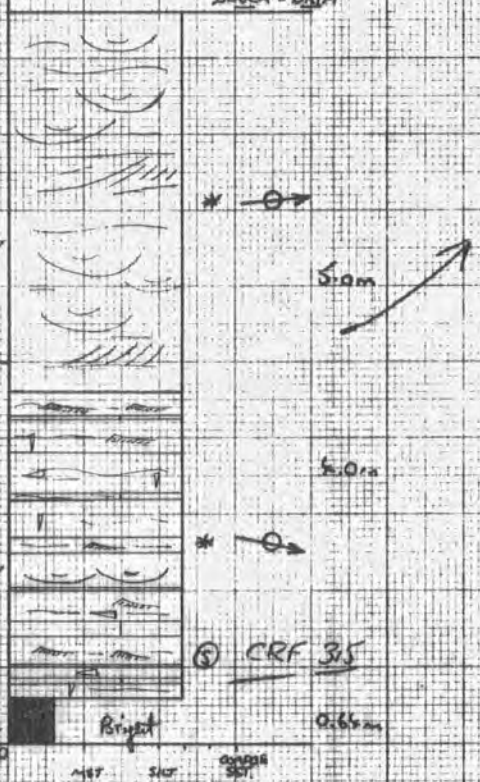
c = 97% n=4.

SECTION 608
LANGLEY A4 EAST

Main part of cut to E - 4.500m log face, trends → 107°.

Near south end.

BENCH - DRIFT



DIRECTIONAL DATA :-

Unit 2 - TxB - 1.5m/092, 1.0m/074, 1.0m/076, 0.7m/081 n = 4. θ = 081° c = 99%

Unit 2 - RxC → 112, 121, 113, 104, 093 n = 5. θ = 109° c = 99% n=5.

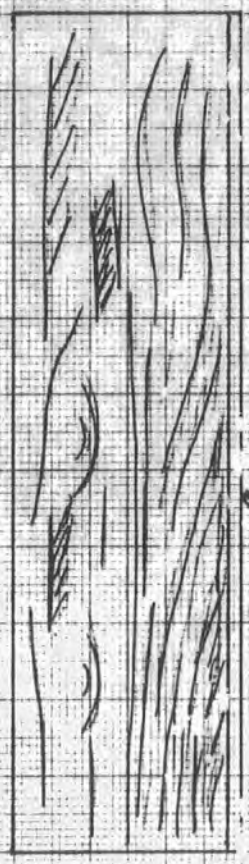
Example of vertical burrows exposed (also vertical and horizontal tubular ones).

mst

sst.

0.01m × 0.01m

marking displaced by dark carb. mst.



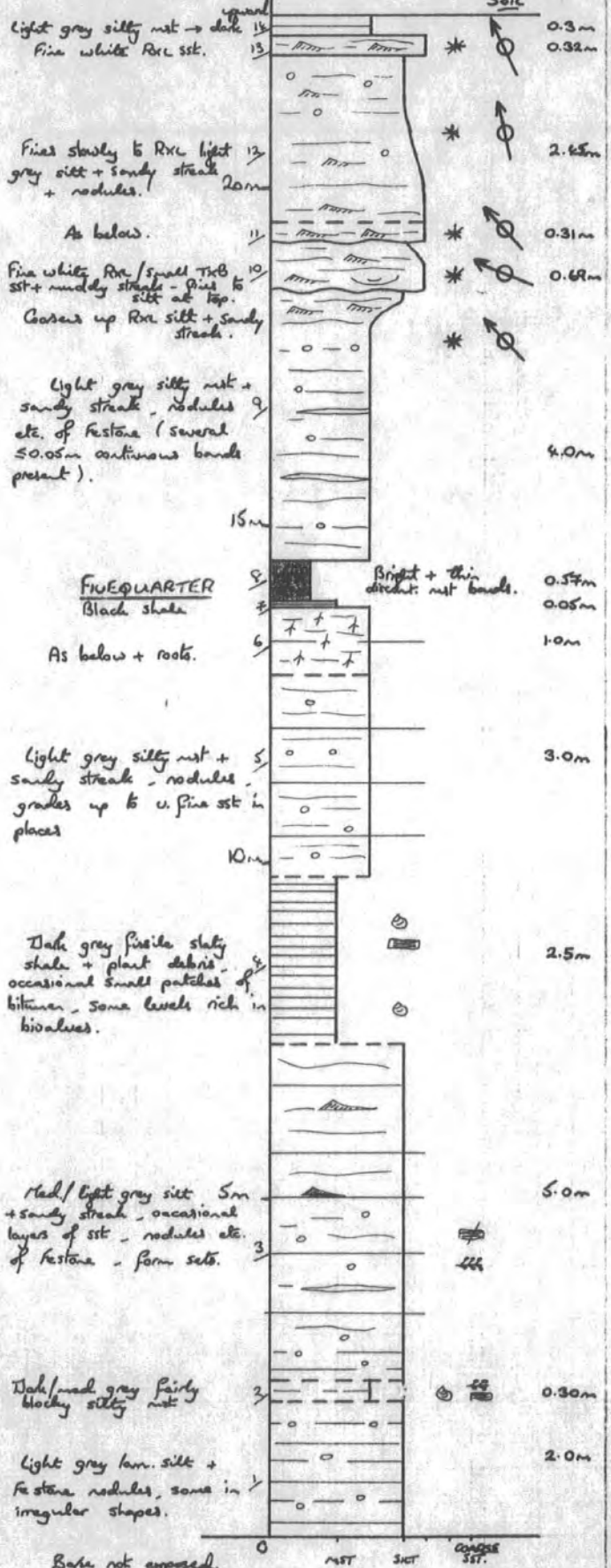
Parallel dipping and cooling near south end of cut - not from smaller cut. Bottom 1m of interbedded facies is 11 bedded, the 2.5m low angle x bedded unit dipping down to SE beyond flat-lying and unlikely near SE end of cut. Top 0.5m flat-lying also. Sharply cuts out only first ≈ 200m of cut - to first corner. 3 planes below. Note SE dip in the channel of the main seam - near. thickest of interbedded unit - corresponds to max. of dipping beds like a large lenticular sequence.

CRF 10.9.81.

SECTION 411
CROSSLEY BRICK QUARRY

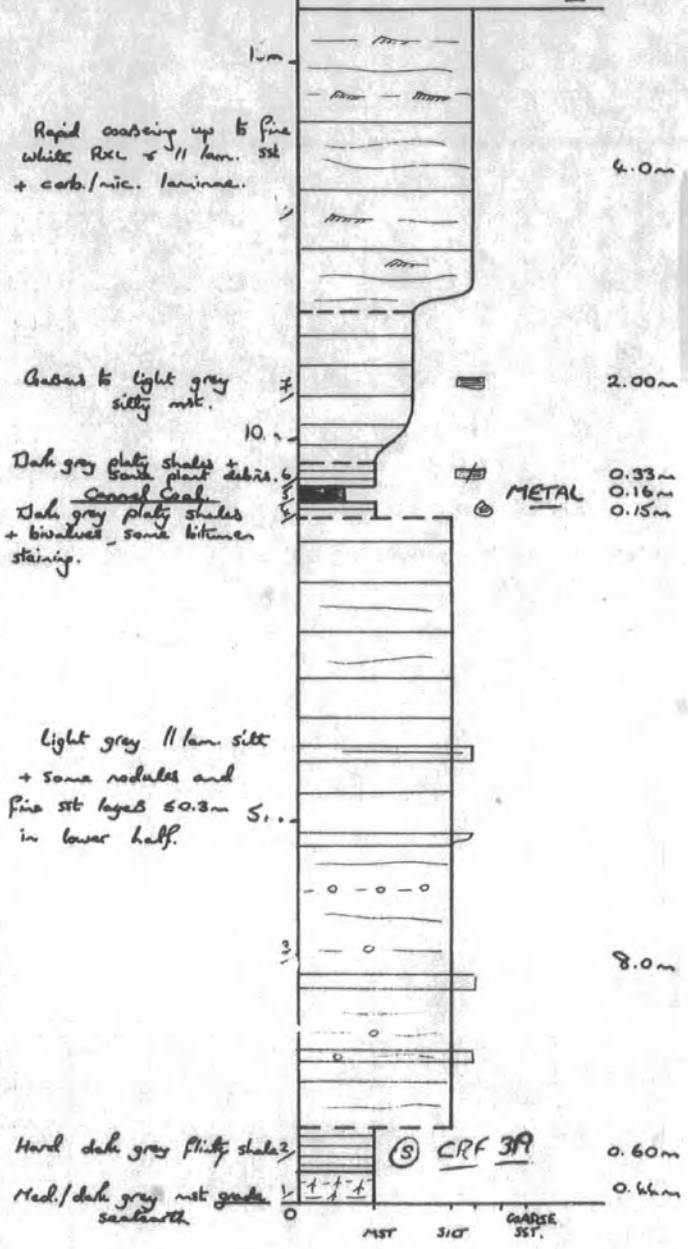
-25m

Composite log - see Description.
Tectonic dip 5/347.



SECTION 412 - AUCKLAND PARK

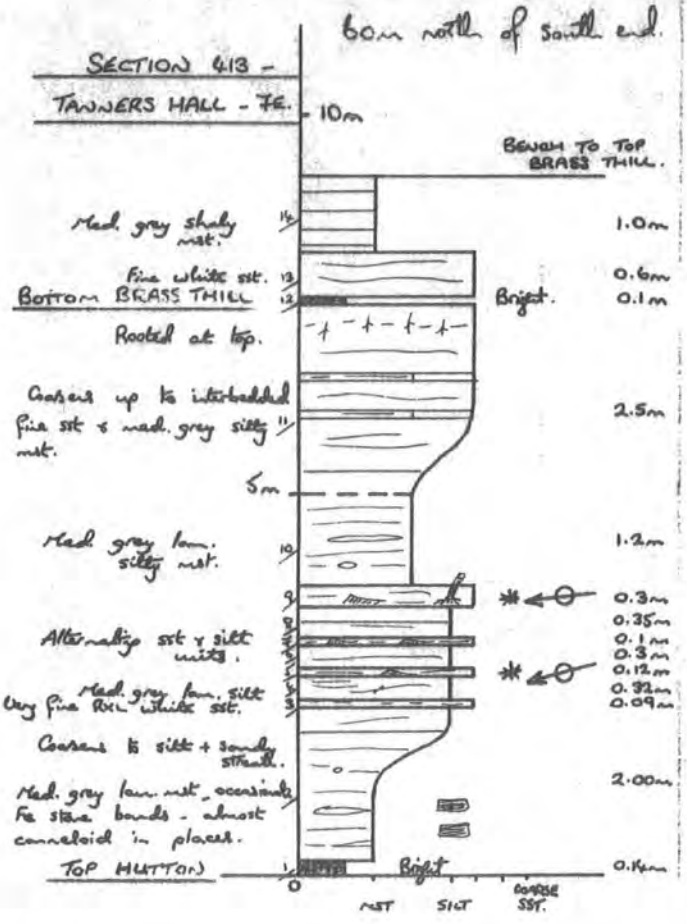
CR NZ 218301 - east bank of River Roundabout - riverside crags Tectonic 11/333
Level - above Fivequarters seam



CRF 11.9.81.

60m north of south end.

SECTION 413 - TANNERS HALL - 7E.



* DIRECTIONAL DATA :-

Unit 9 - Bed-over Calamites in situ - 1. 0.02m × 0.2m → 218°, 2. 0.02m × 0.3m → 295°. n = 2.
Θ = 257° n = 2

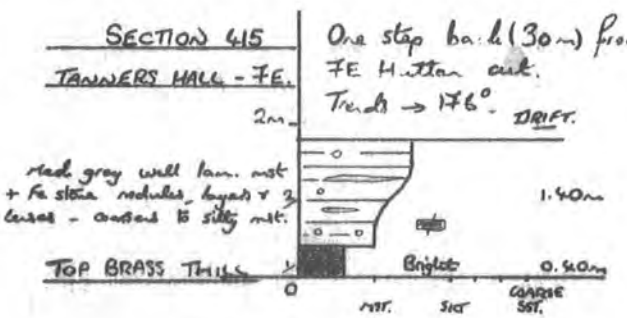
Unit 5 - RxL - A = 0.02m → 252, 264, 241.
Θ = 252° c = 99% n = 3

Unit 7 dies out within 20m to the north. Apart from this facies remain very persistent laterally - thinning of some ssts to the north. Presently dragging ~130m north of south. In places, drift cuts down below level of T.B.T. - outcrop must be quite sinuous.

NB Site ratio 37,778 593 - 1,202 510 - 31.416.

SECTION 415 - TANNERS HALL - 7E.

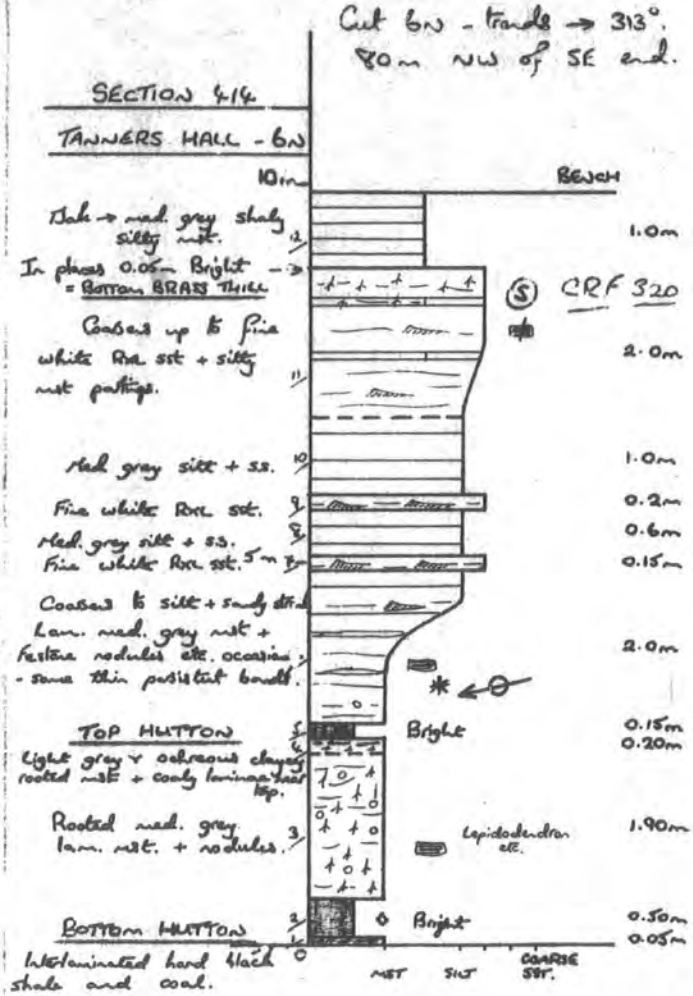
One step back (30m) from 7E Hutton cut. Trends → 176°.



Section taken near north end of cut - drift cuts down to north end → outcrop. Little or no lateral variation - some thin Fe stone bands are very continuous.

Cut 6N - trends → 313°. 80m NW of SE end.

SECTION 414 - TANNERS HALL - 6N



* DIRECTIONAL DATA :-

Unit 6 (Further along face) - orientated plant debris → 247° (n = 1). Θ = 247° (n = 1)

150m along face - over Top Hutton = 1.5m mst 1V, 0.4m sst, 0.6m silt, 0.3m sst, then as before.

250m along face - Hutton 1-2 parting reduced, now into area of old workings. Sequence over Top Hutton - 1.5m mst, 0.3m sst, 0.6m silt, 0.6 sst + mst laminae, 1.2 silt then coarsening up mst. Lepidodendron prints in mst from Hutton 1-2 parting. Plant debris in mst above Top Hutton → 247°. Mst gradually coarsens with sandy stringers & laminae, foram sets visible.

400m along - far end of cut, just before downcutting drift channel. Over Top Hutton - 1.5m mst, 0.15m sst, 0.5m silt, 0.1m sst, 1.5m silt then coarsening up sequence.

At end of cut - roadway, then old cut further to west - last cut taken off Incline site - also numbered 1W on T.H.!
- two thin ssts still visible.

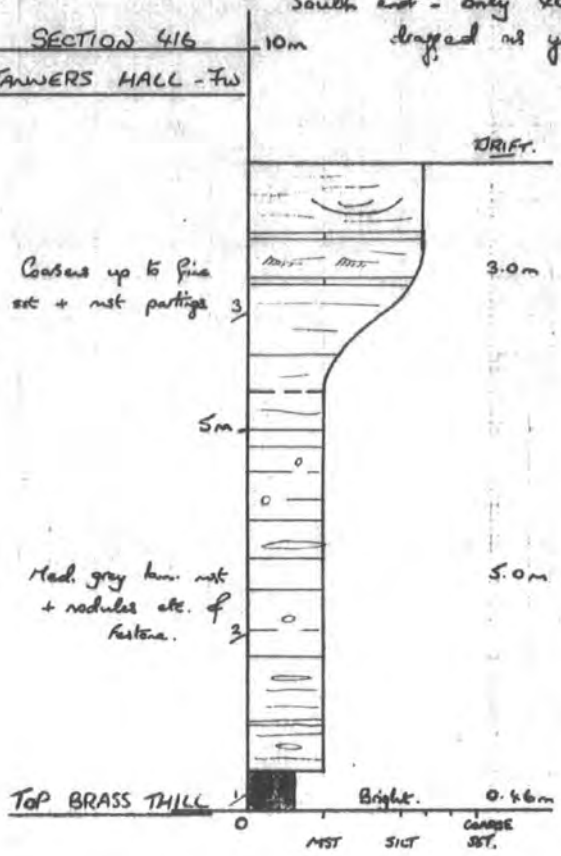
SECTION 415

CRF 11.9.81.

Cut 7w - 10m north of south end - only 40m dragged as yet.

SECTION 416

TANNERS HALL - 7w



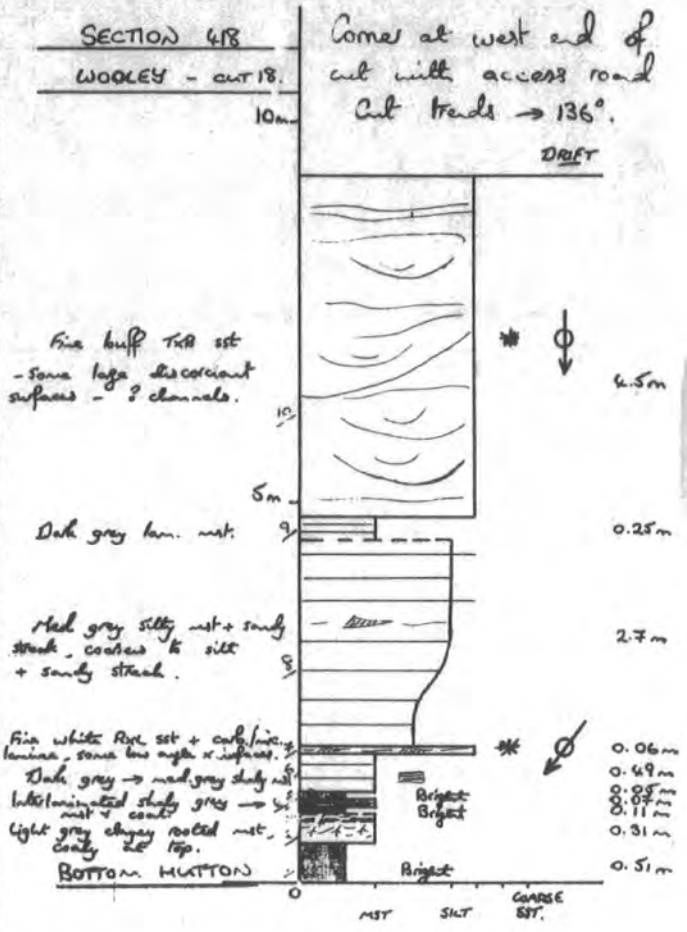
Cut joins onto north end of 6w (seen on last visit) - re mst channel form - section appears more or less symmetrical - possibly orthogonal. - 2 photos.

CRF 14.9.81.

SECTION 418

WOOLEY - cut 18.

Comes at west end of cut with access road Cut trends → 136°.



* DIRECTIONAL DATA:- - on access road.

Unit 10 - Trough x Bedding - 0.3m/173. n = 1.

Unit 7 - RxL Type A, A ≤ 0.02m

→ 238, 228, 205, 212, 230. n = 5.

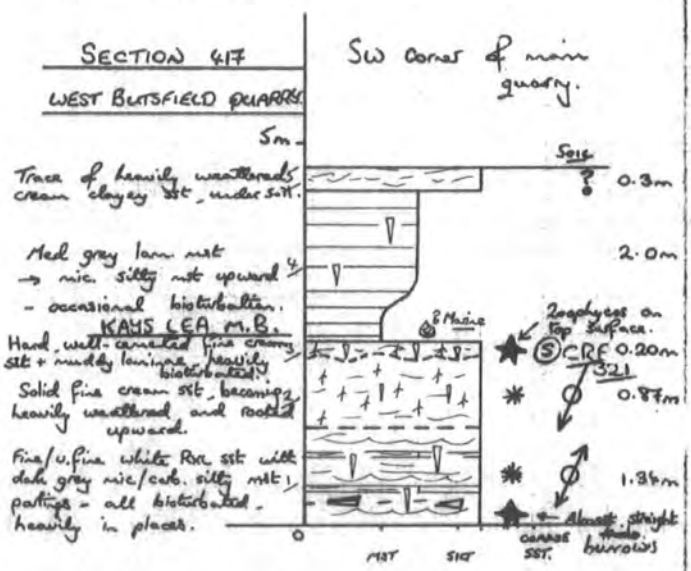
θ = 223° n = 5 C = 98%

CRF 13.9.81.

SECTION 417

WEST BUTSFIELD QUARRY

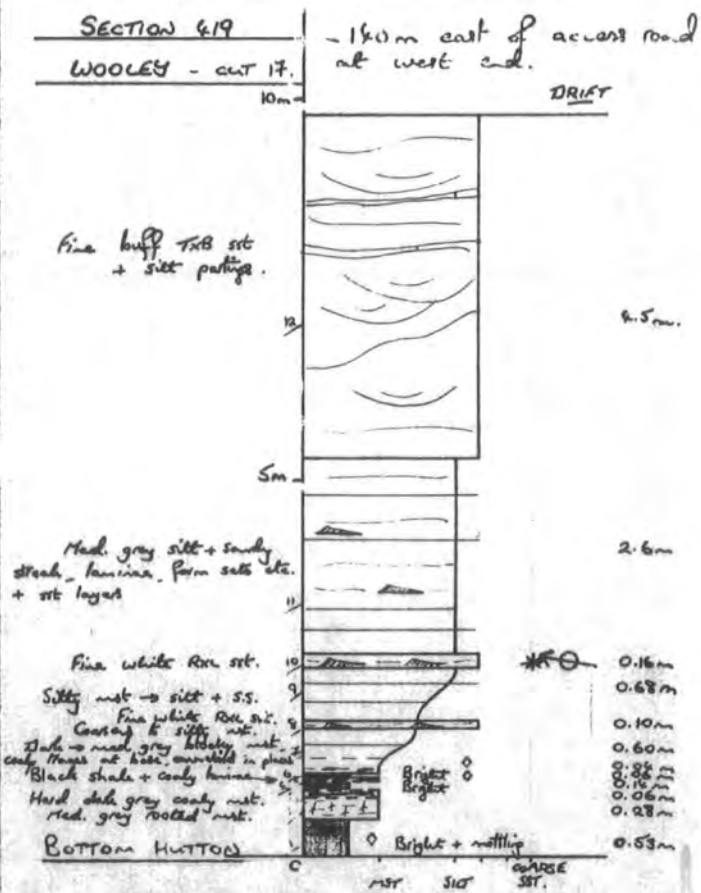
SW corner of main quarry.



SECTION 419

WOOLEY - cut 17.

- 1½0 m east of access road at west end.



CRF	325	- Humbers Hill.
	4	- Fellside
	3	- Sheep Hill
	2	- Foghouse

* DIRECTIONAL DATA - See Over

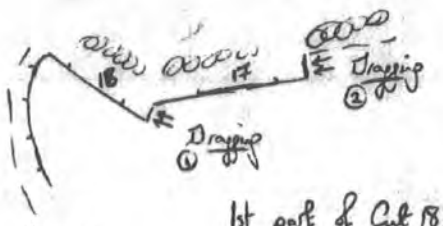
* DIRECTIONAL DATA from Section 419 - Unit 10

Rxl → 279°

+ 275°, 312, 294 further east along face.

Θ = 290°, L = 97%, n = 4

Plan of Workings - Presently working Cuts 17-18.



1st part of Cut 18 trends → 136°. ~60m exposed.

From 1st dragline ~160m exposure of Cut 17 before 2nd dragline - 50-100m more to drag.

Section 419 taken ~80m east of 1st dragline.

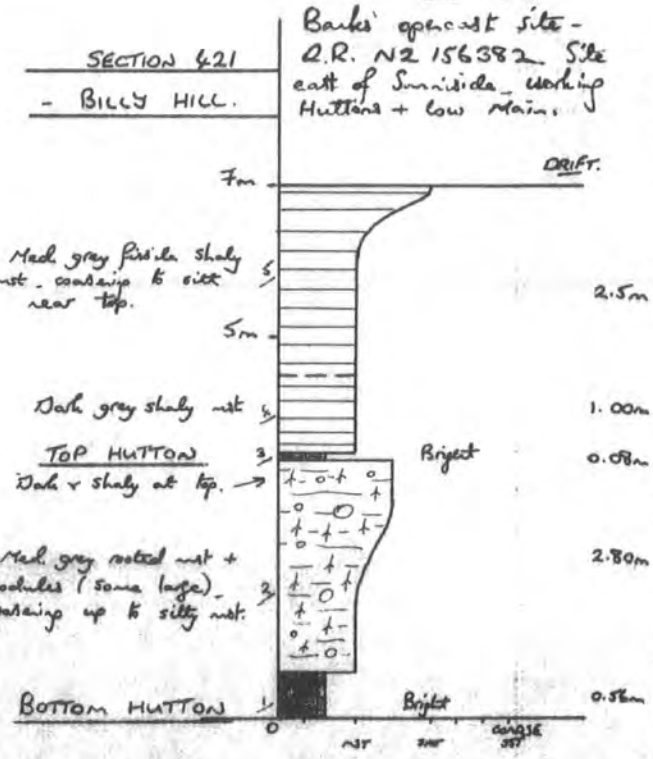
In Cut 18 - thin ssts vary in thickness occasionally along the face, but are persistent right along the face - definitely thicker to the east of Section 419.

To east along cut further thin sst comes in above the 2nd one - 0.7m up - 0.10m thick - dies out westward - hardly present by position of Section 419. Toward east end 2nd thin sst is 0.25m thick and coarses up at the base. 3rd sst is 0.15m thick, thickening to the east. Sense of ripple x lam. in thin ssts is difficult to determine - uneven lamination also present.

C.R.F. 18.9.81

SECTION 421 - BILLY HILL.

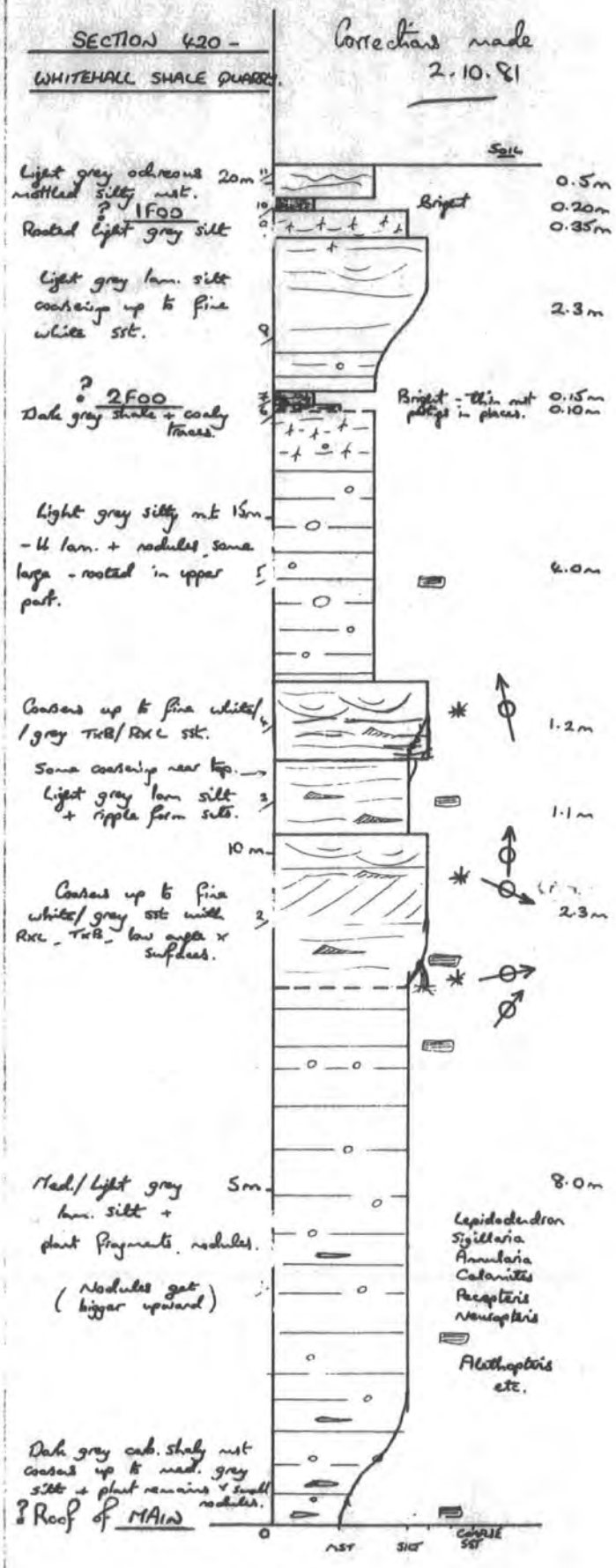
Banks' opencast site - O.R. NZ 156382. Site east of Sunniside. Working Hutton + low Main.



Present working cut - trending E-W - situated ~50m north of a fault (E-W) bringing down low Main to the south. Cut ~150m long - little or no lateral variation visible.

SECTION 420 - WHITEHALL SHALE QUARRY.

Corrections made 2.10.81

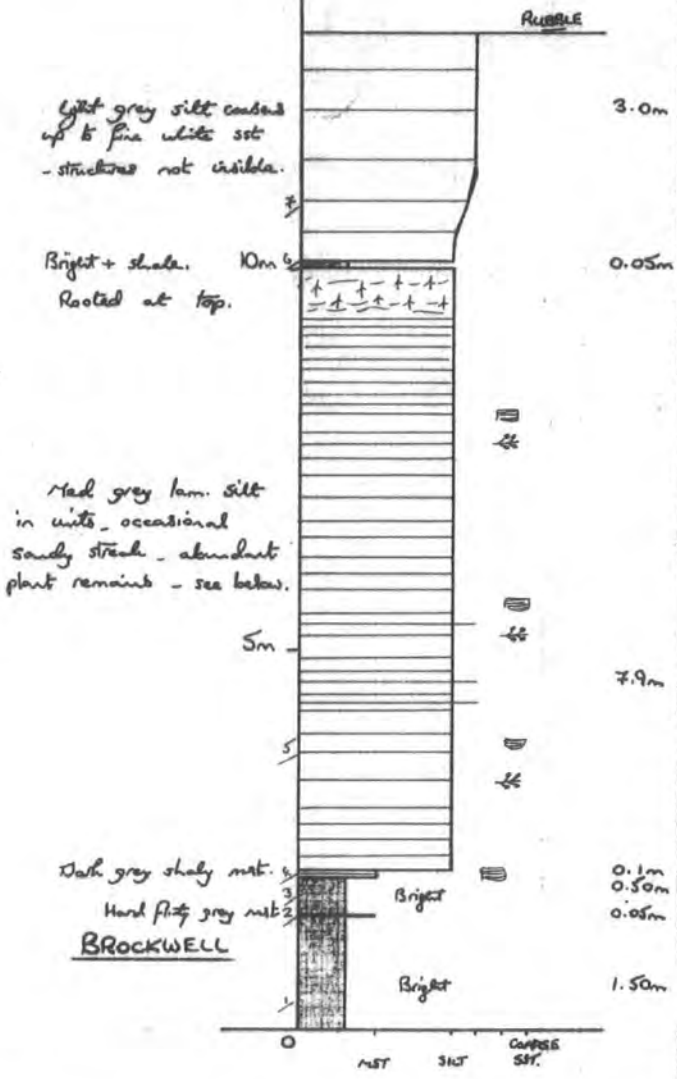


West end of Whitehall Quarry.

CRF 18.9.81

SECTION 422 - WOODLAND.

Banks opencast - north of Woodland village - C.R. NZ 065265.



Section logged in western area of site - deep N-S trending cut ~70m long.
Plant remains very abundant and well preserved in the silts - several types - Calamites, Pteridosperms, etc.
Silt is laminated in 10-20cm packets, separated by ≤0.005m dark grey clayey mst partings - packets become thinner near the top. Gives the section a flaggy appearance.
To the east of the western area (field containing officer) is a small field also exposing Brockwell - similar section exposed.

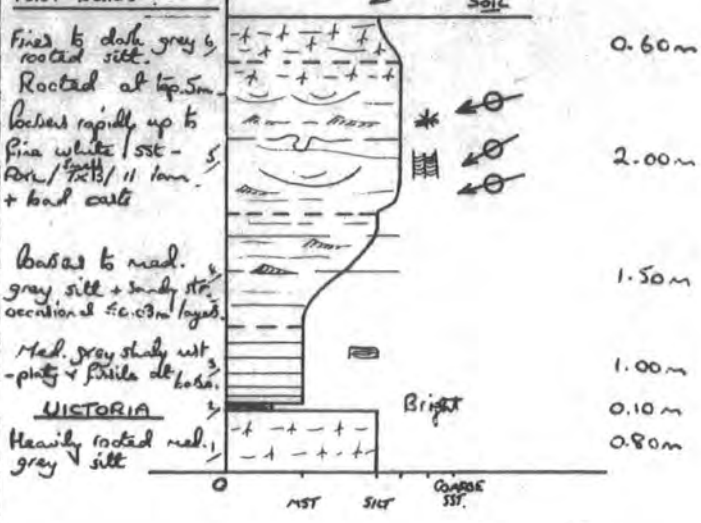
CRF 29.9.81.

Pont Burn 100m upstream of Pont Bridge. C.R. NZ 167562

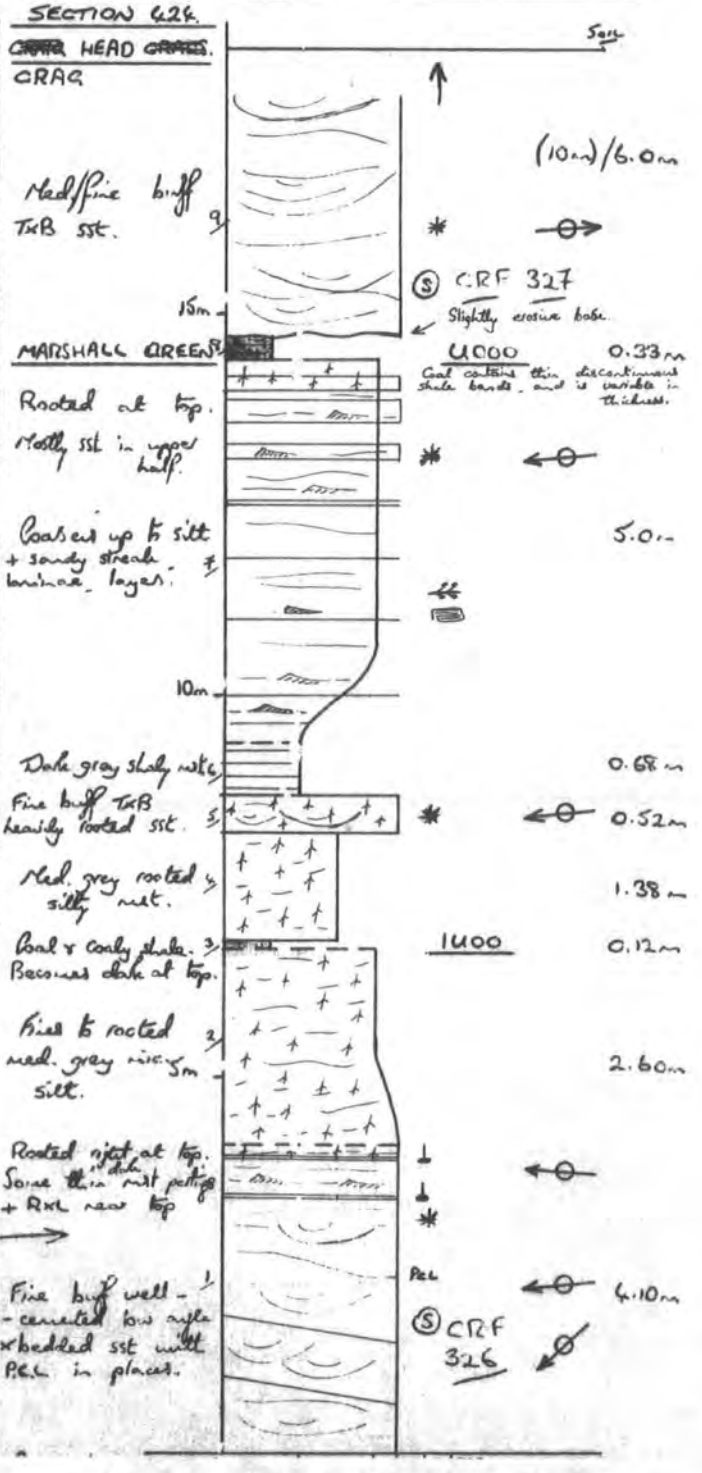
SECTION 423

PONT BURN

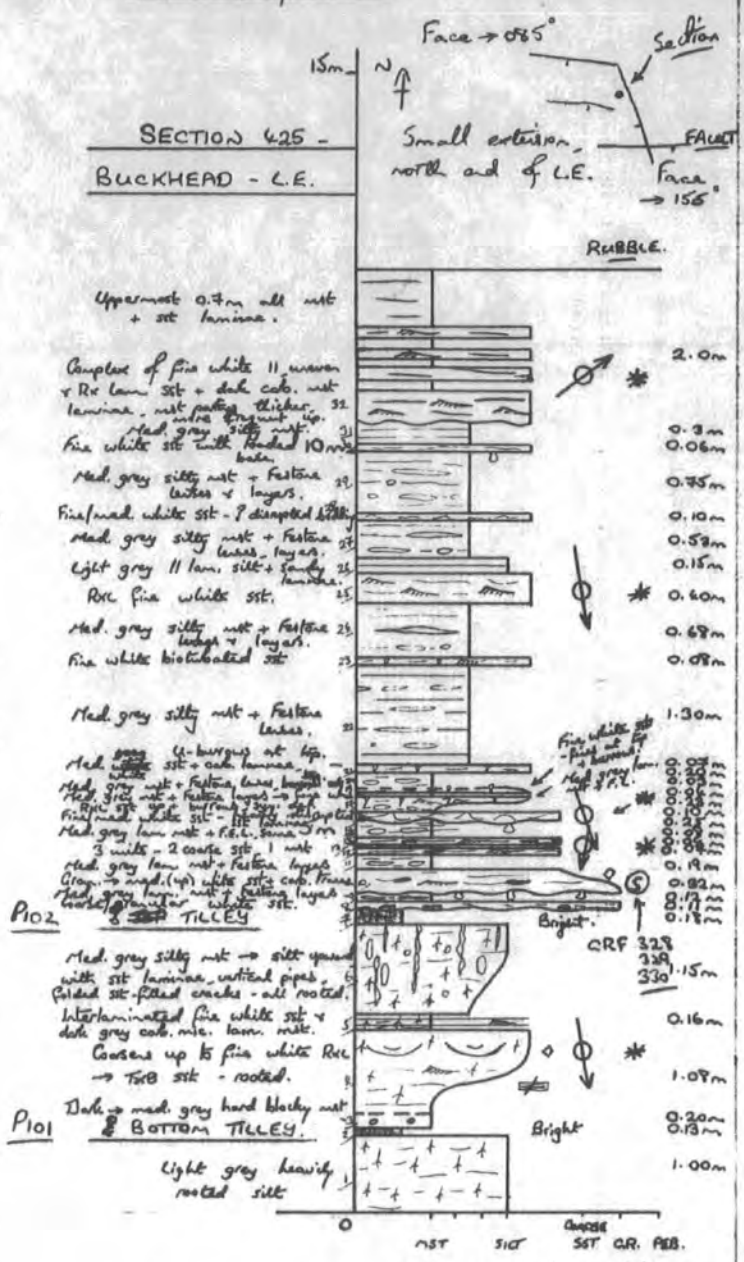
Coal traced in soil.



SECTION 424.



CRF 6.10.81/9.10.81.



⑤ - sst - unbacked (pyrite-coated)

* DIRECTIONAL DATA :-

Unit 32 - Channel orientation → 055° ~ = 1.
(inferred from geometry on faces).

Unit 25 - Rxl, Type A - 0.05m A → 0.01m at top.
→ 186, 178, 165, 173, 184. ~ = 5.

Unit 16 - Rxl, Type A, A = 0.01m.
→ 160°, 165°. ~ = 2.

Unit 16 (Equiv) TxB 0.2m/149°. ~ = 1

Units 12-14 (Equivalent). Trough x Bedding
0.4m/190° ~ = 1.

Unit 4 - Trough x Bedding - 0.15m/154, 0.15/160.
~ = 2.

Rxl - Type A, A ≤ 0.03m
→ 155°, 193°, 200, 167, 152, 165, 195, 162°.
~ = 8.

Also CRF 331 - Unbacked - with

Section located at NE end of the Laundry Extension - small cut under shale heaps. Tectonic dip 9/345°.

Several photos - both b/w and colour - taken.

Units 12-14 coalesce to the SE of the section into a single 0.6m sst unit, with large-scale bedding and one x set.

Sediments are tectonically disturbed 30m south of the wall corner - major fault - downthrows Main and Maudlin to south. - part of Wigglesworth system.

In some ssts - ? dewatering structures - flame-like features, inclined in opposite direction to Rxl - almost like rootlets of dark mst.



Unit 8 wedges out rapidly to the south of the section -



Also - mst unit with Festoon lenses etc. is squeezed down through the underlying sst.

Coaly scoops are abundant in all thin ssts within ~1m of the top coal.

In the section - several marked lateral variations visible, particularly in the geometry of the thin ssts.

Unit 25 thins to 0.3m to south of section.

Unit 23 thickens to 0.3m Rxl sst by 5m to south.

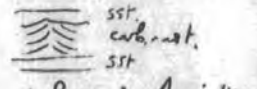
Unit 16 - Thickens rapidly to south (~10m) to 0.6m, and amalgamates with Units 12-14.
- contains large load casts x 0.2m x set.
Also heavily bedded x thickened to north.

Units 12-14 thicken to south to a total of 0.35m - mst unit wedges out.

Unit 8 wedges out to south - see above.

Many of the sst units can be followed onto the E-W face - eg Equivalent to Unit 16 on E-W face is a 0.7m sst with deformed TxB - thins rapidly on N-S face to 0.03m sst - 5m downcurrent, wedges in gradually to south from 0 to 0.10m - Unit 16.

In thick sst, shale clasts, partly rounded, ≤0.05m across present. This sst is overlain on the E-W face by 0.35 mst + sst layers? then 0.2m sst, with burrows at top - Also water escape structures - arching of dark mst layer.



Burrows - Arenicolites ? or not certain Palaeophycus

Sketch



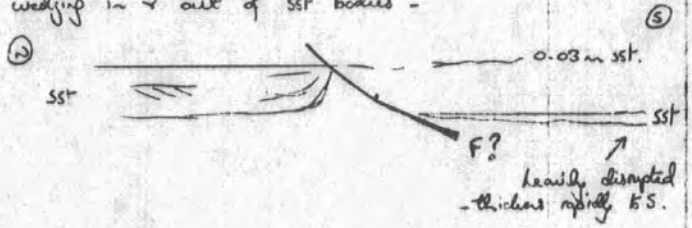
CRF 6 & 9/10/81

Twenty metres to west of corner - 3 small faults - then to west, section above top coal for 3 m ↑ contains 80% sst layers - T×B → 193° - layers mostly ≤0.6 m thick - up to coase grade sand.

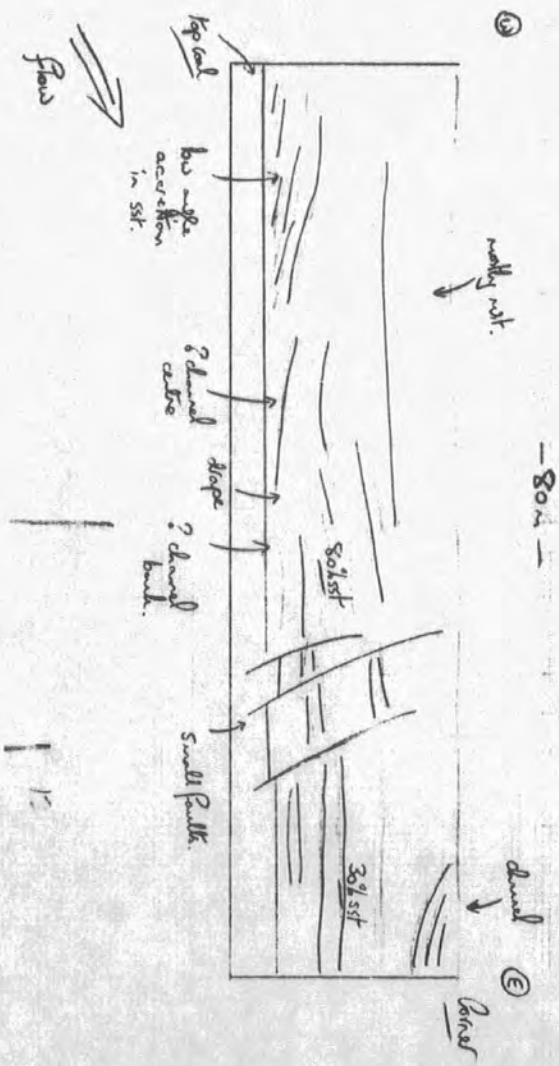
In loose blocks of rooted sst + mst - seatearth for top coal - sst filled - slightly folded cracks - having almost polygonal pattern in plan view.

On E-W face - increase in proportion of sst to ≈80% reflects either base of crevasse channelling - unlikely over 3-4 m extent? - or channel margin.

Possible ? growth fault present - with rapid wedging in & out of sst bodies -



SKETCH OF E-W WALL.



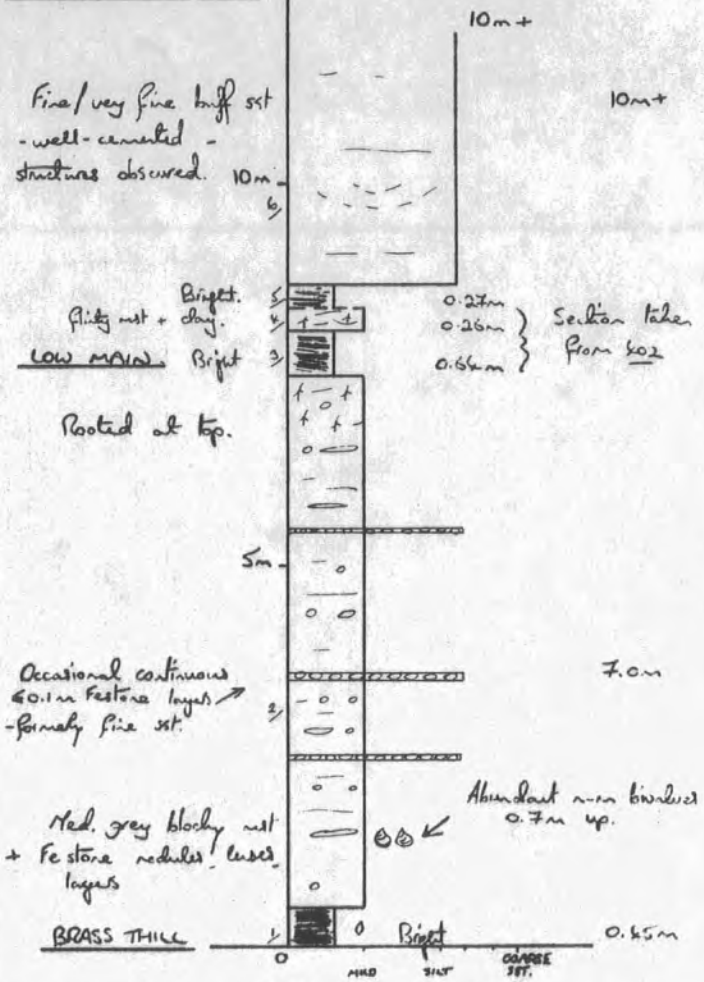
NB The thin granular ssts are not present toward the western half of the E-W face.

No. of plate & samples.

CRF 9/10/81

Section at NW end of long cut - short wall.

SECTION 42's BUCKHEAD - C3?



Present excavations probably one cut back from previous visit - low main being reduced on next step up. - cutting across former inlet cut at east end. NB Above Brass Thill - lack of thin ssts beneath low main seam, as in earlier cuts - appear to wedge out to SW. Ssts appear to come in at NE end of present exposure, across a small fault. Access not possible to low main.

CRF 332 - Kevestone Craggs
333 - Cockfield Reaches
334/5 - Spittal Foreshore - Berwick - L. Carb.

SECTION 427 - Spittal Foreshore - not presented

CRF 4.12.81.

LANGLEY SITE Cuts A9_10 on Main, almost back to Fingerstar outcrop. - Fp is complex seam.

Cut 9 - long wall trends 265°, 150-200m exposed, precisely scaling at east end of cut. Sequence above Main - interbedded lower sequence ~2.5m thick, uniform along most of wall, then thinning gradually towards the east end - showing low-angle inclined bedding. Above - 3m sst with occasional thin dark carb. mst intervals - then platform - ? rockhead.

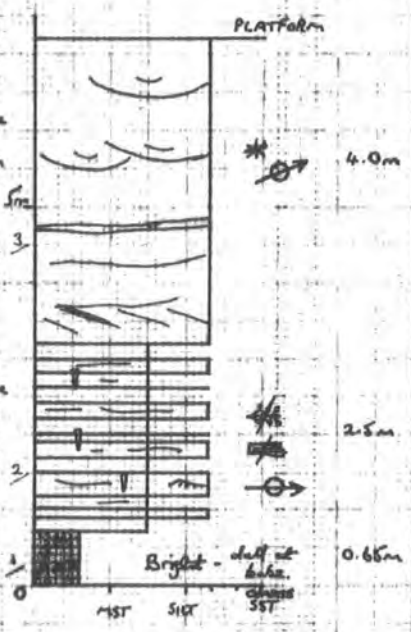
0.8m/089

(*) TxB 2.0m/067, 1.0m/071, 1.0m/051. + in basal part of sst, 2m set trough ≤100m downcurrent

SKETCH OF CROSS SEQUENCE



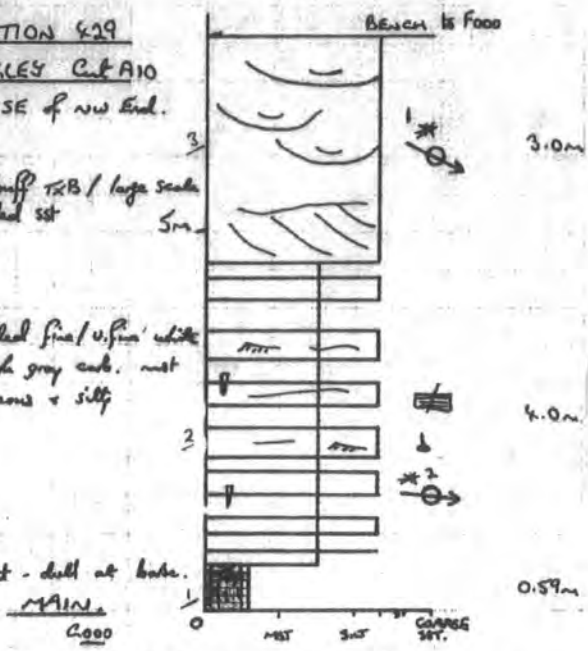
SECTION 428
LANGLEY Cut A9



Immediately over coal - 0.005m dark mst, then fine white sst, interbedded subtidal mostly sst (90%), mst laminae & bands ≤0.10m thick - mostly 11 lam/cm in lower + some Rxl - delicate interlamination in places. Low angle surfaces dip → 110°. Type A Rxl 0.02m A → 098, 085, 101, 092. n = 4. Possibly more & thicker mst laminae upward. Base of Unit 3 planar, mst noticeably erosive. At east end section ~2.5m, dipping at a very low angle → east. (3 colour slides)

NB Coaled out outcrop cut to Fooo above Cuts 9 & 10 - Complex seam - numerous thin ≤0.1m coal leaves interbedded with carb shale & shaly coal - then 0.3m light grey/med. grey/ochre mst, and solid coal for 0.6m. Estimated as several leaves. Old workings common - old winding house exposed near Section 428

SECTION 429
LANGLEY Cut A10
100m SE of NW End.



Cut trends → 114°. Similar section to Cut 9

(*) TxB in Unit 3 - 08m/102, 1.0m/137. - becomes thinly bedded towards top. Interbedded fines thicken to NW - some bioturbation & occasional ? rootlp. (2)(*) Rxl 0.01m A Type A → 095, 113°. 30-40% mst in lower 1.5m, 95% sst in upper part. Interbedding in lower part on 0.05-0.15m scale. Presently reducing ~200m SE of NW end.
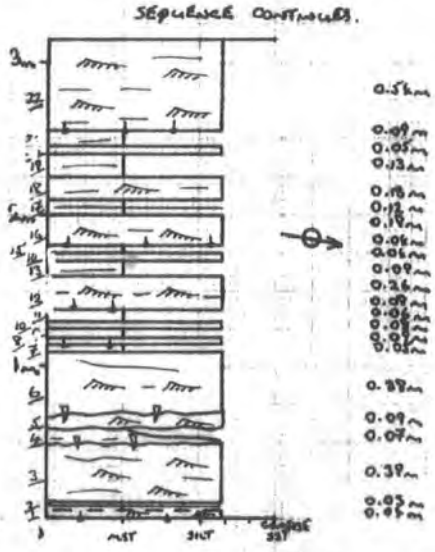
CRF 336 - Algal laminated sst, Blaen Onneu, S. Wales.

CRF 5/1/82 BILLINGE HILL QUARRY, LANCS.

G.R. SD 526015 - Cuthman sst - Lower Westphalian A.

Detailed log of an accessible interval within the laterally accreted unit, near the base, half way along quarry face.

SECTION 430
BILLINGE HILL



SAMPLES CRF 337 - 342.

CRF A-1.92.

CRF 3.2.82. LANGLEY SITE.

On Cut 10 Main 6 Box - Main - 2 Ringmatter

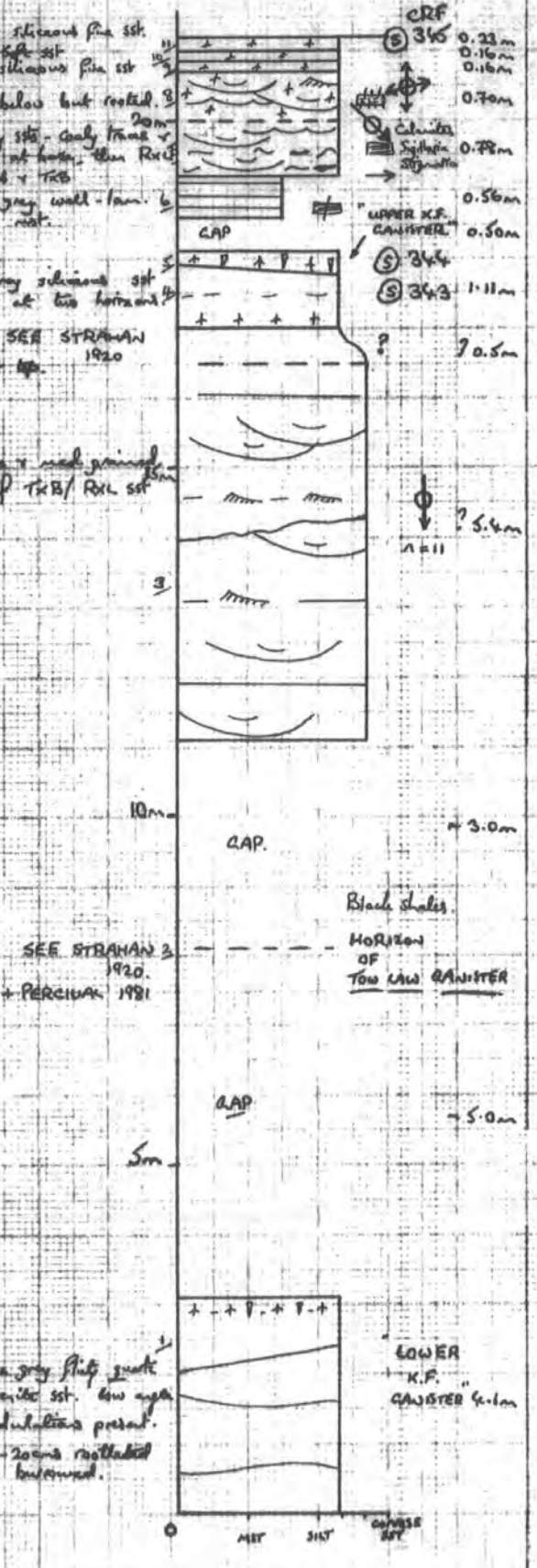
SECTION 431

KNITSLEY FELL QUARRIES

(Composite section)

Tectonic dip 6/086.

C.R. NZ 097345

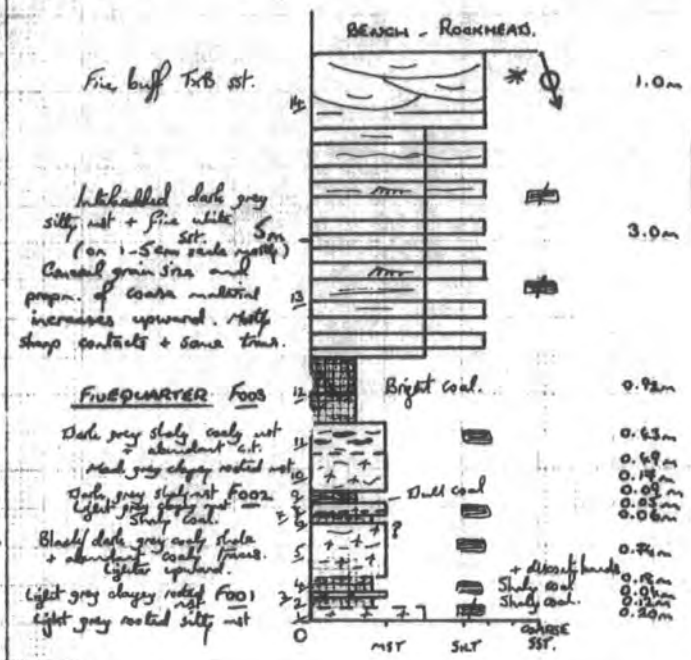


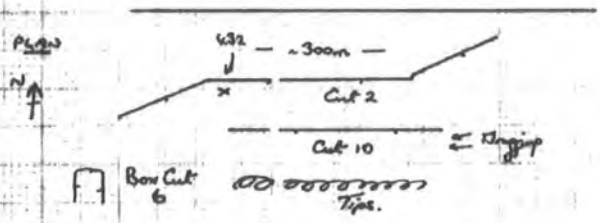
CRF 346 - Tow Law canister - Black Burn

SECTION 432

LANGLEY Fp unit 2.

West end.





East along Cut 2 - sst lies only 1.0m above the roof of Fp coal. Top sst - up to 2.5m exposed.

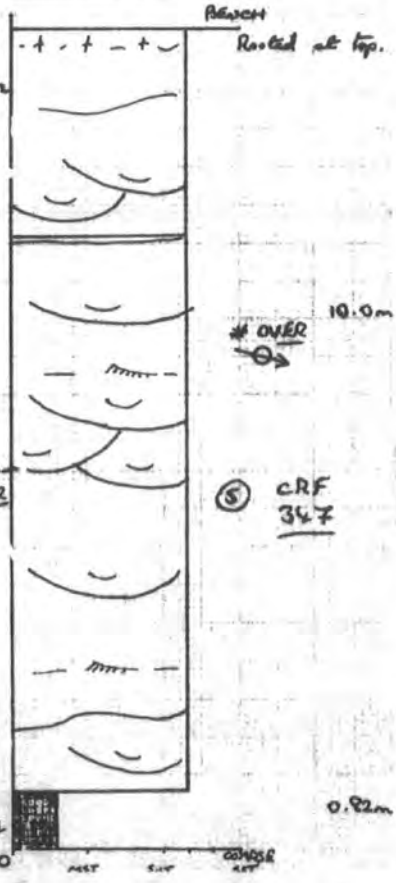
In top sst, cross-sets @ 0.6m/152, 0.6m/176, 0.7m/123.

SECTION 433

LANGLEY Box 6

Trends 200°.

50m north of south end.



COOO - MAIN - Bright

Box cuts - no channel margins precisely exposed - though perhaps exposed to east.

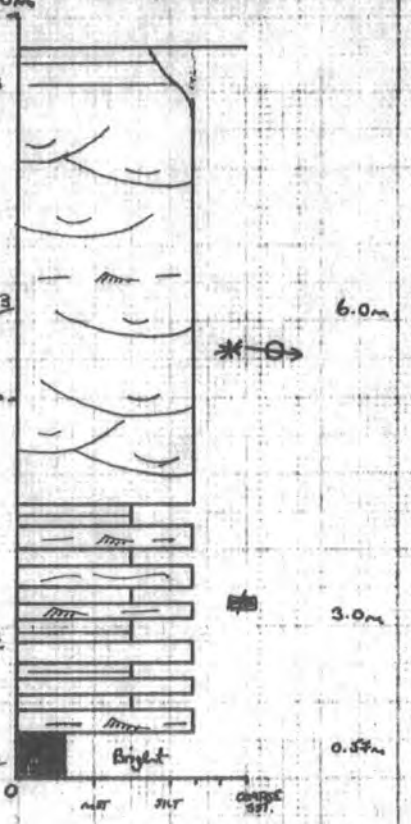
TxB - 0.8m/085 _ 2.0m/058 _ 2.0m/116 _ 1.0m/103 _ 1.0m/091 _ 0.8m/056 _ 2.0m/106. n = 7

Many sets have complex form - of one set - lined set in basal part -



SECTION 434 — Central part of cut.

LANGLEY A10



Section very consistent over ~100m exposure - dipping E. TxB - 0.8m/112 _ 0.3m/100 _ 0.4m/128 _ 0.6/099 _ 0.6/101 _ 0.8m/065 _ 0.4m/085 n = 7

Main coal is markedly variable in thickness over the site - also thickened in one area by the dev. of an extn. unit of cannelloid + shaly coal in the base of the seam. Unit starts ~200m from east end _ extends for ~100m to east - combined thickness up to 1.06m (average 0.66m) G.R. 421000 → 421100. Unit reported in Cut 8 for the first time - patchy, but present in Cuts 9 + 10

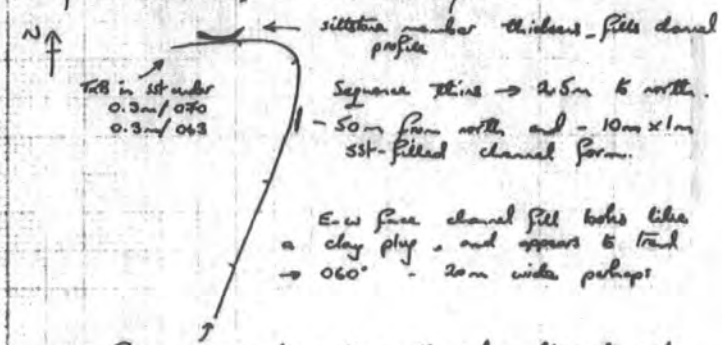
CRF 438 - Flint claystone - Coventry Rd Kenilworth.

SECTION 435 - NOT PRESENTED.

COBEY CARR QUARRY ('TOOHILLS'). Completion of Section 241 and additional notes.

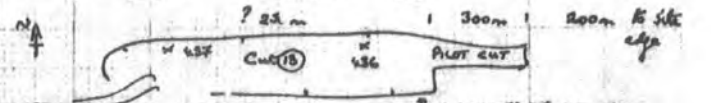
1. Sequence above Top Bastry - bottom 0.3m or so is composed of rhythmically laminated dark + light claystone - 1-3mm interlamination. RxL → 021 _ 028 _ 062 _ 139 _ 176. n = 5.
Sediment appears to be derived from SW + NNW.

2. Over Middle Tilley - ? intirely accretted channel deposit
Top 1m or so is siltstone in grade. RxL only in upper part of deposit. TxB confined to lower part.
TxB 0.1m/155 _ 0.2m/140 (0.6m/wide) _ 0.3m/118 _ 0.5m/100
RxL Type A _ A = 0.01-2mm → 179 _ 126°.
Total interval = 4.5m approx.
Siltstone partings with sst laminae + lenses, ≤ 0.5m thick, contained within the sst member.
Near north end of main face _ sst member takes on flat-topped interbedded character - typically alternations of 15-20cms sst _ 2-7cms dark silty mst.



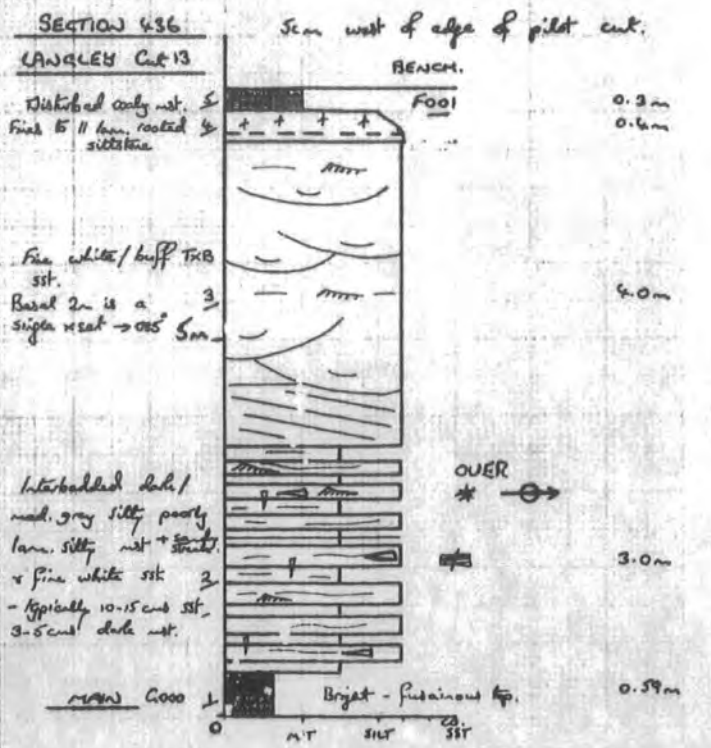
Main face ~200m long. At south end _ partly reduced to ~2.5m where low-angle + sets are exposed - sequence mostly siltstone _ with sst bands. Channel profile visible in part - see notes from previous visit.
Overall impression is of a complex meander belt dev.

CRF 27.5.82. LANGLEY OCC3



SECTION 436 — 5cm west of edge of pilot cut.

LANGLEY Cut 13



CRF 27.5.82. LANGLEY cont.

Thickness of lower sediments varies little along the face - possibly thicken very gradually to the west.

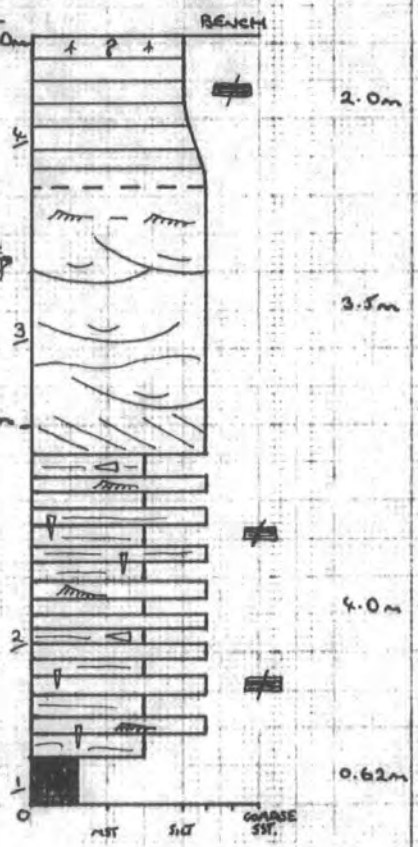
* RxL → 093, 103, 102, 084, 065, 100, 077, 108. n=8

Ripple form sets present in places, and long, straight, bifurcating synaeresis cracks ≤15cms long, 3-5mm wide - composed of sst set in silty mst matrix. No roots in sequence.

Where main coal thickens, the basal unit is either coaly shale (60% ash) with some roots + coaly traces, or cannelly coal (13-20% ash) at base of seam proper. Cannel layer typically 0.20m thick and discontinuous. Often shaly coal only present under Main. Main coal itself 2-3% ash.

SECTION 437
LANGLEY Cut 13

Towards west end of cut. - by access road.



Top bench - extraction of Fivequarter coal - only 10m back from Main cut - similar to faces exposed on previous visit. Presently, no access to coffin cutty.

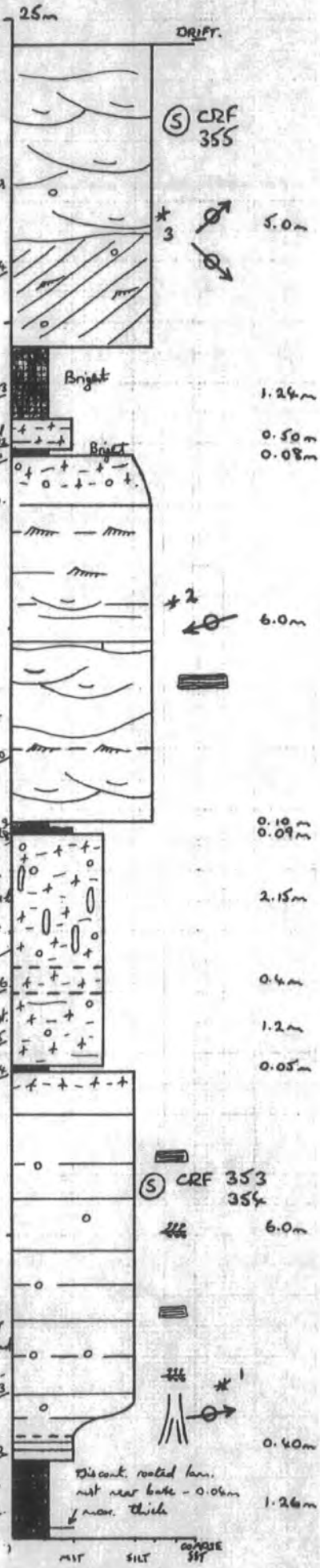
1 Sample of synaeresis cracked sst - CRF 352.

2 colour prints.

C.R.F. 3.6.82.

Composite section.

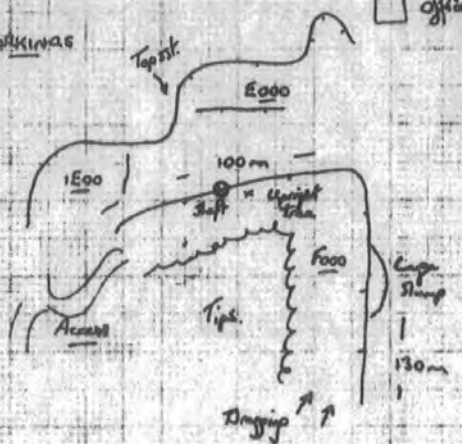
SECTION 438
MOSS CLOSE - Cut 6
(O.C.C.S.)



DETAILS - See Over.

CRF 3.6.82 Cont. Moss Close.

PLAN OF WORKINGS



Cuts advancing eastward with time. Large-scale slumping and old workings causing disturbance of strata.

DIRECTIONAL DATA

#3 3m low angle cross-bedding ? stepped by dish movement 27/227, associated with RxL → 135°, 141, 132. Large sets have asymptotic bases and steep tops.
Another similar suit of surfaces are associated with RxL → 015, 041, 011, 029, 018, 028, 023 n=7. Large sets dip → 337°.

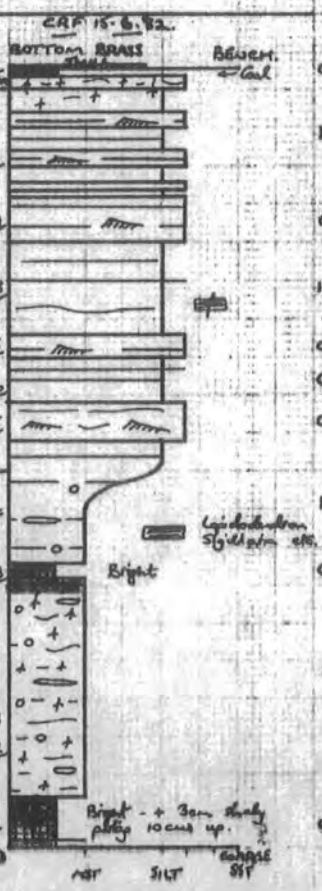
#2 THB 0.6m/300. RxL Type A, As 0.05m, → 240, 244, 282, 275, 258, 232, 247. n=7.

#1 In silts, inclined tree stump, perhaps 3.6m tall, at least 1.60m preserved. - dips → 183/253° in palaeoflow → 073°. Both bark cast and inner silt pith cast.

In silts occasional ≤0.03m partings of dark crumbly mist are present. Seam partings change considerably across the site - F000 - 2E00 parting increases to west.

CRF 15.6.82.

SECTION 4.39
TANNERS HALL 1SE



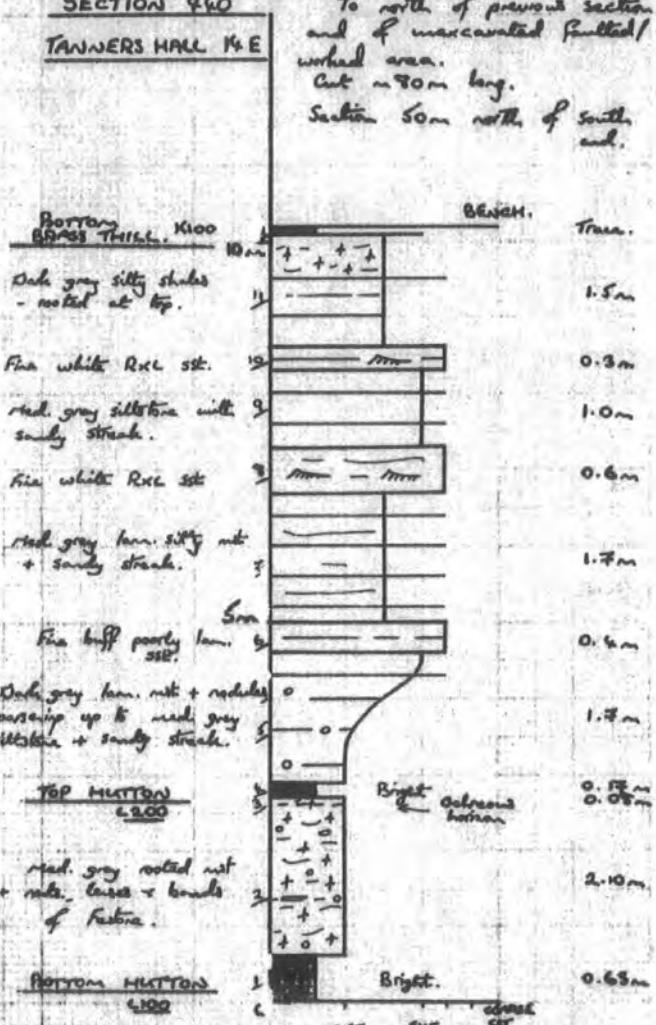
Cut 1SE - 150m north of south end - dragging 30m

C.R.F. 15.6.82 Cont.

2 photos of Cut 1SE taken. Small step fault with 25cm throw 10m south of section. Fault at south end of cut also. Silt persistent along cut mostly - but thin to the south - bottom can dive out gradually within 50m. Drift and fault cutout at south end of cut. Cuts now not as long as previously - due to an area of faulting and heavy old workings.

SECTION 4.40
TANNERS HALL 1+E

To north of previous section, and of excavated faulted/worked area.
Cut ~80m long.
Section 50m north of south end.



#3 In Unit 5, just to south of Section, another sst wedges in → 0.3m within 30m - 0.5m from first sst (Unit 6). Units 6 + 8 both thicken to south. 1 photo taken.
Surface of L100 is bent and buckled towards Southern Fault - in previous cut, the seam was slipped vertically over the fault - still soft at the time of displacement?

Round to north end of site - working thru' long cuts to Brass Thill coals. Cut 9m - long cut trending 305° - exposed Top Brass Thill and overlying strata up to bench of Low Main. Coarsening-upward sequence of former cuts is now a sharply-based sst.

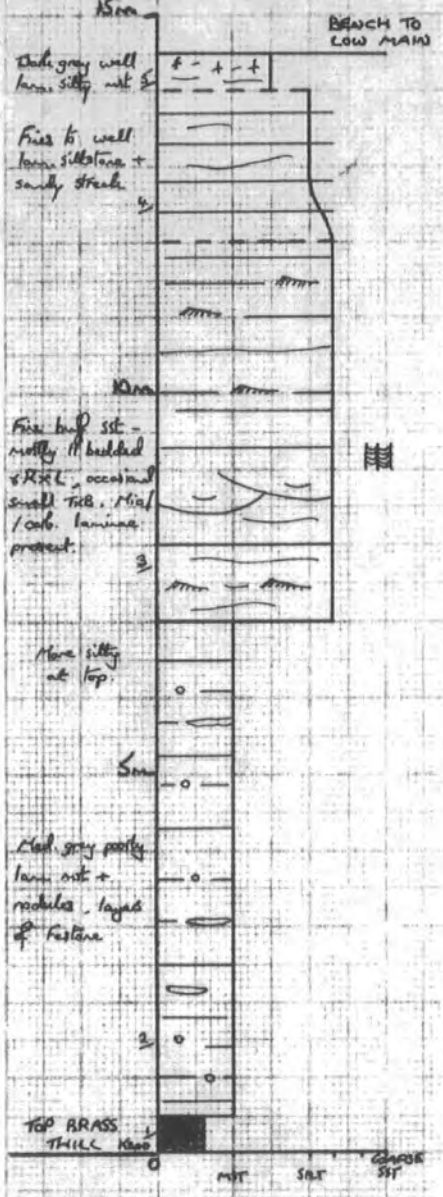
Section 4.41 - over.

CRF 15.6.82 cont.

SECTION 4&1

TANNERS HALL 9N

Section taken by 3m step fault - 150m east of west end.
2 photos taken.

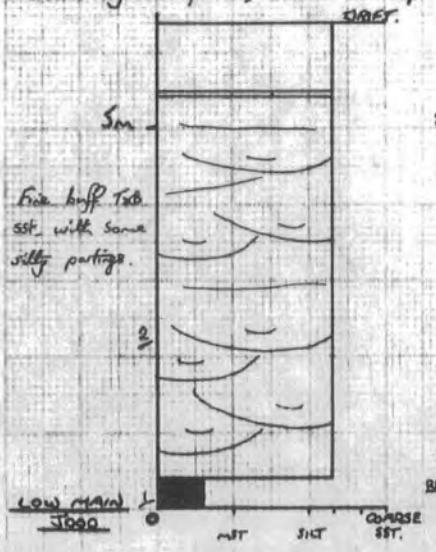


Sst thins to 2.5m thick at existing NW end of cut, over a distance of about 50m - some low-angle x-surfaces present - at the same time, the overlying siltstone interval is represented by 4.0m shales, the top 2.5m of which is rooted. (i.e. sst fines through silt to mst). Low plain present at trace, beneath old colliery workings. Further SE, where down-thrown by 3m fault, worked on top bench.

SECTION 4&2

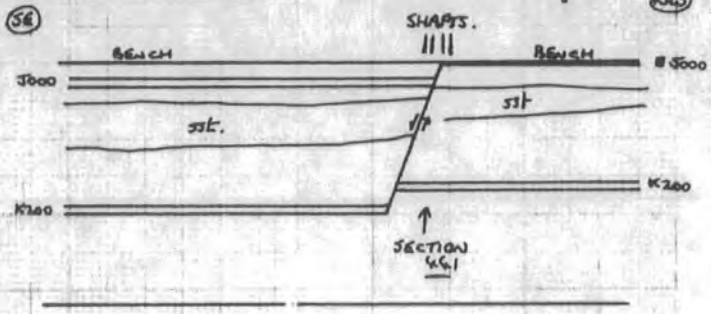
TANNERS HALL 11N

200m south-east of Wooley Colliery pit head.
1 photo taken.



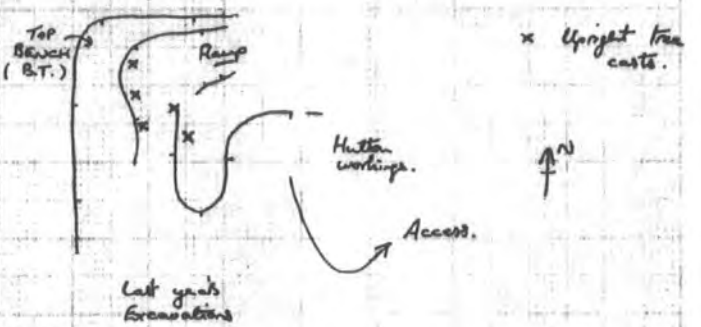
Coal and overlying sst exposed along length of cut 11N with little variation - 6m or so of sst. Sense of Trb difficult to achieve - no palaeocurrent data taken.

SKETCH OF CUT 9N Total ≈ 800m length.



CRF 29.7.82. PHOENIX QUARRY, CRAWCROOK.
G.R. NZ 135 628.

First visited July 198. - see Rough Log of Section 390



Presently working almost at backline of NW site limit, excavating to Hutton coals.

Section 4&3 - OVER.

NOTES In siltstones of Unit 4, nodules seem to be concentrated at regular intervals, in thin horizons spaced 30-40cms apart.

In NW part of workings, casts of 5 upright, in situ trees -
1. 1m ↑, 0.3m wide, inclined 15° → 097°.
2. 2m ↑, 50.3m wide, " → 075°.
3. " " Upright
4. " 0.4m wide "
5. " 0.3m wide "

All rooted into same horizon, just at top of horizon containing sharply-based sst bands, though few roots appear to be preserved - all Lycopods, rooted horizontally. All rooted into a thin, nodule-rich horizon above the sst. - probably established after ? crevasse sand deposition in middle of sequence. - ? shallow water required for Lycopod establishment.

CRF 29.7.82.

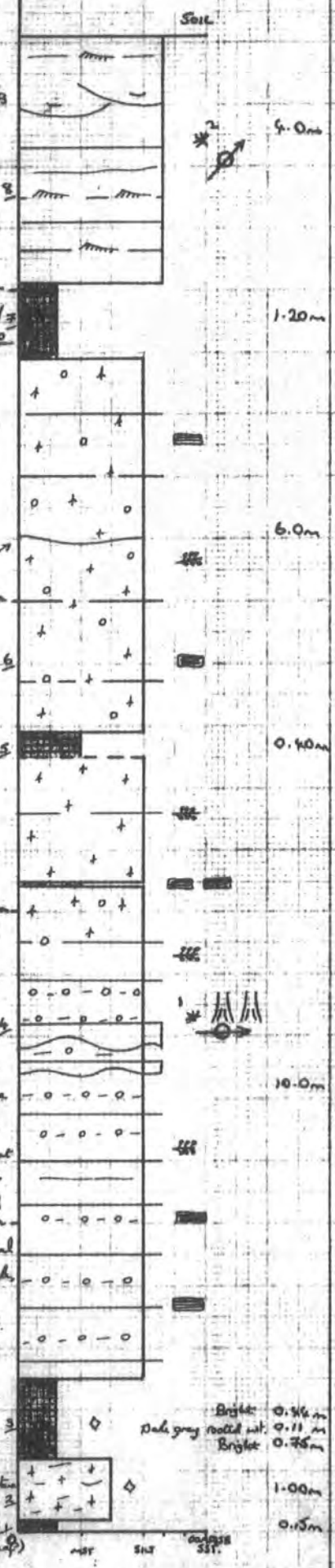
C.R. NZ 135628.

Composite Log - for notes see previous page.

SECTION 443

PHOENIX QUARRY.

(CRAWCROOK) 25m



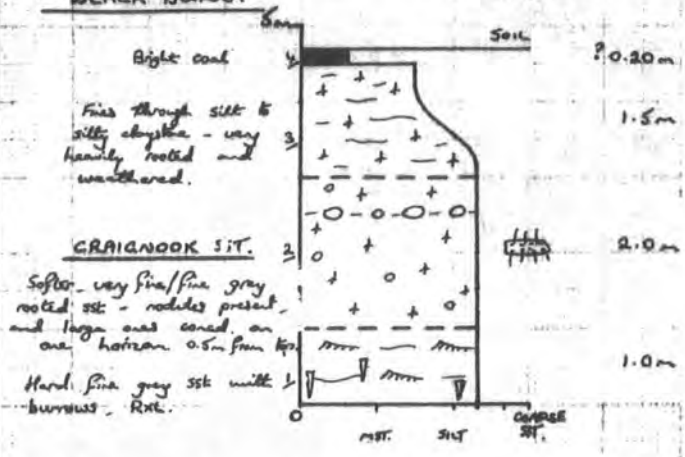
CRF 5.9.82 MIDGEHOLME.

Visit to Black Burn - stream flowing NE from Midgeholme village - exposures of Westphalian. (cf. West. A)

Bank in stream, 100m east of bridge - C.R. NY 642590.

SECTION 444

BLACK BURN.



Fe rich horizons, both vertical & horizontal, probably the result of recent oxidation.

Tectonic dip 14/216. Complete preservation of seatearth at top of Craignook sst. though coal is possibly reduced in thickness.

100m downstream - NY 642590 - south side of stream, cliff 2-4m high x 200m long, entirely composed of sst - upper fluvial main part of Craignook sst. TKB very common, + some ? Coniston. Very downcurrent - persistent salts present, and some 0.5m units with complex arrangements of ~0.15m sets, near base of exposure.

Further outcrops in stream → at least 5-6m exposure.

TKB 0.4m/094, 0.3m/093, 0.7m/101, 0.7m/152, 0.6m/115, 0.4m/113, 0.3/137, 0.4m/118, 0.6m/091, 0.3m/115 0.4m/126, 1m?/171, c.6m/120, 0.4m/133. n = 14.

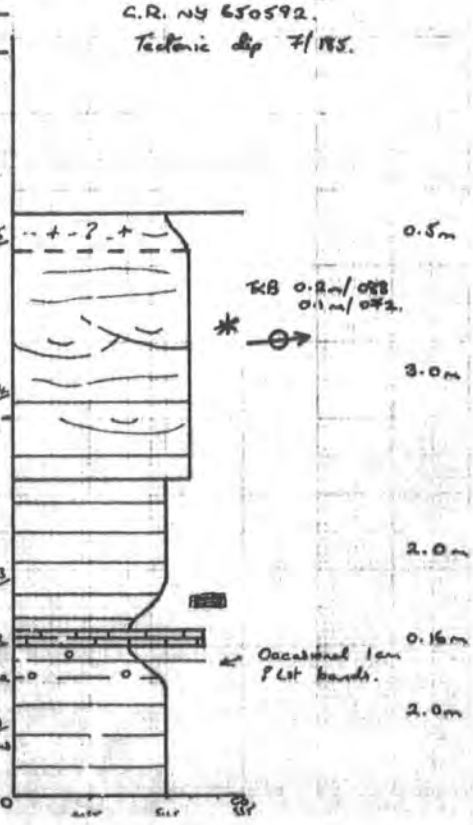
1km downstream - at east edge of old colliery. Further stream bank section, dipping upstream - Stratigraphically above Slag seam - Mid - West. A.

SECTION 445

BLACK BURN

C.R. NY 650592.

Tectonic dip 7/185.



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SEDIMENTOLOGY AND STRATIGRAPHY OF THE DURHAM COAL MEASURES, AND COMPARISONS WITH OTHER BRITISH COALFIELDS

by

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A thesis submitted to the University of Durham for the degree of Doctor of Philosophy

Department of Geological Sciences October 1982

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APPENDIX 2 - PETROGRAPHIC DATA

a) SANDSTONES

N.B. Petrographic details of many lower Westphalian quartz arenites and ganisters not given here may be found in Percival (I98I).

Sample/Strat.level	Environment	Size/ Sorting	Detrital Quartz	Fsp	Heavy Mins.	Mica R.F.s	Qtz.cement Hem.stain Ill./Kaol.	Others + Comments
CRAG HEAD - SECTION 424 CRF 326 - LOWER SST.	MINOR CHANNEL		60.5%	1.25%	0.25%	2.5% —	6.75% 5% 18.25%	∧ = 400 6% Authigenic Opaque.
QUICKBURN QUARRY - SECTION 409 CRF 318 - TOP SST.	MAJOR CREVASSE	2.82ϕ ± 0.87 F.S. MOD.	62.5%	1.25%	—	1.5% 1.5%	5.75% 5% 17%	∧ = 400 5.5% Authigenic Opaque.
QUICKBURN QUARRY - SECTION 409 CRF 317 - CANISTER	? REWORKED SPLAY / / PODZOLIC SOIL	2.74ϕ ± 0.65 F.S. MOD.	71.75%	—	0.75%	— —	2.25% — 23.25%	∧ = 400 2% Authigenic opaque
QUICKBURN QUARRY - SECTION 409 CRF 316 - ABOVE GAN. CLAY	MAJOR CHANNEL	2.09ϕ ± 1.06 F.S. POOR.	65.25%	1.5%	0.25%	1.5% 0.5%	3.25% 2.75% 20.25%	∧ = 400 4.25% Authigenic Opaque
WEST BUTSFIELD - SECTION 346 CRF 246 - UNDER KAYS LEA MB.	MINOR DELTA FILL + MARINE INCURSION	3.11% ± 0.67 U.F.S. MOD.	56%	1%	—	3.25% 0.25%	4.75% 2.5% 18%	∧ = 400 * 12.75% Vermicular Kaolinite 1.5% Auth. Opaque
WEST BUTSFIELD - SECTION 345 CRF 245 - BUTSFIELD CANISTER	CHENIER RIDGE	2.82ϕ ± 0.49 F.S. WELL.	82%	—	0.5%	— —	12.5% 4.5% —	∧ = 200 0.5% Siderite.
UIEWLY HILL - — CRF 308 - TOP OF SST.	REWORKED CHANNEL DEPOSIT.	1.62ϕ ± 0.35 M.S. WELL	87.75%	—	0.5%	— —	8.75% 0.5% 2 %	∧ = 400 XRD → QTZ / KAOLWITE / / SIDERITE
UIEWLY HILL - — CRF 307 - THIRD GRIT	MAJOR CHANNEL	1.78ϕ ± 0.83 M.S. MOD.	66.5%	—	0.25%	0.5% —	3.25% 1.25% 24.75%	∧ = 400 0.5% Authigenic opaque phase.
QUARRY WOOD - — CRF 301 - THIRD GRIT	MAJOR CHANNEL	2.79ϕ ± 0.69 F.S. MOD.	63.25%	1%	0.75%	4% —	7% 11.75% 12.25%	∧ = 400
CROSS'S UPPER CAN. QUARRY - SECTION 388 - CRF 299 - THIRD GRIT	MAJOR CHANNEL	1.41ϕ ± 0.69 M.S. MOD.	71.5%	0.5%	2%	0.75% —	4.5% 5.5% 15.25%	∧ = 400.
BESSY'S BANK - SECTION 242 CRF 192 - LR QTZ. ARENITE	? REWORKED SPLAY / / PODZOLIC SOIL	3.12ϕ ± 0.65 U.F.S. MOD.						SEE PERCIVAL 1981
BESSY'S BANK - SECTION 242 CRF 189 - THIN SST.	SUBAQUEOUS LEVEE	3.28ϕ ± 0.72 V.F.S. MOD.	? 80%					
BESSY'S BANK - SECTION 242 CRF 190 - THIRD GRIT	MAJOR CHANNEL	2.33ϕ ± 0.89 F.S. MOD.	56%	0.5%	1.5%	2.25% 0.25%	2.75% 18.75% 17.50%	∧ = 400. XRD → QTZ / KAOL. / MUSCOVITE.

* CRF 246 - XRD ANALYSIS INDICATES THE PRESENCE OF QUARTZ, KAOLINITE, MUSCOVITE, FELDSPAR AND CHAMOSITE.

Sample/Strat.level	Environment	Size/ Sorting	Detrital Quartz	Fsp	Heavy Mins.	Mica R.F.s	Qtz.cement Hem.stain Ill./Kaol.	Others + Comments
COBEY CARR - SECTION 241 CRF 186 - ABOVE MID-TILLEY	MINOR CHANNEL		59%	0.5%	—	2% —	13.5% 0.5% 22.5%	Λ = 400 0.5% Auth. Opaque 1.5% Verm. Kaolinite
BUCKHEAD O.C.C.S. - SECTION 425 CRF 330 - ABOVE BTM. TILLEY	CREVASSE SPLAY		66.5%	0.5%	—	0.25% —	13.5% — 11%	Λ = 400 2% Pyrite / Marcasite 6.25% Dolomite
CABIN HOUSE O.C.C.S. - SECTION 256 CRF 196 - ABOVE BTM. TILLEY	CREVASSE SPLAY		52.75%	—	—	1.5% 0.25%	16.25% 1% 25%	Λ = 400 2.25% Auth. Opaque 3% Verm. Kaolinite
BINCHESTER CRAGS - SECTION 192 CRF 155 - ABOVE TOP BUSTY	OVERBANK		12.5%	—	—	2% —	— — 1.5%	Λ = 200 5% Auth. Opaque 79% Siderite
CABIN HOUSE O.C.C.S. - SECTION 075 CRF 099 - ABOVE TOP BUSTY	CREVASSE SPLAY		60%	0.5%	1%	1% —	10% 0.5% 26%	Λ = 200 1% Auth. opaque.
CABIN HOUSE O.C.C.S. - SECTION 308 CRF 219 - ABOVE TOP BUSTY	CREVASSE CHANNEL		49%	—	0.75%	1.5% —	4.75% 2% 30.5%	Λ = 200 1.5% Auth. Opaque 1% Siderite
DEBORAH O.C.C.S. - (SECTION 292) CRF 215 - ABOVE BTM. BUSTY.	SUBAQUEOUS LEVEE.	3.04ϕ ± 0.54 U.F.S. MOD.	53%	—	—	3.75% —	7% — 16.5%	Λ = 400 0.5% Verm. Kaolinite 20% Siderite.
DEBORAH O.C.C.S. - SECTION 130 CRF 132 - ABOVE BTM. BUSTY.	CREVASSE CHANNEL	2.75ϕ ± 0.59 F.S. MOD.	70.75%	—	1%	0.5% —	3.25% — 17%	Λ = 400 7.5% Calcite
DEBORAH O.C.C.S. - SECTION 137 CRF 125 - ABOVE BTM. BUSTY	CREVASSE SPLAY	3.15ϕ ± 0.59 U.F.S. MOD.	61.5%	—	—	3% —	9% — 19.25%	Λ = 400 1.75% Auth. Opaque 5% Siderite
COCKFIELD REEVES - — CRF 333 - ABOVE BUSTY.	MAJOR CHANNEL		60.25%	4.25%	—	1.25% —	3.75% 1.5% 20%	Λ = 400 8.5% Auth. opaque 0.5% Verm. Kaolinite.
CABIN HOUSE O.C.C.S. - SECTION 154 CRF 137 - ABOVE BOTTOM BUSTY	CREVASSE SPLAY		42%	0.25%	—	2.5% —	8.25% — 13%	Λ = 400 1.5% Verm. Kaolinite 32.5% Siderite
MIDDRIDGE - SECTION 367 CRF 269 - ABOVE BROCKWELL	MAJOR CHANNEL		71.25%	4%	0.5%	— 1.25%	12.25% 0.5% 8.5%	Λ = 400 0.75% Auth. Opaque 1% Verm. Kaolinite.
GREENFIELD NO. 1 - — CRF 302 - UNDER MARSHALL GREEN	MAJOR CHANNEL		76.5%	1%	—	— —	8% 1.5% 11.25%	Λ = 400 1.25% Auth. Opaque 1.5% Verm. Kaolinite
GREENFIELD NO. 2 - — CRF 303 - TOW LAW CANISTER	? CREVASSE SPLAY / PODZOLIC SOIL	3.28ϕ ± 0.78 U.F.S. MOD.	82%	—	0.75%	— —	12.25% — 3%	Λ = 400 2% Authigenic Opaque
CRAG HEAD - SECTION 424 CRF 327 - MARSHALL GREEN +	MAJOR CHANNEL		56.5%	2%	—	1% —	6.75% 3.5% 25.25%	Λ = 400 5% Authigenic Opaque

Sample/Strat.level	Environment	Size/ Sorting	Detrital Quartz	Fsp	Heavy Mins.	Mica R.F.s	Qtz.cement Hem.stain Ill./Kaol.	Others + Comments
WEAR GORGE, DURHAM – DC 2 – LOW MAIN POST.	MAJOR CHANNEL	3.32 ϕ ± 0.53 U.F.S. MOD.	41.75%	0.5%	0.25%	1.25% –	11.75% – 37.5%	∧ = 400 7% Auth. Opaque.
FINCHALE PRIORY – – DC. 1 – LOW MAIN POST	MAJOR CHANNEL	2.59 ϕ ± 0.90 F.S. MOD.	42%	2%	–	– 1%	10% 1% 37%	∧ = 400 7% Auth. Opaque.
LANGLEY WEST – SECTION 338 CRF 241 – ABOVE HARVEY M.B.	MAJOR CHANNEL	3.10 ϕ ± 0.64 U.F.S. MOD.	71.25%	0.25%	–	0.25% –	10.75% 0.5% 12.25%	∧ = 400 5.5% Auth. Opaque 1.75% Verm. Kaolinite
ESH WINNING O.C.C.S. – SECTION 040 CRF 087 – ABOVE HARVEY	CREVASSE SPLAY		38%	–	0.25%	1.75% –	6% 6.75% 6.25%	∧ = 400 37.25% Dolomite 3.5% Auth. Opaque 0.25% Verm. Kaolinite
MOWN MEADOWS O.C.C.S. – SECTION 215 CRF 168 – TOP TILLEY +	? MINOR CREVASSE.		38.75%	0.25%	0.25%	0.25% –	8% – 15.25%	∧ = 400 1.25% Auth. Opaque 36% Siderite.
CABIN HOUSE O.C.C.S. – SECTION 323 CRF 229 – TOP TILLEY +	PROXIMAL MAJOR CREVASSE.		74%	–	–	– –	18.75% 0.25% 4.75%	∧ = 400 2.25% Auth Opaque
DEBORAH O.C.C.S. – SECTION 133 CRF 126 – TOP TILLEY +	MAJOR CHANNEL		61.5%	1%	–	0.25% –	10.5% 0.25% 24.5%	∧ = 400 2.25% Auth. Opaque.
ROWLEY O.C.C.S. – SECTION 135 CRF 127 – TOP TILLEY +	CHANNEL.		63.75%	0.25%	–	0.5% –	11.75% – 16.25%	∧ = 400 5.5% Siderite 2% Auth. Opaque.
ROWLEY O.C.C.S. – SECTION 073 CRF 097 – MIDDLE TILLEY +	THIN CREVASSE IN EXTREME SOUTH.		17.75%	–	–	1.25% –	10.25% 0.25% 13%	∧ = 400 3.75% Auth. Opaque 53.75% Siderite.
ROWLEY O.C.C.S. – SECTION 010 CRF 062 – MIDDLE TILLEY +	INJECTION INTO PEAT SEAM.	2.82ϕ ± 0.71 F.S. MOD.	56.75%	–	0.25%	0.5% 0.25%	10.75% – 27.75%	∧ = 400 1.25% Auth. Opaque 2.5% Verm. Kaolinite CEMENT – SUPPORTED.
ROWLEY O.C.C.S. – SECTION 087 CRF 109 – MIDDLE TILLEY +	MINOR CREVASSE CHANNEL.	2.02ϕ ± 1.06 F.S. POOR	58.75%	0.25%	0.75%	0.25%	8.5% 3% 20.25%	∧ = 400 Auth. Opaque 8% Verm. Kaolinite 0.25%
ROWLEY O.C.C.S. – SECTION 091 CRF 111 – MIDDLE TILLEY +	CHANNEL BANK	2.38ϕ ± 0.64 F.S. MOD.	62%	–	–	0.5% –	12.5% – 17.5%	∧ = 200 5.5% Siderite 1.5% Auth. Opaque 0.5% Verm. Kaolinite
ROWLEY O.C.C.S. – SECTION 026 CRF 079 – MIDDLE TILLEY +	CHANNEL FLOOR	3.33ϕ ± 0.65 U.F.S. MOD.	52.5%	0.5%	0.25%	2.25% –	8.25% – 23%	∧ = 400 1.75% Verm. Kaolinite 10% Siderite *
ROWLEY O.C.C.S. – SECTION 087 CRF 110 – MIDDLE TILLEY +	CREVASSE SPLAY FROM NORTH	3.04ϕ ± 0.48 U.F.S. WELL.						Heavily cemented by finely crystalline Siderite.
ROWLEY O.C.C.S. – SECTION 083 CRF 105 – MIDDLE TILLEY +	CREVASSE SPLAY FROM SOUTH	1.74ϕ ± 0.52 M.S. MOD.	70.5%	–	–	– –	11% 1.25% 8%	∧ = 400 8.25% Dolomite 1% Auth. Opaque

* CAF 079 – also 1.5% Authigenic Opaque.

NOTES

1. Analyses are given for a representative sample of Westphalian A sandstones, and for a small number of Westphalian B major channel sandstones.
2. Sorting coefficients have been significantly affected by diagenesis.
3. Recrystallization of matrix and of quartz grains decreases irregularly through the succession from Westphalian A - C.
4. Feldspar is mainly plagioclase, with occasional alkali varieties, including microcline, and is generally partly altered to kaolinite.
5. Heavy minerals are mainly zircon, tourmaline, rutile and opaques, with rare sphene, garnet, pyroxene.
6. Mica (white mica) is of muscovite or illite composition.
7. Rock fragments are metamorphic polycrystalline quartz and intraformational shale and siltstone .

Xray Diffraction analyses indicate that the Westphalian sandstones are predominantly composed of quartz, with minor proportions of disordered kaolinite, illite or muscovite, siderite, feldspar and dolomite.

Sample/Strat.level	Environment	Size/ Sorting	Detrital Quartz	Fsp	Heavy Mins.	Mica R.F.s	Qtz.cement Hem.stain Ill./Kaol.	Others + Comments
IBBETSONS O.C.C.S. - SECTION 031 CRF 080 - HIGH MAIN POST	MAJOR CHANNEL	2.62 ϕ ± 0.68 F.S. MOD.	70.25%	0.25%	—	0.25% 1.5%	4% 2% 16.25%	$\wedge$ = 400 5.5% Auth. Opaque
FELLSIDE QUARRY - — CRF 324 - LOW MAIN POST	MAJOR CHANNEL	2.35 ϕ ± 0.59 F.S. MOD.	62.5%	2.25%	0.25%	2.5% —	7.25% 4.75% 14.75%	$\wedge$ = 400 5% Auth. Opaque 0.75% Vern. Kaolinite
INCLINE O.C.C.S. - SECTION 006 CRF 057 - LOW MAIN POST	MAJOR CHANNEL	2.88 ϕ ± 0.65 F.S. MOD.	40.75%	3%	—	2.25% —	9% — 27%	$\wedge$ = 400 17% Siderite 1% Auth. Opaque
CROXDALE QUARRY - SECTION 122 CRF 120 - LOW MAIN POST	MAJOR CHANNEL	2.49 ϕ ± 0.78 F.S. MOD.	47.5%	6.25%	0.5%	1.5% —	12% 1.5% 23.25%	$\wedge$ = 400 6.75% Auth. Opaque 0.75% Vern. Kaolinite

KAOLINITE CLAYROCKS - PETROGRAPHIC DESCRIPTION
(with particular reference to samples from Rowley O.C.C.S.)

Hand Specimen - black/grey/brown coloured, texture ranges from homogeneous "clastic claystone" to the Fragmental Clayrock lithology (dark claystone matrix with blebs of buff-coloured kaolinite), and through amalgamation of kaolinite blebs to a homogeneous kaolinite rock. Contacts with enclosing lithologies appear sharp ; exclusively associated with coal seams, and generally occur as 0-5cm thick bands or lenses within coals. Often continuous laterally over a few kms, but may die out or bifurcate.

Thin Section - composed largely of kaolinite; in addition to the blebs of crystalline kaolinite, much of the "groundmass" appears to be kaolinite. Separating areas of kaolinite are occasional laminae of organic matter, scattered quartz grains and mica flakes. The rock may be laminated, due to preferred orientation of finely crystalline kaolinite plates and organic material. Kaolinite crystals (up to 6mm) are often vermiform, and display undulose or hexagonal extinction. Rootlet impressions are recognizable as (often circular) areas of admixed small kaolinite crystals and opaque organic matter, and rootlet hairs may be seen as thin strings of opaque organic material.

Quartz grains show a variety of shapes and sizes (up to Imm) - often poorly sorted. Apart from micas, virtually no other grain types are present. Occasional soft-sediment deformation features occur; microfaults, loading and injection.

b) KAOLINITE CLAYROCKS

Sample	CRF 243	CRF 059	CRF 067	CRF 086	CRF 188	CRF 058	CRF 184	CRF 185
Kaolinite Crystals	1.5%	3.3%		8.25%	3.5%	3.25%	—	5%
Graupen	—	11.3%		16%	47%	54.75%	31.5%	67%
Laminated Microcrystals	—	—		—	0.5%	0.75%	—	—
Groundmass	52.5%	57.7%		37.5%	28.25%	25.25%	35.25%	17%
Pseudomorphs	—	—		—	—	—	—	—
Qtz. grains	1.5%	18.7%		4%	0.75%	5.75%	0.25%	0.5%
Qtz. veins	1.5%	—		—	—	—	—	—
Heavy Mins.	—	0.3%		—	—	0.25%	—	—
White Mica	—	0.3%		—	0.25%	—	0.25%	—
Brown organic material	5.5%	1%		0.25%	—	—	1%	4%
Black organic material	37.5%	7.3%		34%	19.75%	10%	31.75%	6.5%
Comments	∧ = 200 MOD. WELL-LAMINATED	∧ = 300	GRAUPEN ≤ 7mm long Gradational Boundaries.	∧ = 400	∧ = 400 Many Graupen have diffuse boundaries	∧ = 400	∧ = 400 LAMINATED LITHOLOGY. —	∧ = 200 AMALGAMATED KAOLINITE MASSES.

Xray Diffraction analyses indicate that the kaolinitic claystones are composed almost entirely of organic matter, quartz and well-ordered kaolinite.

N.B. "Graupen" are irregular aggregates of microcrystalline kaolinite - granules.

Sources of samples.

CRF 243 - ROWLEY O.C.C.S. - MIDDLE TILLEY - SUB P201 - SECTION 344.
CRF 059 - ROWLEY O.C.C.S. - MIDDLE TILLEY - P201/2 - SECTION 008
CRF 067 - ROWLEY O.C.C.S. - MIDDLE TILLEY - P202/3 - SECTION 019
CRF 086 - ROWLEY O.C.C.S. - MIDDLE TILLEY - P202/3 - SECTION 037
CRF 188 - ROWLEY O.C.C.S. - MIDDLE TILLEY - P202/3 - SECTION 240.
CRF 058 - ROWLEY O.C.C.S. - MIDDLE TILLEY - P202/3 - SECTION 007
CRF 184 - DEBORAH O.C.C.S. - ABOVE BOTTOM BUSTY - SECTION 231
CRF 185 - MOUNT MEADOWS O.C.C.S. - MIDDLE TILLEY P202/3 - SECTION 234

LIST OF ENCLOSURES

1. Scale drawing of sandstone exposure at Greenfield No. 1 Quarry
2. Cabin House/Mown Meadows O.C.C.S. - Site Plan
3. Rowley O.C.C.S. - Site Plan
4. Deborah O.C.C.S. - Site Plan
5. Deborah O.C.C.S. - Bottom Busty to Bottom Tilley interval
6. Detailed longitudinal sections from Rowley O.C.C.S. Area A, Tilley excavations (Sheets A and B)
7. Deborah O.C.C.S. - Top Busty to Middle Tilley interval
8. Deborah O.C.C.S. - Middle to Top Tilley interval
9. Buckhead O.C.C.S. - Site Plan
10. The Tilley seams and enclosing strata at Buckhead O.C.C.S. Area L.E.
11. Esh Winning O.C.C.S. Final Extension - Site Plan
12. Wooley O.C.C.S. - Site Plan
13. Tanners Hall/Wooley/Incline/Billy Hill O.C.C.S's - Hutton to Brass Thill interval
14. Tanners Hall O.C.C.S. - Site Plan
15. Langley O.C.C.S. - Site Plan
16. Langley O.C.C.S. - Main to Fivequarter interval
17. Edmondsley O.C.C.S. - Site Plan
18. Edmondsley O.C.C.S. - Fivequarter to 2E00 interval

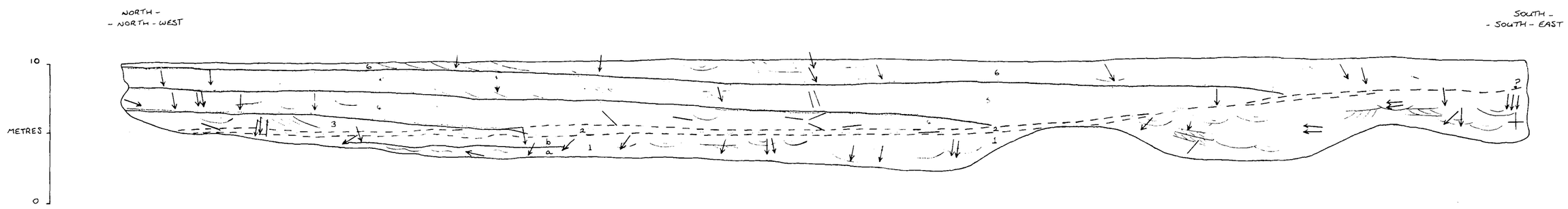
APPENDICES

1. Graphic sedimentary logs
2. Petrographic data

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ENCLOSURE 1. SCALE DRAWING OF SANDSTONE EXPOSURE AT GREENFIELD Nº1 QUARRY SCALE 1:250





KEY

- BOUNDING SURFACE
- CHAOTIC UNIT
- IRREGULAR BEDDING
- TROUGH CROSS-BEDDING.
- CROSS-BEDDING ORIENTATION
- PLANAR ORIENTATION
- 6 LITHOLOGICAL UNIT NUMBER (SEE TEXT)

NOTES

1. LOCATION OF QUARRY - G.R NZ 095413.
2. STRATIGRAPHIC HORIZON - IMMEDIATELY BELOW MARSHALL GREEN COAL (4000) - C WESTPHALIAN A
3. QUARRY FACE TRENDS → 331°, IE SLIGHTLY OBLIQUE TO PALAEOFLOW DIRECTION
4. TECTONIC DIP IS 7° TOWARDS 119°, APPROXIMATELY
5. SEE TEXT, CHAPTER 6.3.2.3 AND PLATE 6.4.

PALAEOCURRENT DATA

1. CROSS-BEDDING

UNIT 6 :- θ = 166°, L = 96%, n = 8
UNIT 5 :- θ = 169°, L = 99%, n = 5
UNIT 4 :- θ = 160°, L = 93%, n = 6
UNIT 3 :- NO INFORMATION.
UNIT 2 :- CHAOTIC UNIT.
UNIT 1 :- θ = 210°, L = 87%, n = 28

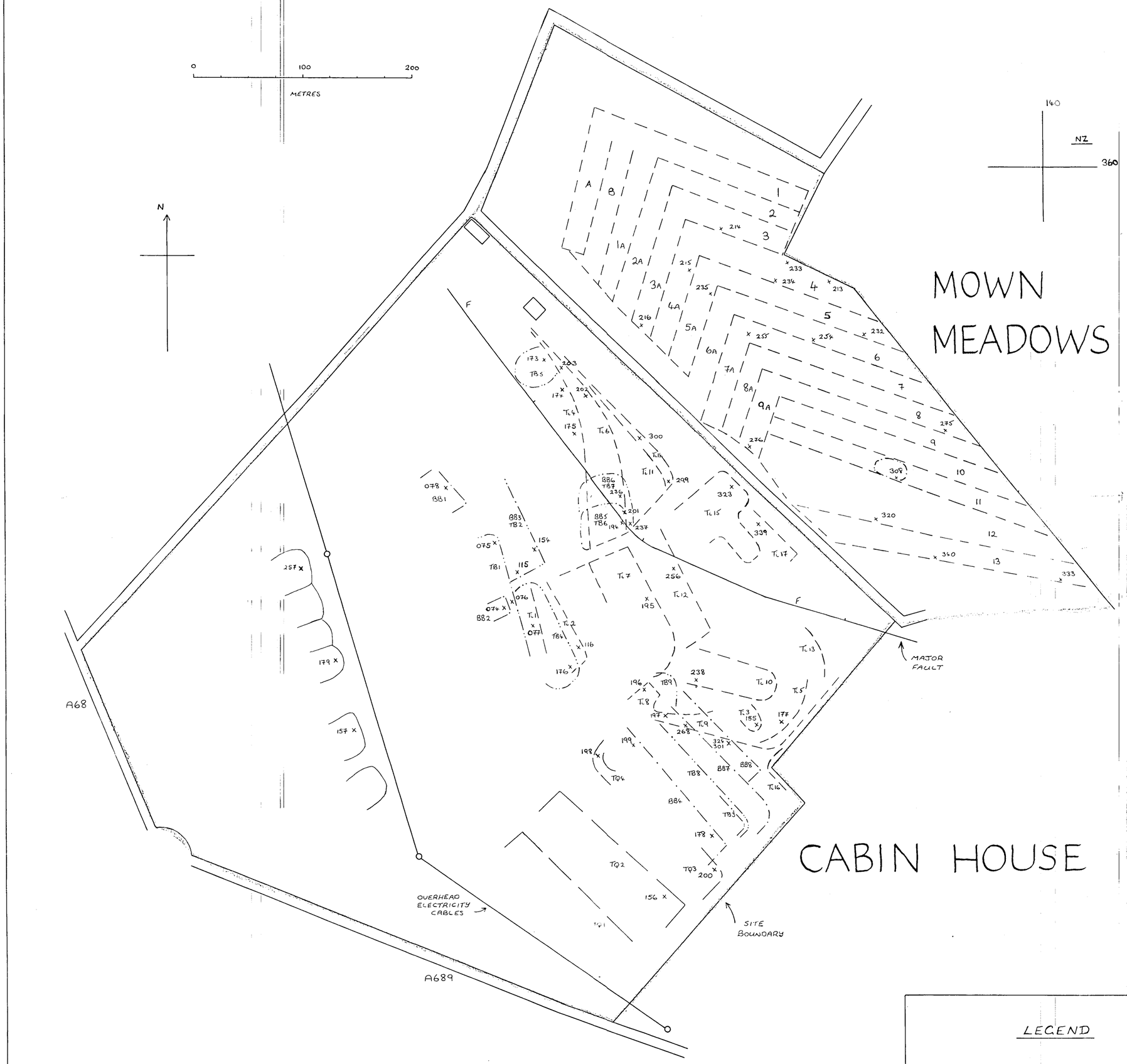
2. PLANT CASTS

θ = 181°, L = 58%, n = 14

OVERALL (CROSS-BEDDING)



θ = 189°
L = 85%
n = 47



ENCLOSURE 2

CABIN HOUSE / MOWN MEADOWS

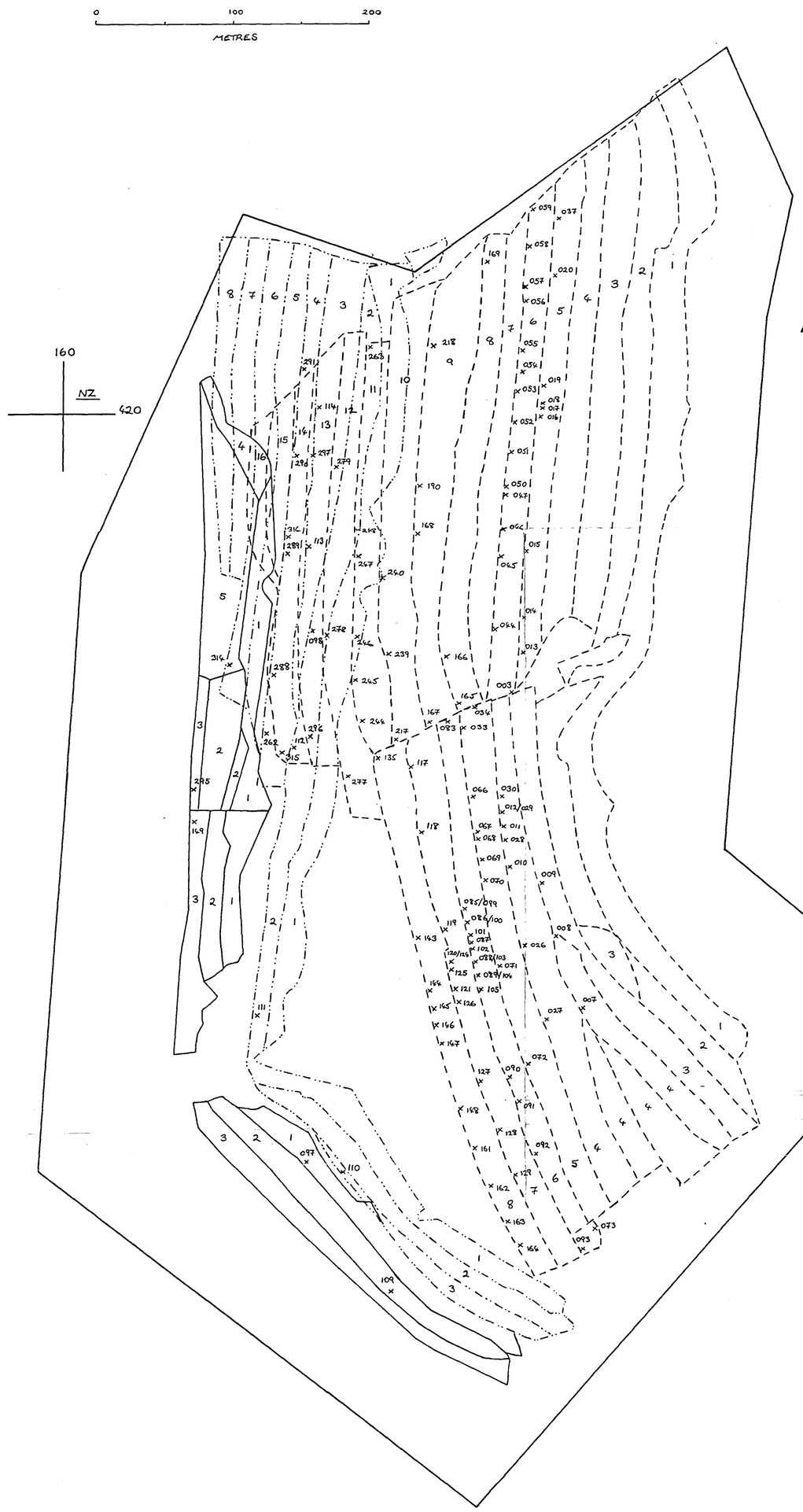
O.C.C.S. - SITE PLAN

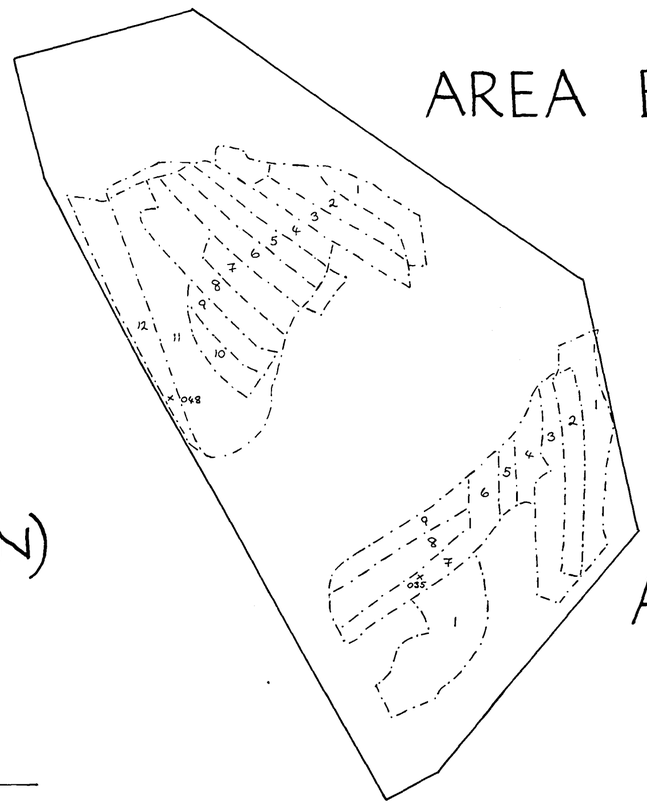
SCALE 1:2,500

LEGEND

- WORKINGS IN TILLEY SEAM
- WORKINGS IN TOP BUSTY SEAM
- WORKINGS IN BOTTOM BUSTY SEAM
- WORKINGS IN THREEQUARTER SEAM
- WORKINGS IN BROCKWELL SEAM
- 231 X — LOGGED BOREHOLE
- 10 — CUT NUMBER - MOWN MEADOWS
- TL 5 — CUT NUMBER - CABIN HOUSE

ENCLOSURE 3
ROWLEY O.C.C.S. SITE PLAN
SCALE 1:2,500





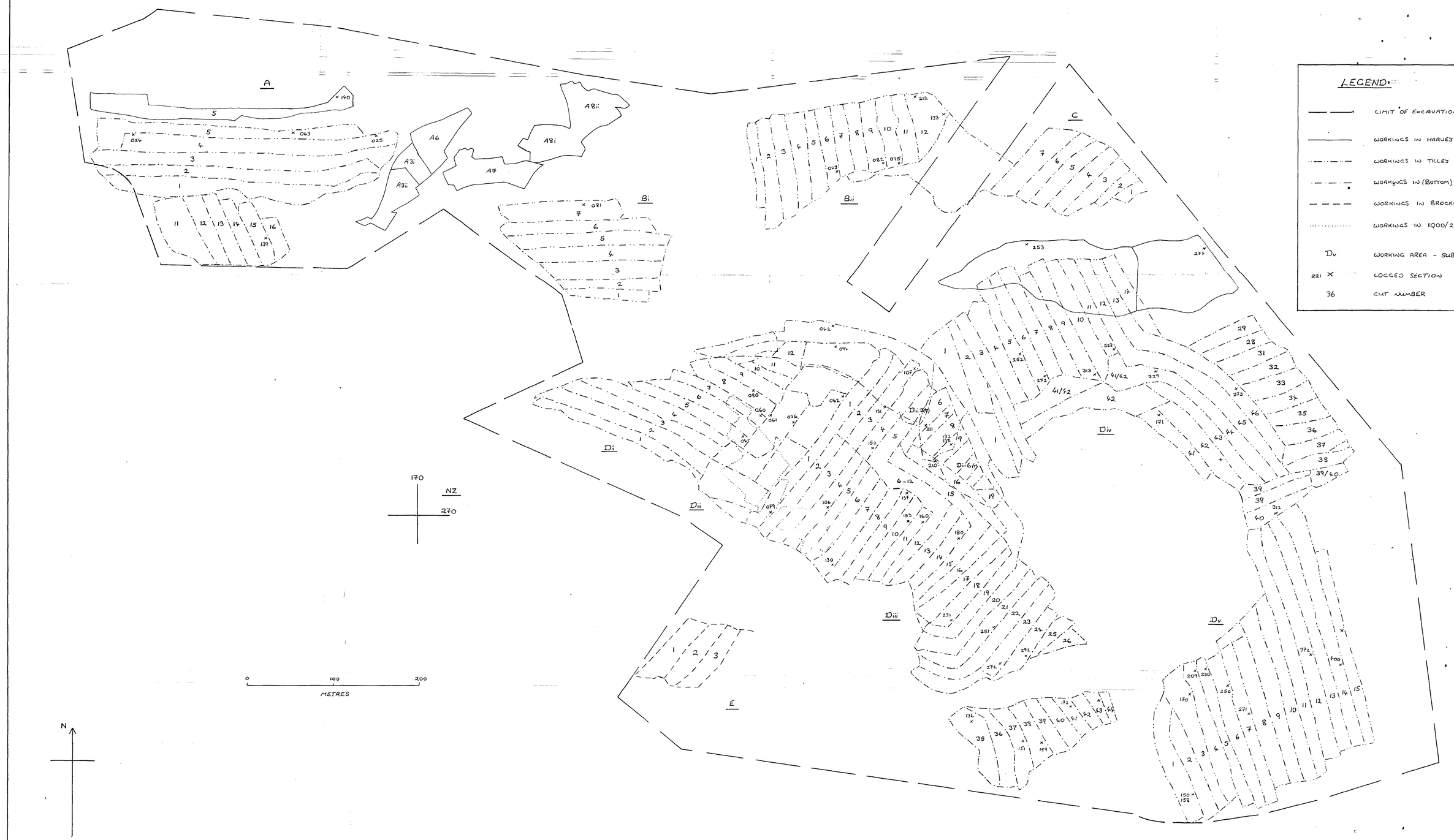
N

LEGEND

- LIMIT OF EXCAVATION
- WORKINGS IN HARVEY MARINE SEAM
- WORKINGS IN HARVEY SEAM
- WORKINGS IN TILLEY SEAMS
- WORKINGS IN BUSTY SEAMS
- 119 X LOGGED SECTION
- 6 CUT NUMBER

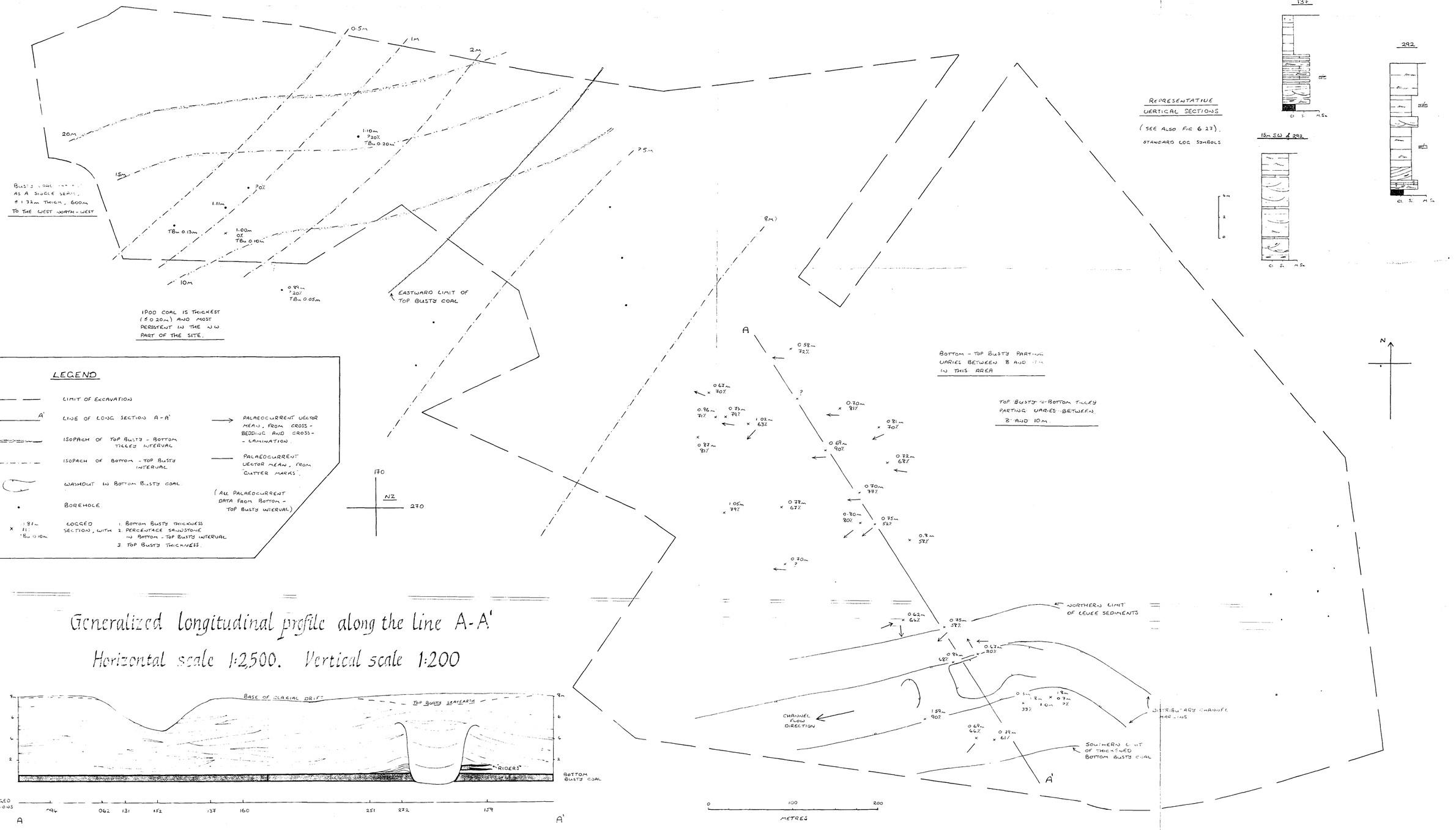
ENCLOSURE 4 DEBORAH O.C.C.S. SITE PLAN

SCALE 1:2,500



ENCLOSURE 5. DEBORAH O.C.C.S. Bottom Busty to Bottom Tilley Interval

SCALE 1:2,500



LEGEND

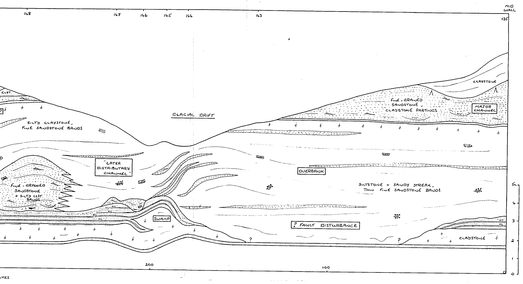
- LIMIT OF EXCAVATION
- A — A' LINE OF LONG SECTION A-A'
- ISOPACH OF TOP BUSTY - BOTTOM TILLEY INTERVAL
- ISOPACH OF BOTTOM - TOP BUSTY INTERVAL
- WASHOUT IN BOTTOM BUSTY COAL
- BOREHOLE
- 0.81m ?1% TBu 0.10m — CORED SECTION, WITH 1. BOTTOM BUSTY THICKNESS 2. PERCENTAGE SANDSTONE IN BOTTOM - TOP BUSTY INTERVAL 3. TOP BUSTY THICKNESS.
- PALAEOCURRENT VECTOR MEAN, FROM CROSS-BEDDING AND CROSS-LAMINATION.
- PALAEOCURRENT VECTOR MEAN, FROM 'CLUTTER MARKS'.

(ALL PALAEOCURRENT DATA FROM BOTTOM - TOP BUSTY INTERVAL)

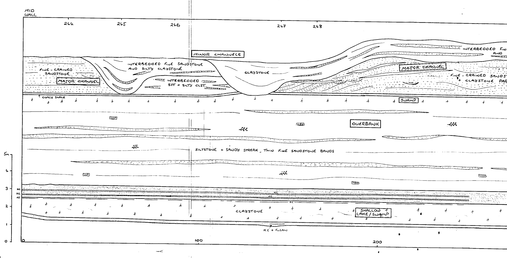
Generalized longitudinal profile along the line A-A'

Horizontal scale 1:2,500. Vertical scale 1:200

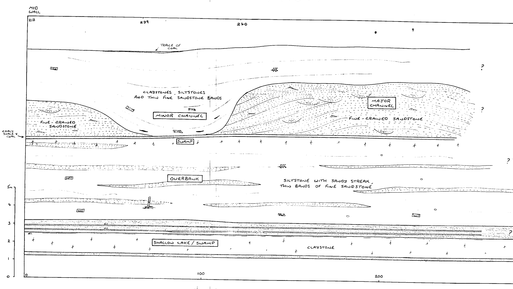
A8S



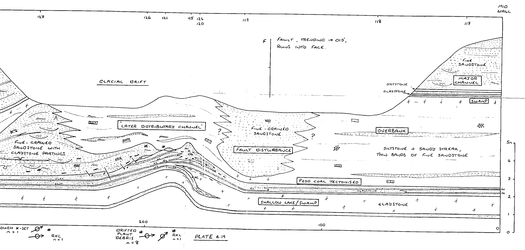
A11N



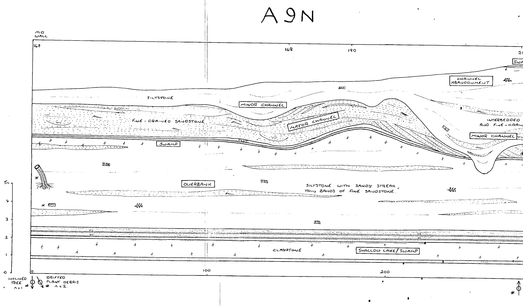
A10N



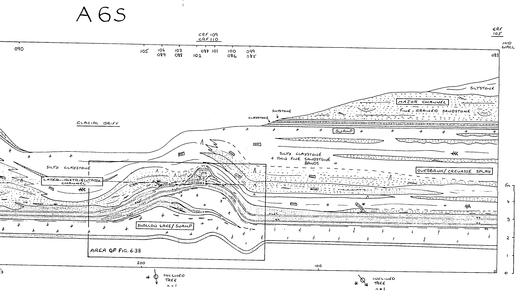
A7S



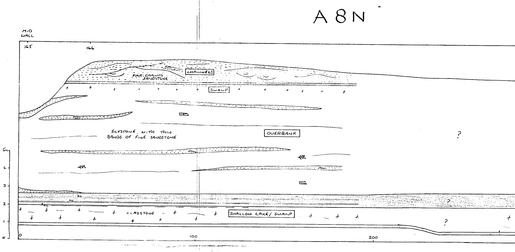
A9N



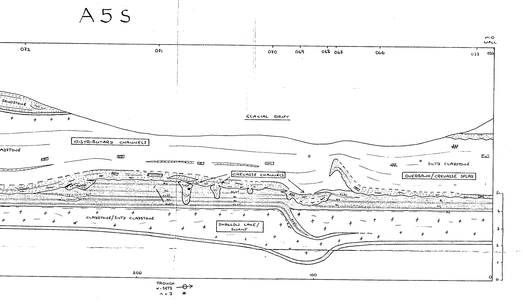
A6S



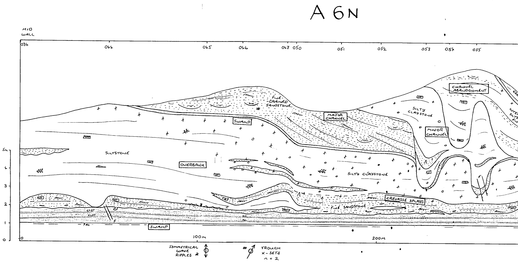
A8N



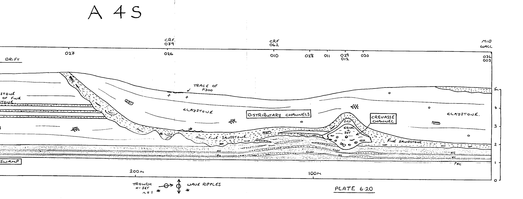
A5S



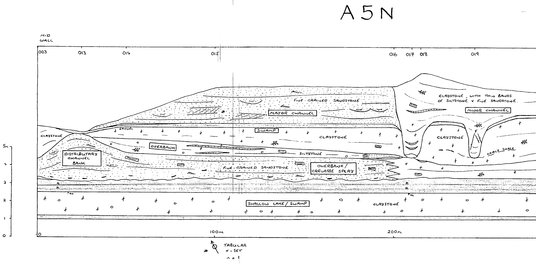
A6N



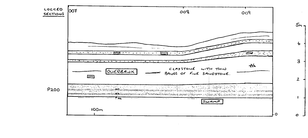
A4S



A5N

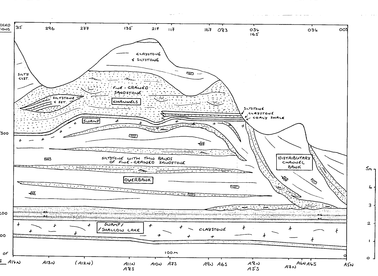


A4S



MIDWALL

WEST EAST



ENCLOSURE 6 SHEET A

Detailed longitudinal sections from Rowle

Area A. Tilley excavations

SCALE. Horizontal 1:1,000 .. Vertical 1

NOTES

EACH LONG SECTION SHOWS THE STRATA EXPOSED ALONG A GIVEN 'CUT', AND REPRESENTS A COMPILATION OF NUMBERED VERTICAL SECTIONS, DRILLHOLES AND OTHER FIELD DATA. EXACT POSITIONAL RELATIONSHIPS OF CUTS ARE SHOWN ON ENCLOSURE 3

THE LONG SECTIONS ARE ARRANGED TO SHOW A MIDWALL SO TO SHOW THE RELATIVE POSITIONS OF CUTS AND LATERAL LITHOLOGICAL CHANGES) AS REALISTICALLY AS POSSIBLE, ABOVE THE 'MIDWALL', IE, THE BOUNDARIES BETWEEN AREAS A1S AND A1N, AND THE MIDDLE TILLEY SEAM, AS REFERENCE POINTS

PLACING SHEET B ABOVE THE RIGHT-HAND HALF OF SHEET A GIVES THE COMPLETE COVERAGE IN THE CLOSEST JUXTAPOSE.

STANDARD COAL SYMBOLS ARE USED, + [dotted] = SANDSTONE. [hatched] = SILTSTONE & CLAYSTONE. LITHOLOGY OVERBURDEN = ENVIRONMENTAL INTERPRETATION

SAMPLES NUMBERED ABOVE SECTIONS ARE DETAILED IN APPENDIX 2
VERTICAL SECTIONS AND OTHER FIELD DATA ARE CONTAINED WITHIN APPENDIX 1.

ENCLOSURE 6 SHEET B

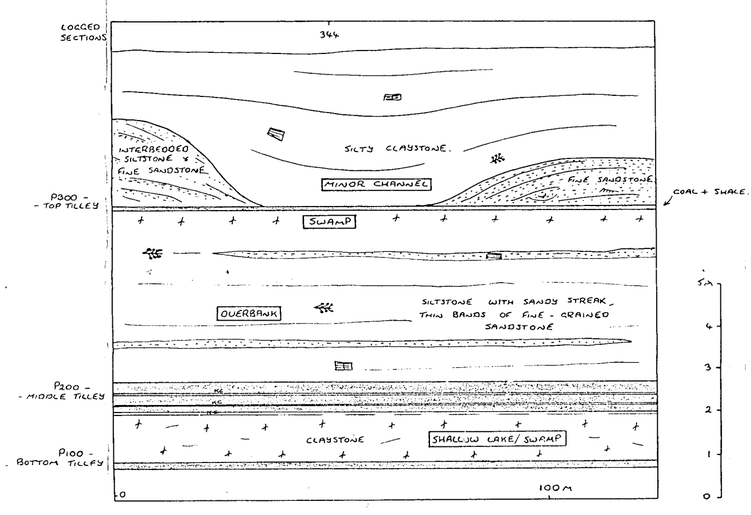
Detailed longitudinal sections from Rowley O.C.C.S.

Area A : Tilley excavations

SCALE Horizontal 1:1,000 . Vertical 1:100

SOUTH NORTH

A 16 N



A 14 N

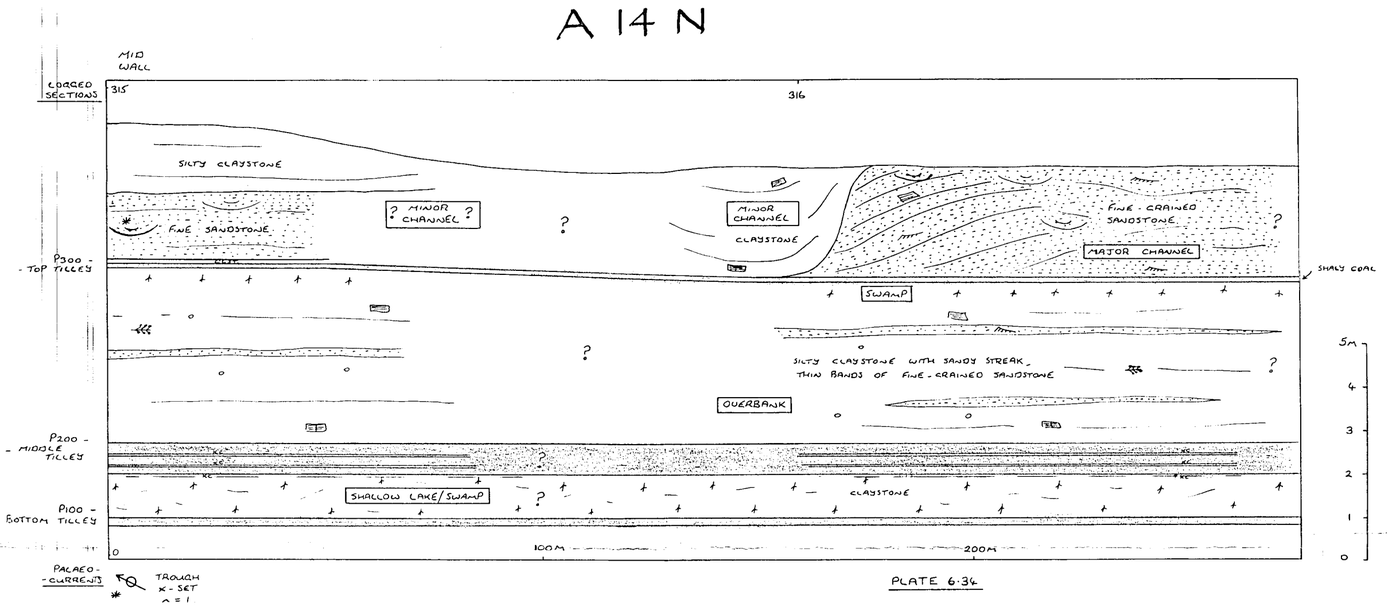


PLATE 6.34

A 13 N

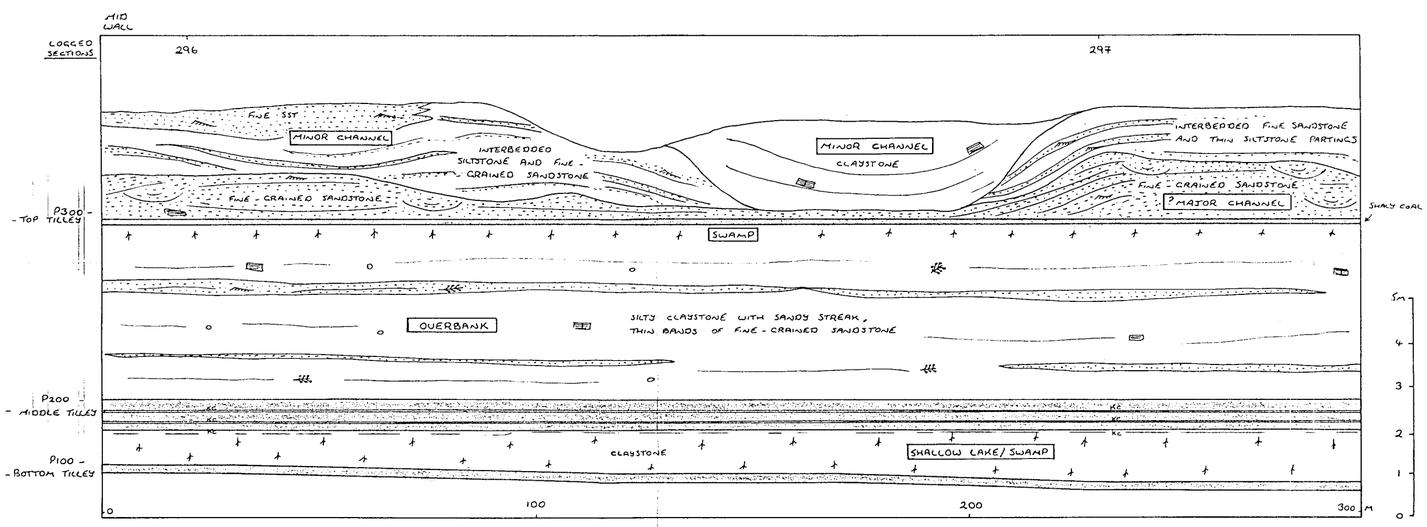
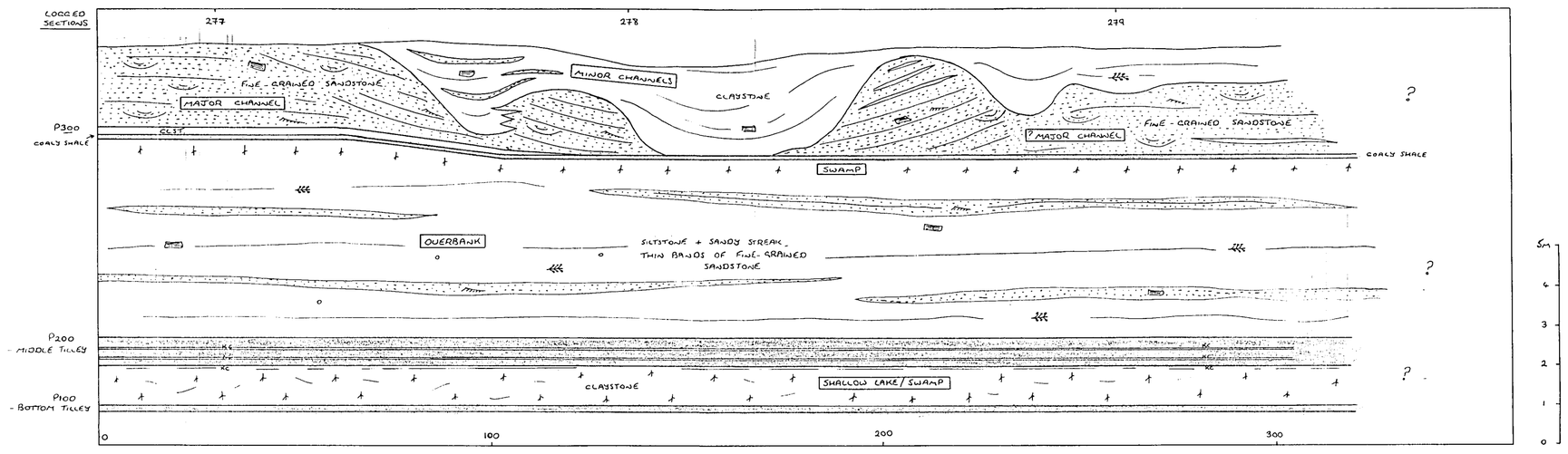


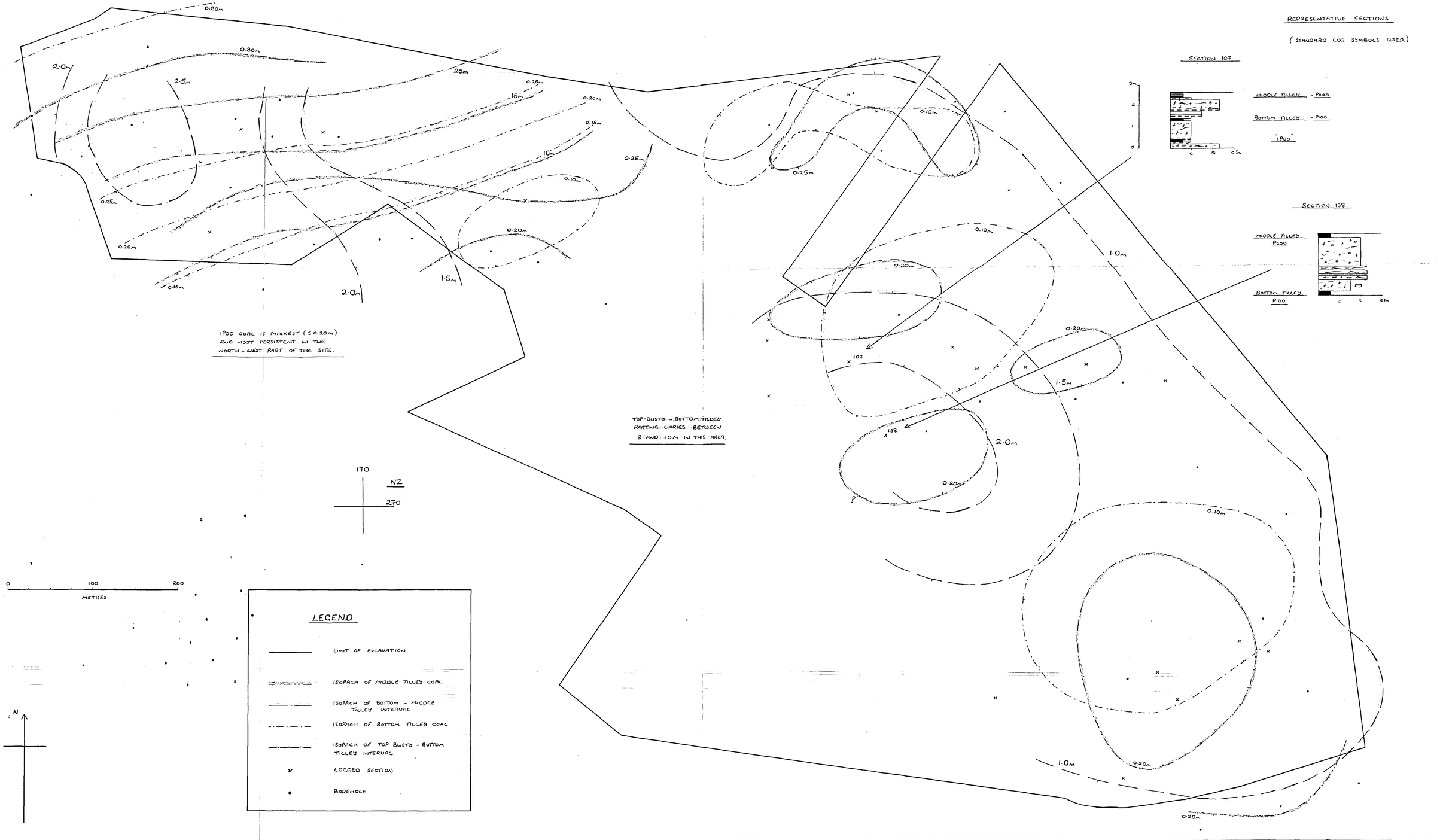
PLATE 6.33

A 12 N



ENCLOSURE 7 DEBORAH O.C.C.S. Top Busty to Middle Tilley Interval

SCALE 1:2,500



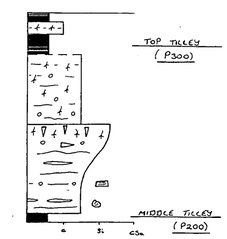
ENCLOSURE 8 DEBORAH O.C.C.S. Middle to Top Tilley Interval

SCALE 1:2,500

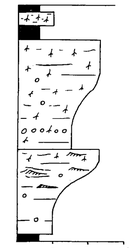
REPRESENTATIVE SECTIONS

(STANDARD COC SYMBOLS USED)

SECTION 133



SECTION 373



0.30m 0.34m 0.38m 0.58m 0.38m 2.37m 6.31m 0.65m 0.62m 7.0m TOTAL 0.38m 5.75m TOTAL 0.43m 0.28m 0.34m 0.35m 0.38m (2.30m) 2.25m 0.40m (2.00m) 2.51m 0.53m 0.44m 0.40m (1.70m) 2.96m 0.45m 0.49m 0.44m 0.42m 0.50m 0.37m 0.43m 0.45m 0.36m (2.25m) 3.15m 0.45m 0.38m 2 (2.00m) 2.80m 0.43m 2.05m 0.42m 2.80m 2.80m 2.00m 1.70m (3.34m) 3.04m 0.39m 0.39m 0.38m 0.39m 0.34m 3.10m 2.35m 0.39m 0.43m 0.40m (3.15m) 3.08m 4 0.36m 0.41m 0.36m 0.36m 2.67m 2.80m 0.40m 2.30m 2.80m 0.41m 0.38m 0.36m 0.34m 0.45m 2.10m 2.30m 0.36m 0.33m 3.27m 2.85m 0.31m 0.39m 3.39m (2.90m) 0.38m 0.40m 0.38m 0.40m

170 NZ 270

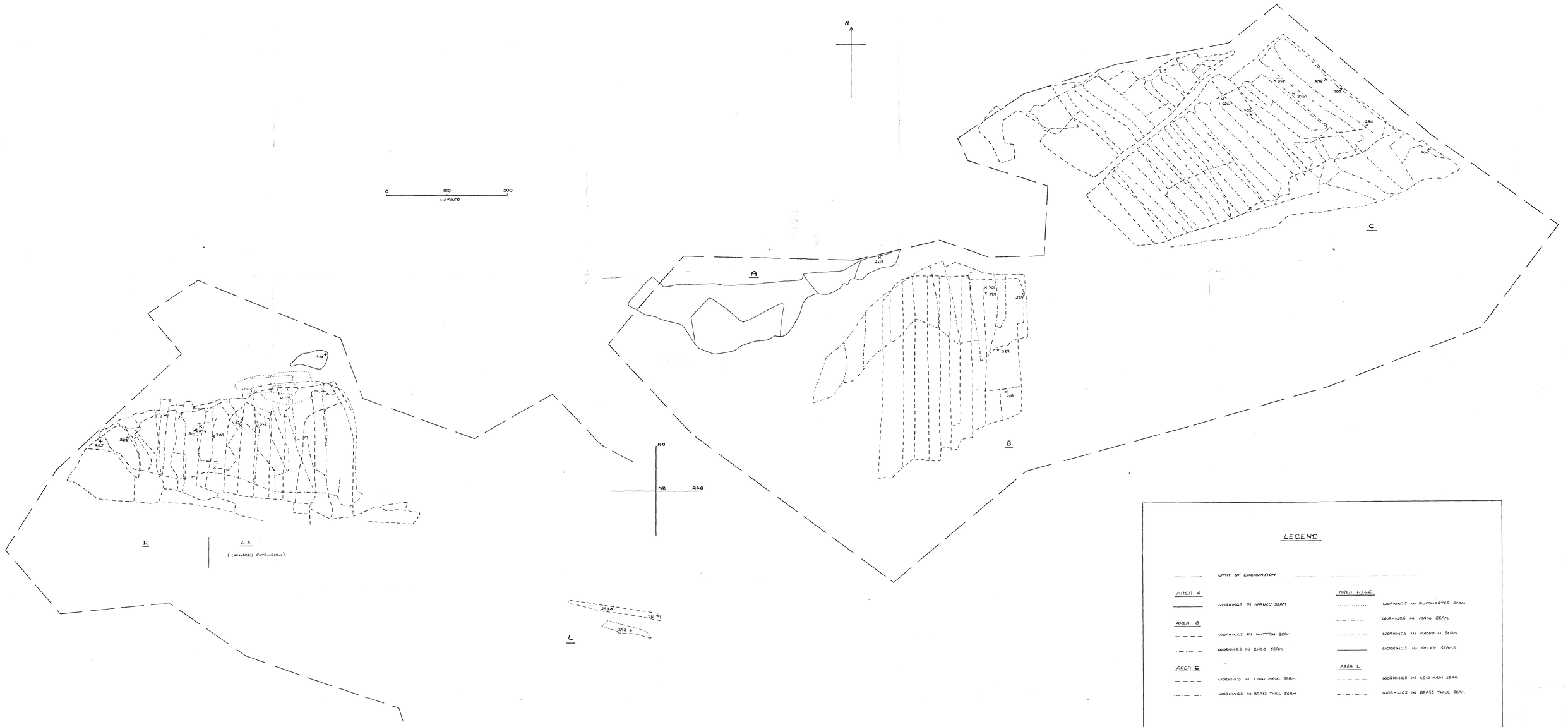
0 100 200
METRES

N

LEGEND

- LIMIT OF EXCAVATION
- APPROXIMATE EXTENT OF "EARLY" MINOR DELTA LOBES.
- APPROXIMATE EXTENT OF "LATER" MINOR DELTA LOBES
- × LOGGED SECTION
- • BOREHOLE
- 3.10m / 2.85m — THICKNESS OF TOP / BOTTOM } MINOR DELTA LOBES, OR EQUIVALENT ( ).
- 0.42m — THICKNESS OF P301 COAL (TOP TILLEY, BOTTOM LEAF)
- ⓑ NON-MARINE BIVALVE REMAINS.
- PALAEOCURRENT VECTOR MEAN, WITH NUMBER OF DATA

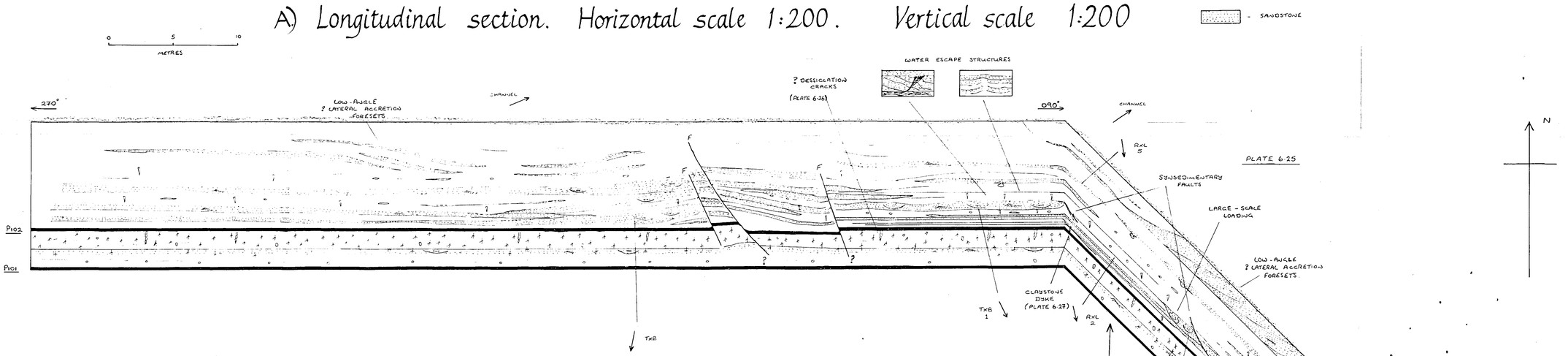
SITE PLAN. SCALE 1:2,500



ENCLOSURE 10

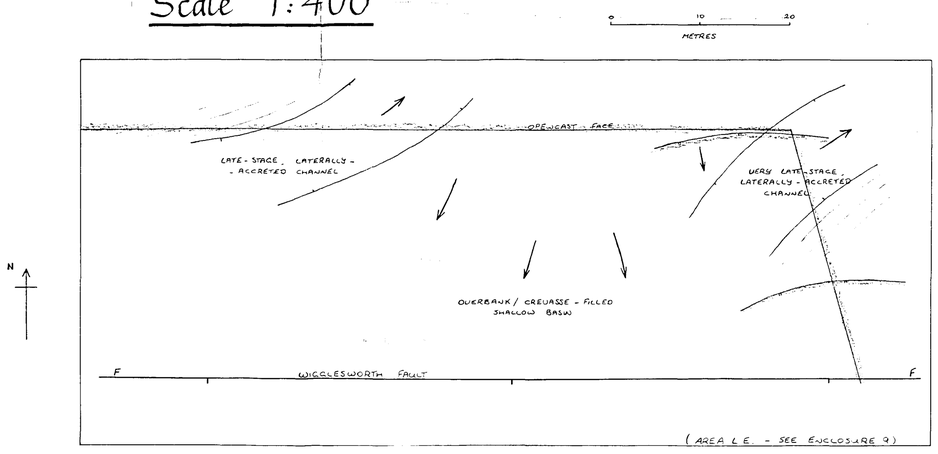
The Tilley seams and enclosing strata at Buckhead O.C.C.S. (Area L.E.)

A) Longitudinal section. Horizontal scale 1:200. Vertical scale 1:200



B) Interpretive plan.

Scale 1:400



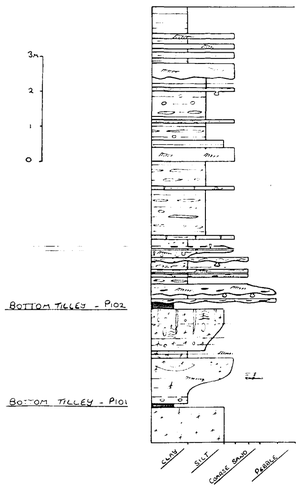
N

LEGEND

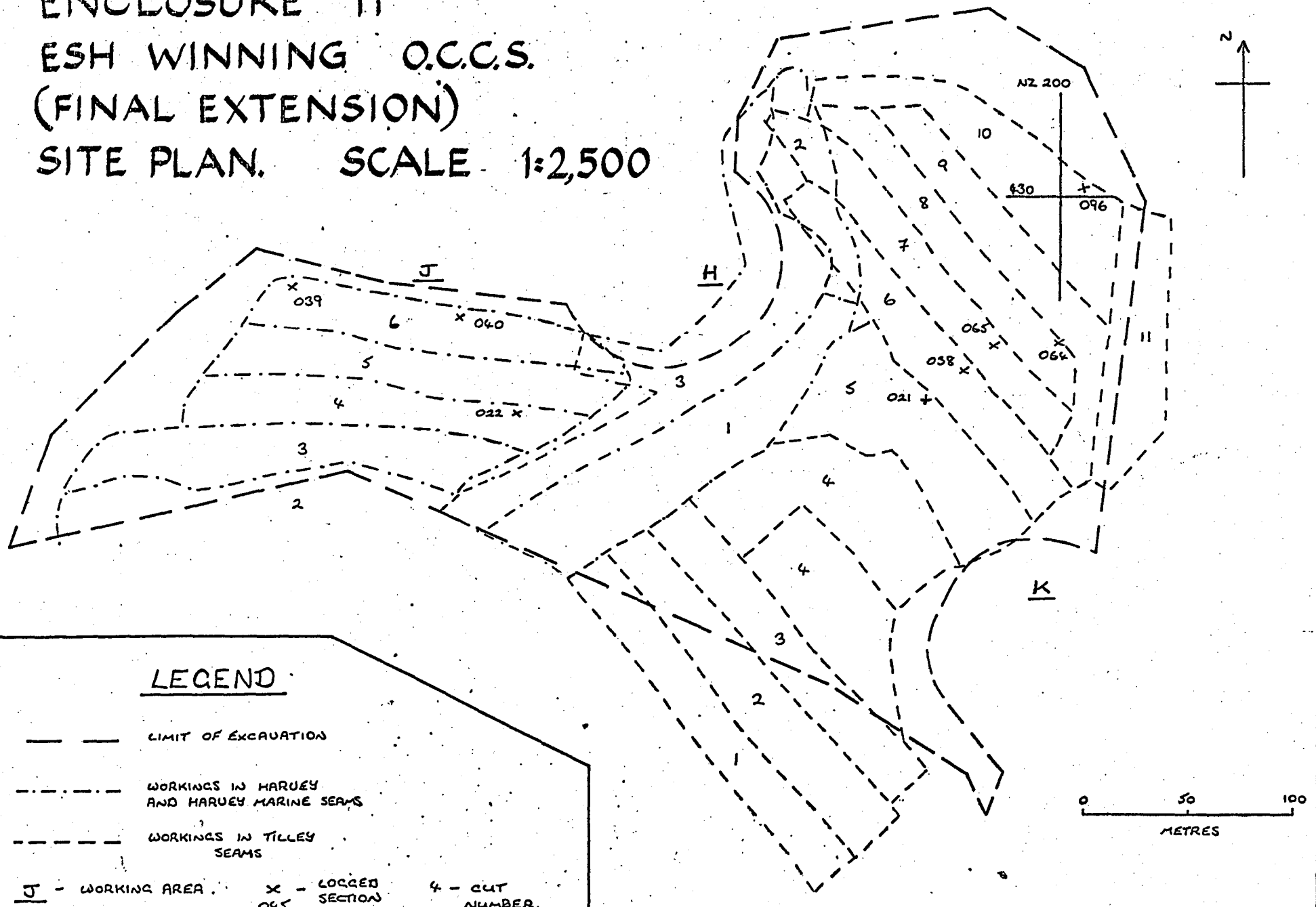
- OPENCAST CUT-WALL
- APPROXIMATE MINOR CHANNEL MARGINS, WITH LATERAL ACCRETION SURFACES
- LISTRIC SYNSEDIMENTARY FAULTS
- GENERALISED DIRECTION OF PALAEOFLOW

SECTION 425 (SEE APPENDIX 1).

STANDARD LOG SYMBOLS USED



ENCLOSURE 11
ESH WINNING O.C.C.S.
(FINAL EXTENSION)
SITE PLAN. SCALE 1:2,500



LEGEND

LIMIT OF EXCAVATION

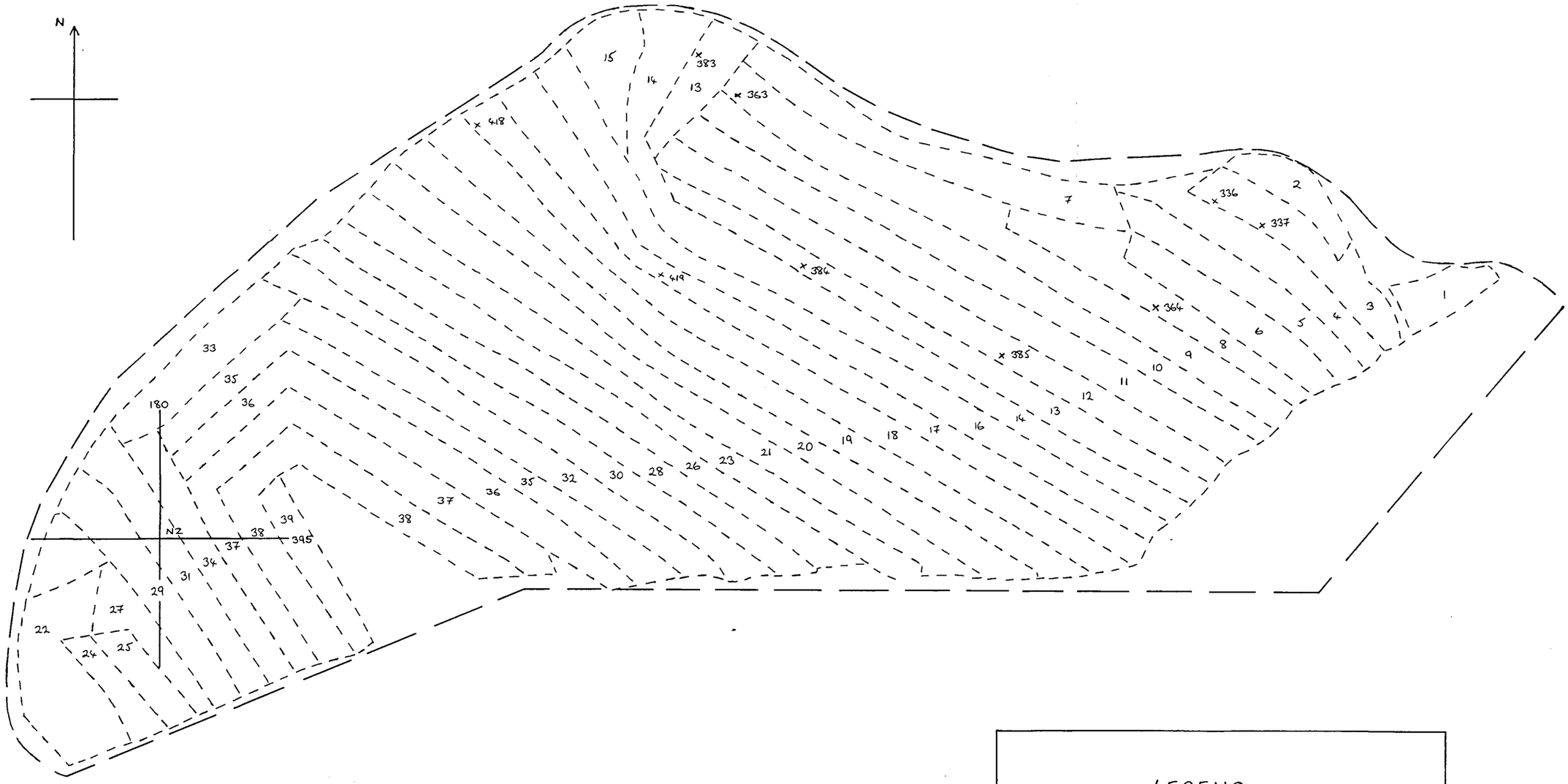
WORKINGS IN HARUEY AND HARUEY MARINE SEAMS

WORKINGS IN TILLEY SEAMS

J - WORKING AREA. x 045 - LOGGED SECTION 4 - CUT NUMBER.

ENCLOSURE 12 WOOLEY O.C.C.S.

SITE PLAN. SCALE 1:2,500



0 100 200

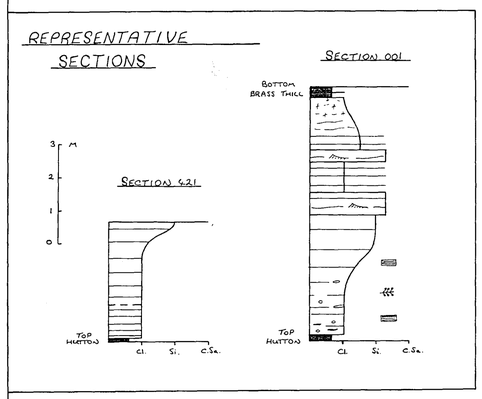
METRES

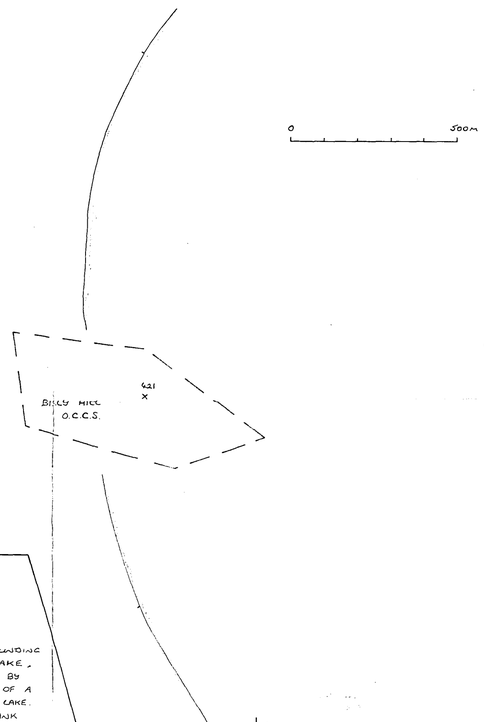
LEGEND

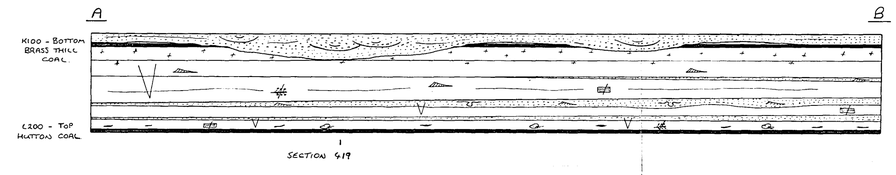
— —	LIMIT OF EXCAVATION
- - - - -	WORKINGS IN HUTTON SEAMS
35	CUT NUMBER
× 361	LOCCED SECTION

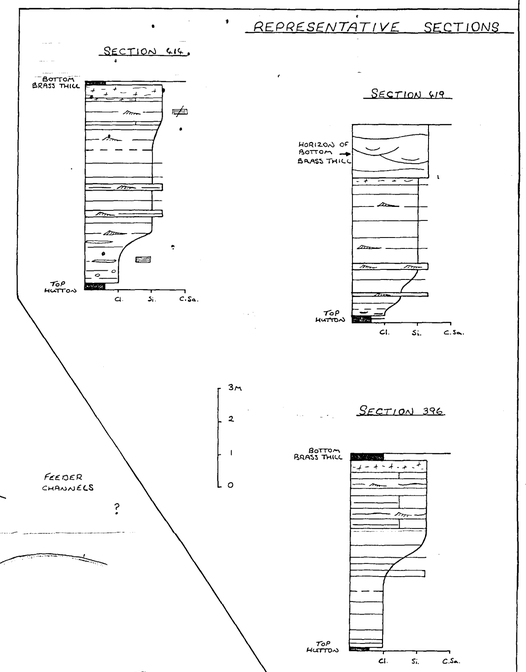
ENCLOSURE 13
TANNERS HALL / WOOLEY / INCLINE
BILLY HILL O.C.C.S.s

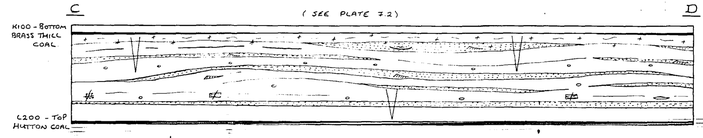
Hutton to Brass Thill Interval. SCALE 1:10,560

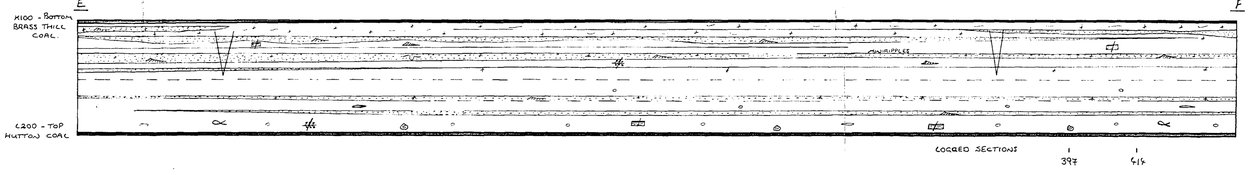












NOTES AND LEGEND

THE TOP HUTTON - BOTTOM BRASS THILL INTERVAL IN THE AREA SURROUNDING TANNERS HALL O.C.C.S. IS INTERPRETED AS THE FILL OF A SHALLOW LAKE, UP TO 6m DEEP. FOLLOWING AN INITIAL PASSIVE PHASE CHARACTERISED BY FALLOUT OF CLAY GRADE MATERIAL FROM SUSPENSION, PROGRADATION OF A MINOR DELTA SYSTEM WAS RESPONSIBLE FOR COMPLETELY INFILLING THE LAKE. THIS MINOR DELTA INITIATED BY CREVASSING OF A MAJOR CHANNEL BANK SOME 3 KMS TO THE EAST OF TANNERS HALL (SEE FIG 7.5)

PLAN SCALE 1:10,560

- OPENCAST SITE LIMIT
- X — Y : LINE OF LONG SECTION X - Y
- 421 × : LOGGED SECTION
- ← : GENERALISED PALAEOCURRENT DIRECTION
- ← : SPECULATIVE PALAEOCURRENT DIRECTION
- SPECULATIVE CONTOURS ON MINOR DELTA DEPOSIT (TACS FACE DOWNWARD)
- CHANNEL MARGINS (MOSTLY SPECULATIVE)

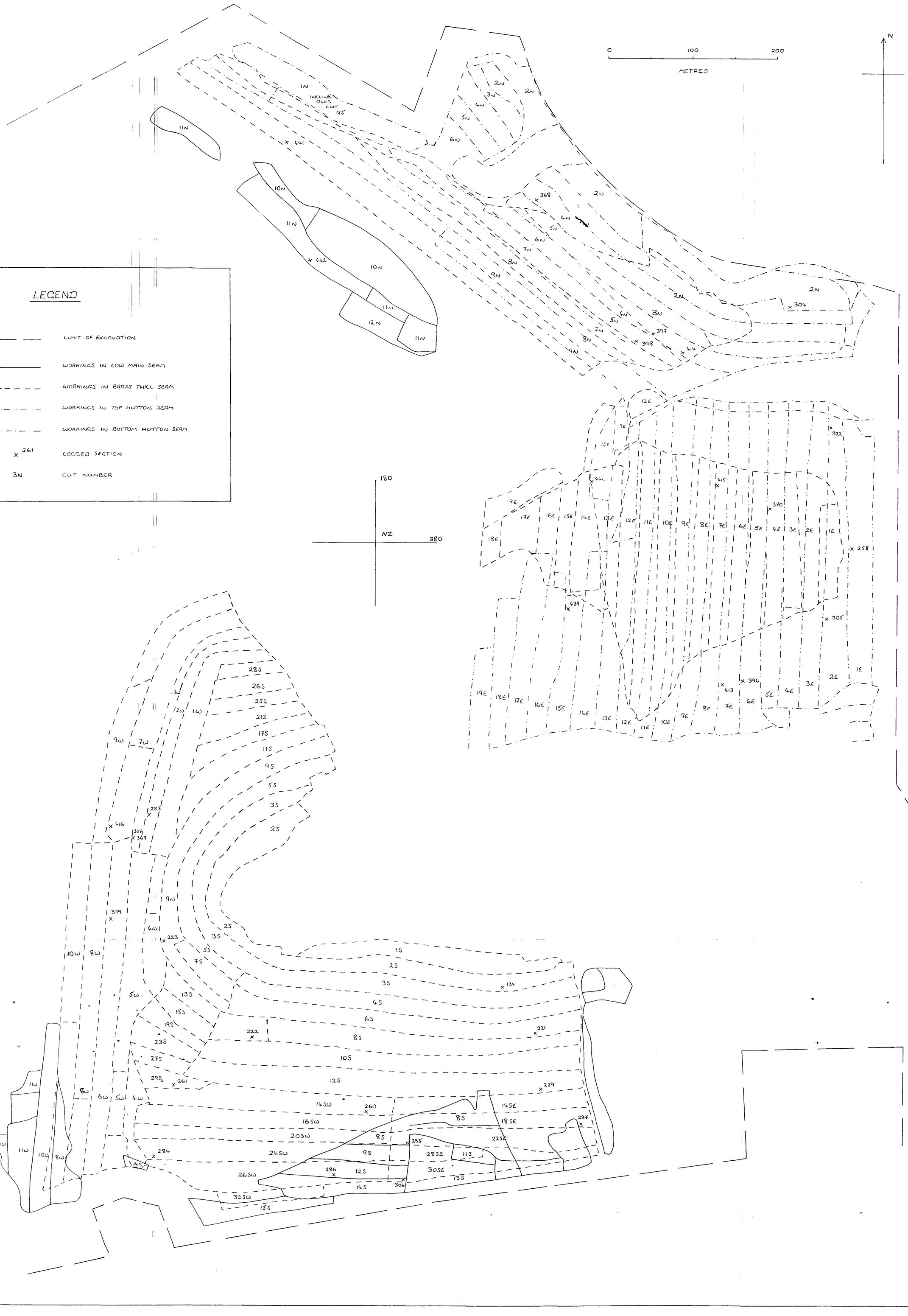
LONG SECTIONS SCALE :- HORIZONTAL 1:2000, VERTICAL 1:200

STANDARD SYMBOLS USED, + ▨ - SANDSTONE, COARSENING - UPWARD SEQUENCE

VERTICAL SECTIONS SCALE 1:100 STANDARD SYMBOLS USED.

ENCLOSURE 14 TANNERS HALL O.C.C.S.

SITE PLAN. SCALE 1:2,500



ENCLOSURE 15 LANGLEY O.C.C.S.

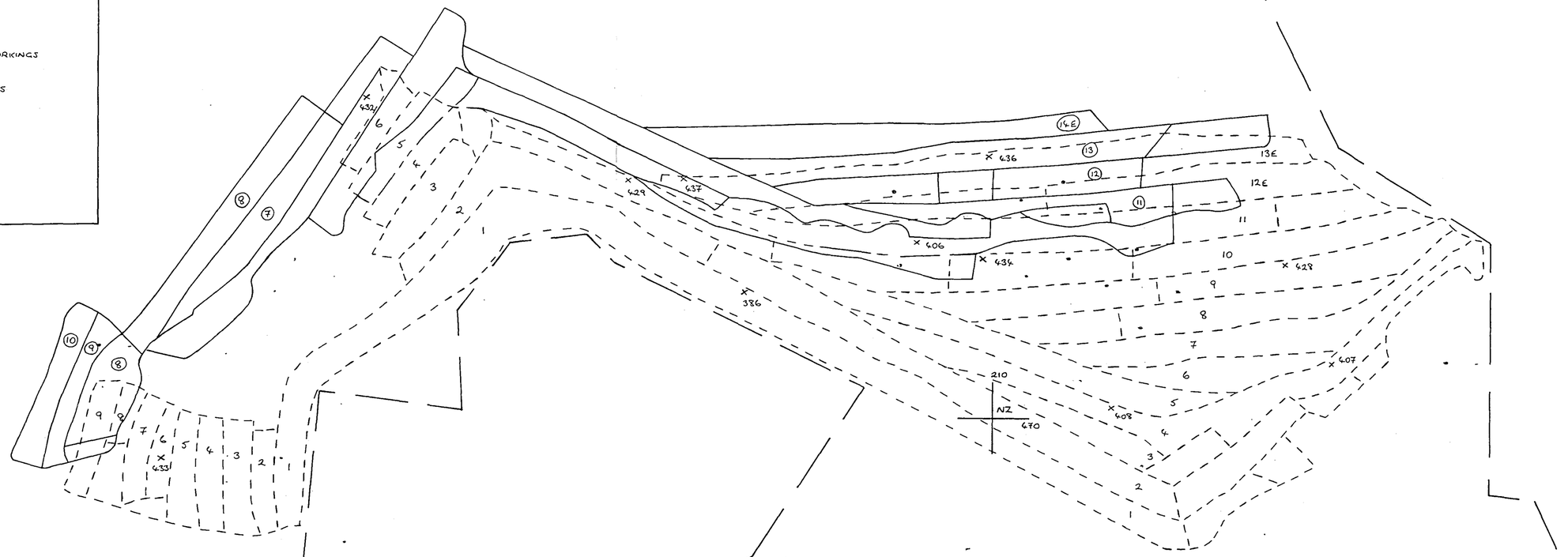
SITE PLAN SCALE 1:2,500

LEGEND

- ——— WORKINGS IN FIVEQUARTER SEAM
- – – – – WORKINGS IN MAIN SEAM.
- (10) CUT NUMBER - FIVEQUARTER WORKINGS
- 4 CUT NUMBER - MAIN WORKINGS
- 241 × LOGGED SECTION
- ——— LIMIT OF EXCAVATION

METRES
0 100 200

N



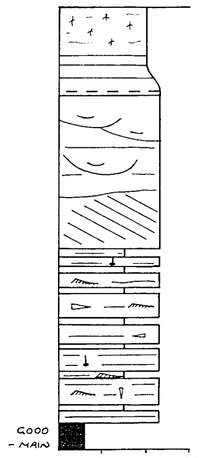
ENCLOSURE 16 LANGLEY O.C.C.S

Main to Fivequarter Interval. SCALE 1:2,500

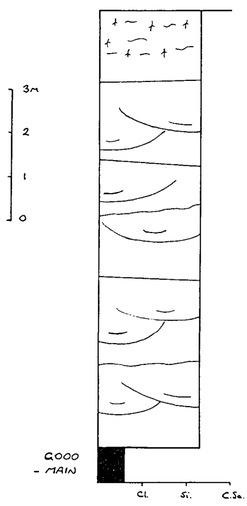
REPRESENTATIVE SECTIONS

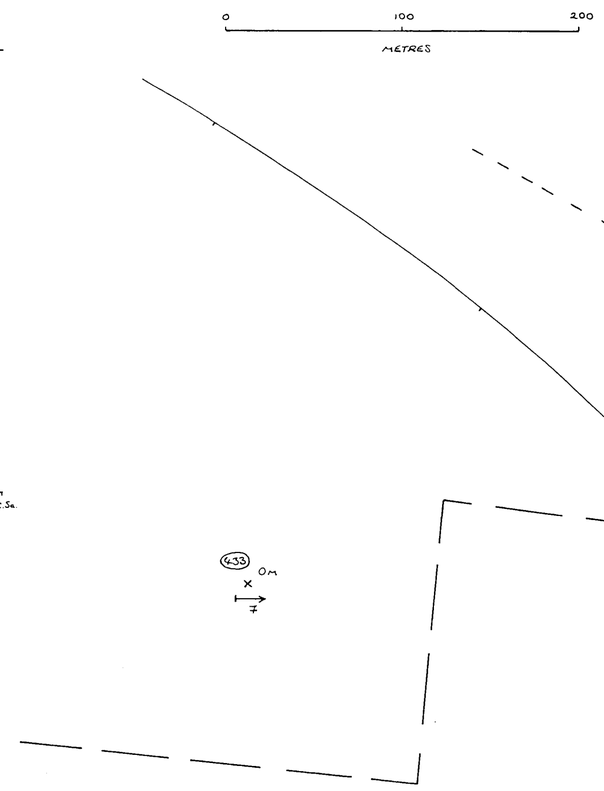
(STANDARD LOG SYMBOLS)

SECTION 637



SECTION 633





BOREHOLE RECORDS INDICATE THAT CHANNEL SANDSTONES OCCUPY THE ENTIRE INTERVAL FOR AT LEAST 1 KM TO THE WEST.

EXTRAPOLATION OF THE GRADIENT OF THE LEVEE SURFACE E.N.E. - WARD GIVES A TOTAL WIDTH OF ~1 KM FOR THE LEVEE DEPOSIT.

NOTES AND LEGEND

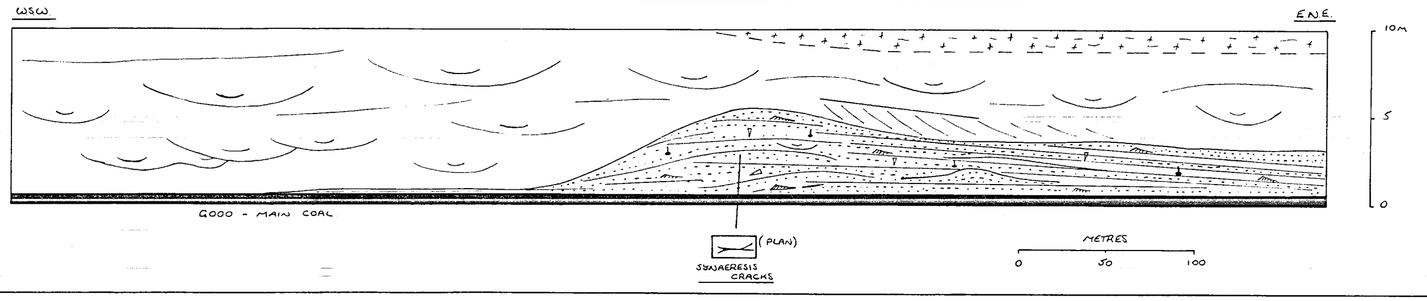
THE MAIN - FIVEQUARTER INTERVAL AT LANGLEY O.C.C.S. IS INTERPRETED AS THE RESULT OF SEDIMENTATION IN MAJOR CHANNEL AND CHANNEL MARGIN LEVEE ENVIRONMENTS. THE MAJOR CHANNEL, INFERRED FROM BOREHOLE RECORDS TO HAVE BEEN SINUOUS AND 2-3 KMS WIDE, FLOWED TOWARDS THE SOUTH-EAST AND DEPOSITED A LEVEE UP TO AT LEAST 6M HIGH AND ABOUT 1KM WIDE ON THE OUTER, EROSIVE BANK OF A RIGHT-HAND BEND. THIS LEVEE WAS ENTIRELY SUBAQUEOUS.

A MAJOR CREVASSE EVENT THEN BREACHED THE CHANNEL BANK, CAUSING A NEW CHANNEL TO FLOW EASTWARD OVER THE PREVIOUSLY-DEPOSITED LEVEE, BUT NOT LEADING TO COMPLETE AVULSION OF THE OLD CHANNEL COURSE.

——— ———	LIMIT OF EXCAVATION
– – – – – – 4.0m	ISOPACH OF LEVEE SEQUENCE (TAGS POINT TOWARD THINNER SEQUENCE)
3.5m X	LOGGED SECTION, WITH THICKNESS OF LEVEE SEQUENCE.
6	PALAEOCURRENT VECTOR MEAN FOR a) CHANNEL SANDSTONES b) LEVEE SEDIMENTS, WITH NUMBER OF DATA.

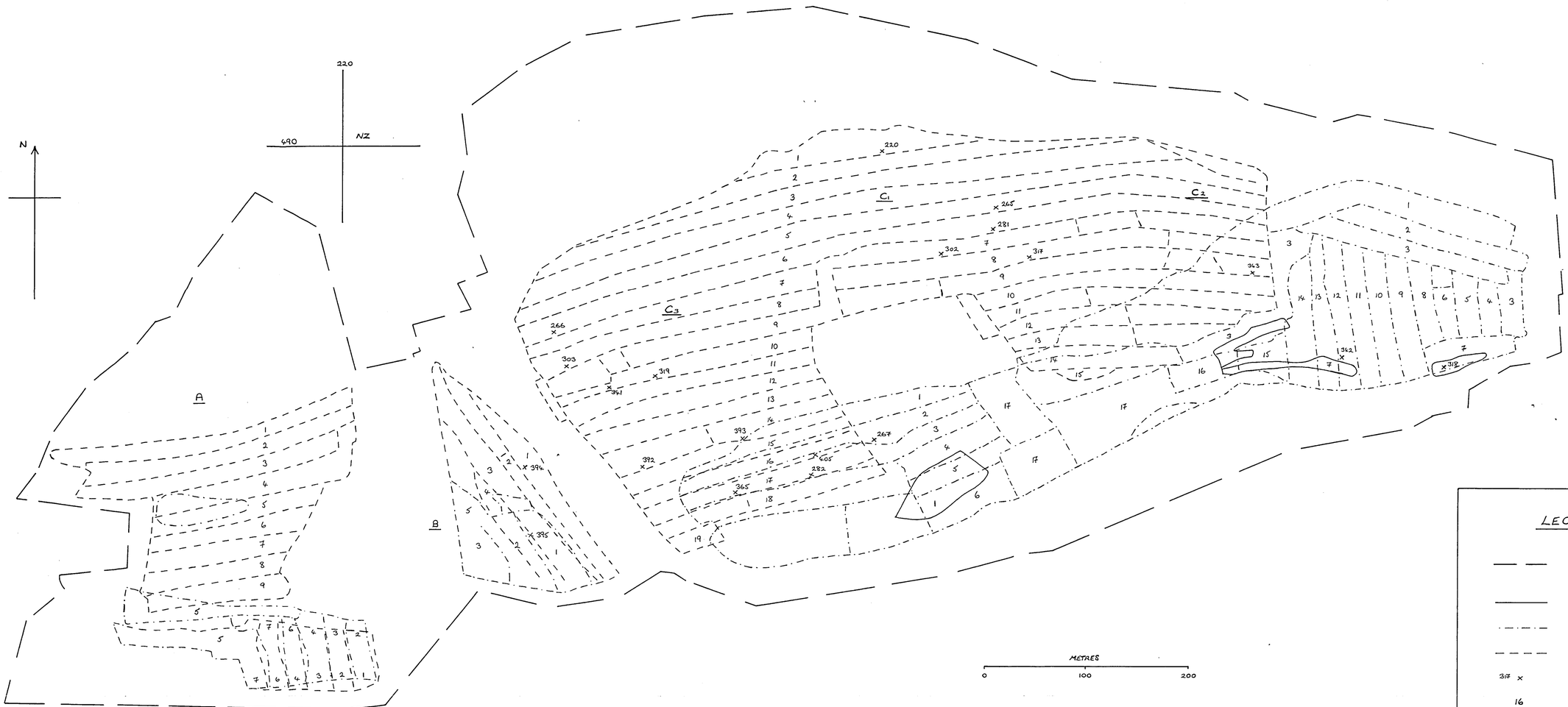
COMPOSITE, WSW-ENE. LONGITUDINAL SECTION ACROSS THE AREA OF STUDY.

SCALE - HORIZONTAL = 1:2500, VERTICAL 1:250



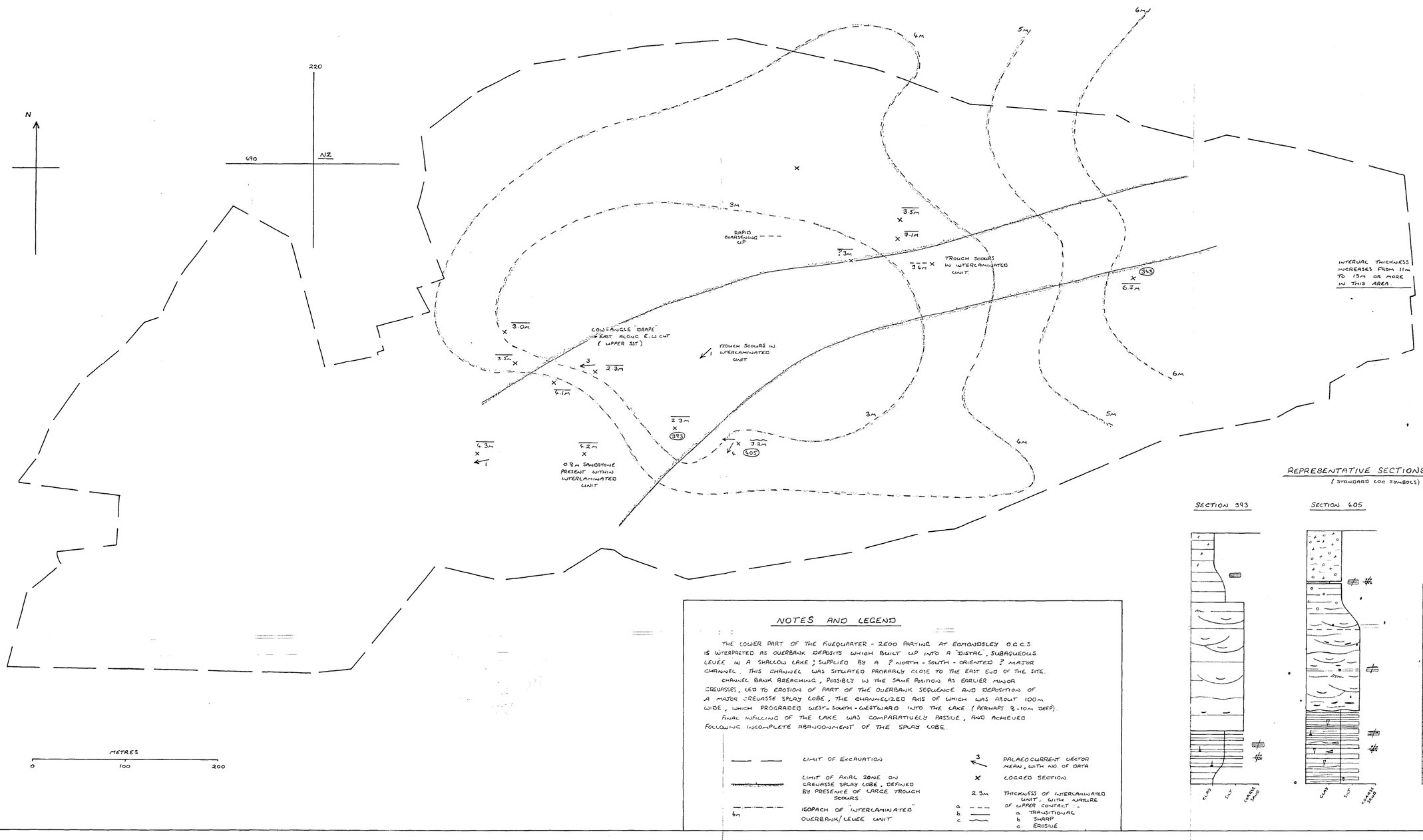
ENCLOSURE 17 EDMONDSLEY O.C.C.S.

SITE PLAN SCALE 1:2,500



ENCLOSURE 18 EDMONDSLEY O.C.C.S. Fivequarter to 2E00 Interval.

SCALE 1:2,500



NOTES AND LEGEND

THE LOWER PART OF THE FIVEQUARTER - 2E00 PARTING AT EDMONDSLEY O.C.C.S IS INTERPRETED AS OVERBANK DEPOSITS WHICH BUILT UP INTO A "DISTAL", SUBAQUEOUS LEVEE IN A SHALLOW LAKE; SUPPLIED BY A ?NORTH - SOUTH - ORIENTED ? MAJOR CHANNEL. THIS CHANNEL WAS SITUATED PROBABLY CLOSE TO THE EAST END OF THE SITE.

CHANNEL BANK BREACHING, POSSIBLY IN THE SAME POSITION AS EARLIER MINOR CREVASSES, LED TO EROSION OF PART OF THE OVERBANK SEQUENCE AND DEPOSITION OF A MAJOR CREVASSE SPLAY LOBE, THE CHANNELIZED AXIS OF WHICH WAS ABOUT 100m WIDE, WHICH PROGRADED WEST-SOUTH-WESTWARD INTO THE LAKE (PERHAPS 8-10m DEEP).

FINAL INFILLING OF THE LAKE WAS COMPARATIVELY PASSIVE, AND ACHIEVED FOLLOWING INCOMPLETE ABANDONMENT OF THE SPLAY LOBE.

- LIMIT OF EXCAVATION
- LIMIT OF AXIAL ZONE ON CREVASSE SPLAY LOBE, DEFINED BY PRESENCE OF LARGE TROUGH SCOURS.
- 6m — ISOPACH OF "INTERLAMINATED" OVERBANK/LEVEE UNIT
- 3 — PALAEOCURRENT VECTOR MEAN, WITH NO. OF DATA
- X — LOGGED SECTION
- 2.3m — THICKNESS OF INTERLAMINATED UNIT, WITH ANNEXE
- OF UPPER CONTACT :-
  - a. TRANSITIONAL
  - b. SHARP
  - c. EROSIVE.

REPRESENTATIVE SECTIONS

(STANDARD LOG SYMBOLS)

