The Genesis of Coal Measure Blackband Ironstones

by

E.L. Boardman BSc MIGeol

Thesis submitted to the University of Aston for the
Degree of Doctor of Philosophy
October 1981

Edric Lloyd Boardman PhD 1981

SUMMARY

Blackband ironstones are essentially thin (c. 75 cm thick) siderite rich (total iron up to 40%), carbonaceous, layered mudrocks which commonly occur in grey coal measure sequences at coal seam horizons. In the United Kingdom they are restricted in commercial development to the Midland Valley of Scotland (Namurian E) and the North Staffordshire Coalfield (Westphalian C) although they are now no longer exploited. During the course of this study, in addition to material from these two areas, examples of blackband ironstone developments were also obtained from the Nottinghamshire Coalfield although the majority of the work was concentrated on an opencast coal site a few miles to the north of Newcastle-Under-Lyme and nearby collieries (National Coal Board) and boreholes in the North Staffordshire Coalfield. Similar blackband developments are also recorded occurring in the Westphalian of the Ruhr, Germany and the Pennsylvanian of Ohio, USA.

In addition to their conspicuous layered macro-texture the blackbands exhibit many other primary textures including root disturbed layers, sideritised unflattened spores and preservation of plant cell detail which all point to a very early, in some cases pre-compaction siderite formation. A study of their enclosing sediments clearly shows that they were deposited in an environment intermediate between a complex delta top alluvial flood plain and coastal plain swamps; an environment likely to have been one in which small areas were subjected to periods of lacustrine deposition. The presence of varved mudstones and oil shales in the measures directly above many of the blackband ironstones and the distinctive fine layering of the blackbands themselves are evidence of such a depositional environment.

The blackbands are considered to have been formed in a similar way to Recent bog iron ores. They are therefore fossil bog iron ores formed contemporaneously in the proto-coal peat bogs; the iron being concentrated by precipitation due to oxidation in the surface waters of the bog and subsequently reduced to siderite in the top few metres of the carbon-rich sediment of the substrate.

In support of these conclusions detailed mineralogical, petrological, sedimentological and stable isotope data are presented herein.

CARBONIFEROUS BLACKBAND IRONSTONE SIDERITE GENESIS

To Jude

CONTENTS

List of Plates

Page

List of Figures

Acknowledgement

The author gratefully acknowledges the assistance of the National Coal Board both for their financial support and for permission to include some of the borehole data herein. Thanks are also extended to Dr P Turner, University of Aston, for his helpful criticism and counselling and to many colleagues for their help and for providing a source of stimulating discussion. In particular I should like to thank B Besley (Shell), R H Hoare and A H V Smith (NCB) and M Coleman (IGS). The stable isotope study was funded by a NERC grant.

Chapter One

General Introduction

1.1 General Introduction

The term blackband has for many years been used to describe coal measure carbonaceous ironstones which are dominantly sideritic in composition, have a bedded or layered occurrence and are intimately associated with a coal seam or carbonaceous horizon. The term has also been used to distinguish this type of ironstone from the other commonly occurring coal measure type, the clayband ironstone, which occurs as nodules or discrete thin concretionary horizons, usually parallel to the bedding, in the mudstones or shales surrounding a coal seam. Because of this tendency to develop at discrete horizons the claybands can appear to be bedded or layered and have often been confused with the blackbands especially when occurring very close to a coal seam. Both types of ironstone are developed in the coal measures of the United Kingdom but the blackbands are particularly well developed in the coalfields of north Staffordshire and the Midland Valley of Scotland, being of considerable economic importance in both these areas during the second half of the 19th Century. It was the perfection of the hot-blast process by Neilson in 1828 that opened the way for these relatively thick, though impure ironstones to be utilised in the iron making process. Prior to this they had only been used on a small scale as road metal.

Blackbands also occur in coal measure sequences in other parts of the world, notably in the Pennsylvanian of Ohio, USA and in the Namurian and Westphalian of the Ruhr, Germany.

In the summer of 1976 a company of civil engineering contractors commenced work on an opencast coal site (Mitchell's Wood) at Red

Street near Newcastle-under-Lyme, north Staffordshire. During the succeeding months they exposed the full sequence of measures containing the blackband ironstones (the Blackband Group). This provided an opportunity to study the ironstones *in situ* together with their associated strata and enabled samples of fresh material to be collected for detailed analysis.

A review of the history of research into the blackbands was initially undertaken and this together with the preliminary findings of a detailed study of the ironstones and their containing measures was published in the Transactions of the North Staffs Journal of Field Studies, Volume 18, 1978 (Appendix 1). The study of the strata associated with the ironstones revealed a very interesting relationship between red and grey coal measure facies; a relationship which was hitherto not recognised and one which has considerable bearing on the environment of deposition of deltaic 'red beds'. It also contributes to the understanding of the environment of formation of the blackbands, since, in north Staffordshire it can be demonstrated that the blackband ironstones are closely associated with and laterally equivalent to formations containing 'red beds'. The origin of coal measure red beds of the Etruria Marl facies has been discussed in detail by Besley and Turner (1981).

Results of the detailed petrology and mineralogy of the ironstones from Mitchell's Wood and a nearby private licensed coal mine at Apedale are discussed in Chapter 2. The coal petrography of the Bassey Mine seam is described in Chapter 3 and Chapter 4 contains comments regarding the faunas containing sediments of the blackband ironstones. Chapter 2 also includes details of samples of blackband ironstones encountered in two National Coal Board (NCB) boreholes and those obtained from Hem Heath colliery (NCB) all situated in the south and south-western parts of the exposed north Staffordshire coalfield (Fig 1).

The succeeding Chapter 5 presents and discusses the results of a detailed study of blackband ironstones obtained from borehole cores from Nottinghamshire and Scotland. A comparison is made between these and the north Staffordshire blackbands.

Chapter 6 presents and discusses the results of carbon and oxygen stable isotope determinations carried out on the siderites and discusses the likely mode of formation of the siderite in the ironstones.

Concluding remarks are presented in Chapter 7 and in Chapter 8 recent new provings of some of the north Staffordshire blackbands are described and discussed.

This study presents, for the first time, detailed mineralogical, petrological, sedimentological and stable isotope data which has provided a basis for the formulation of a model for the genesis of blackband ironstones.

1.2 Stratigraphic and Sedimentological Framework

The exposed north Staffordshire coalfield occupies an area of approximately 100 sq miles (267 sq km) centred around the city of Stoke-on-Trent. The coalfield is one of several comprising the Pennine Province of coalfields which extends from Birmingham in the south to north Wales in the north-west and Selby in the north-east.

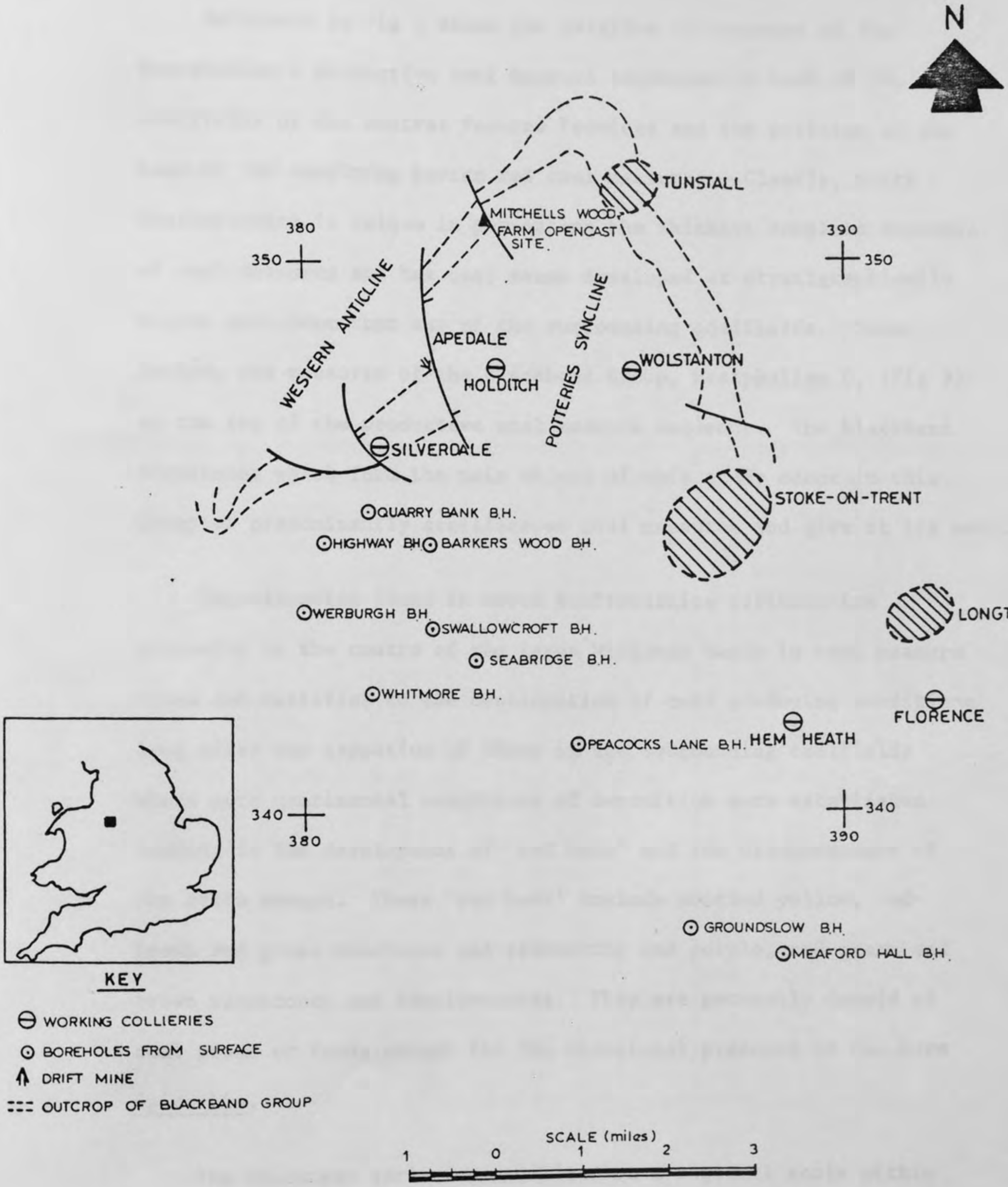


Fig 1 - Location of recent provings of the blackband ironstones in the north Staffordshire coalfield

Reference to Fig 2 shows the relative thicknesses of the Westphalian C productive coal measure sequences in each of the main coalfields of the central Pennine Province and the position of the base of the overlying barren red coal measures. Clearly, north Staffordshire is unique in possessing the thickest complete sequence of coal measures and has coal seams developed at stratigraphically higher positions than any of the surrounding coalfields. These include the measures of the Blackband Group, Westphalian C, (Fig 3) at the top of the productive coal measure sequence. The blackband ironstones which form the main object of this study occur in this Group of predominantly argillaceous coal measures and give it its name.

The situation found in north Staffordshire reflects its proximity to the centre of the large Midlands basin in coal measure times and testifies to the continuation of coal producing conditions long after the cessation of those in the surrounding coalfields where more continental conditions of deposition were established leading to the development of 'red beds' and the disappearance of the delta swamps. These 'red beds' include mottled yellow, red-brown and green mudstones and seatearths and purple, red-green and brown sandstones and conglomerates. They are generally devoid of coal seams or fauna except for the occasional presence of the worm Spirorbis.

The thickness variation exhibited on a regional scale within the coalfields is also evident on a smaller scale within the north Staffordshire coalfield itself. When traced towards the west the productive Coal Measures are reduced in thickness in comparison with those of the central part of the coalfield some 5 km (3 miles) away by about 460 metres (1500 feet). These two areas are also

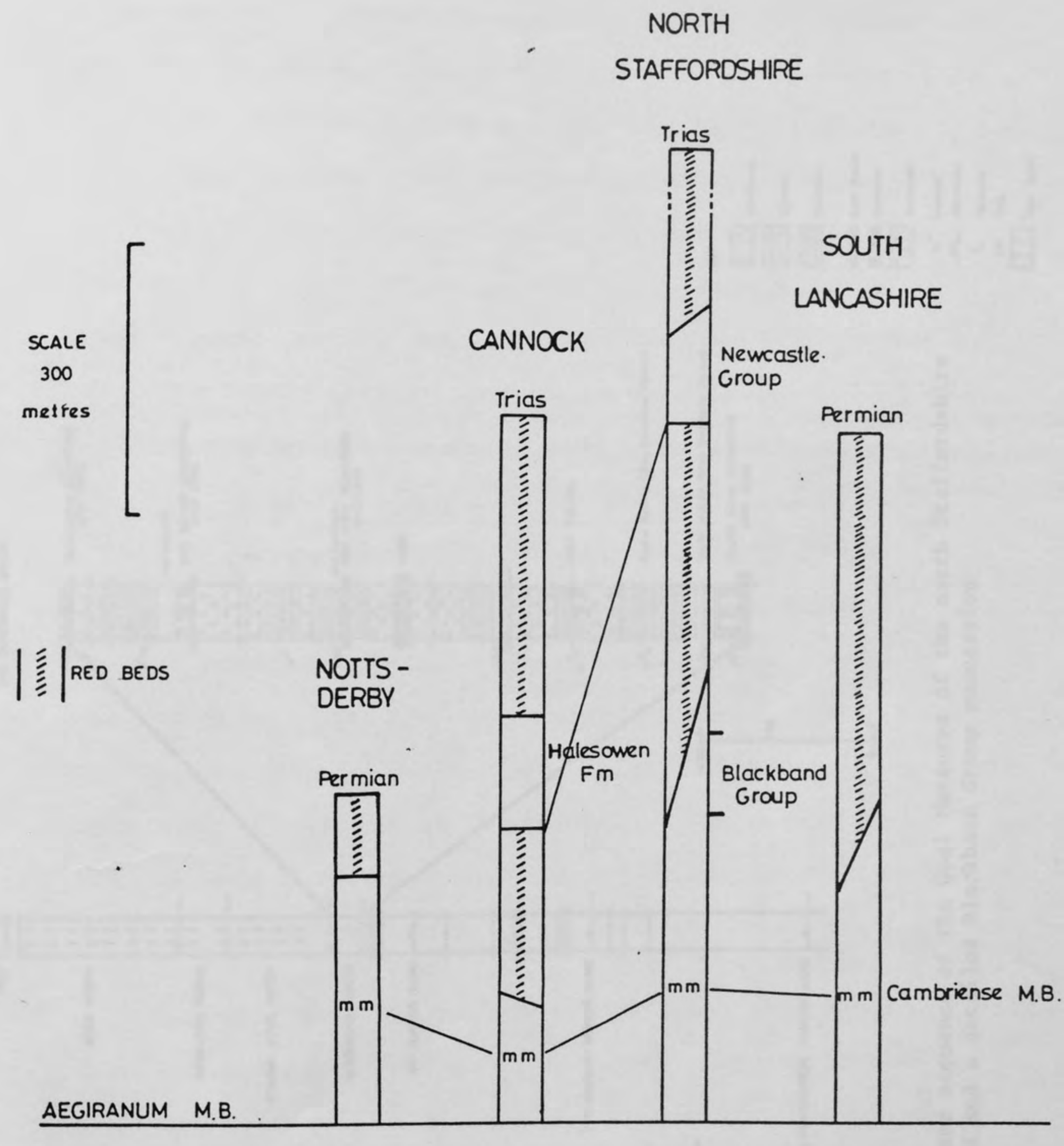


Fig 2 - Comparative sections of Westphalian C and higher coal measures of the central part of the Pennine Province

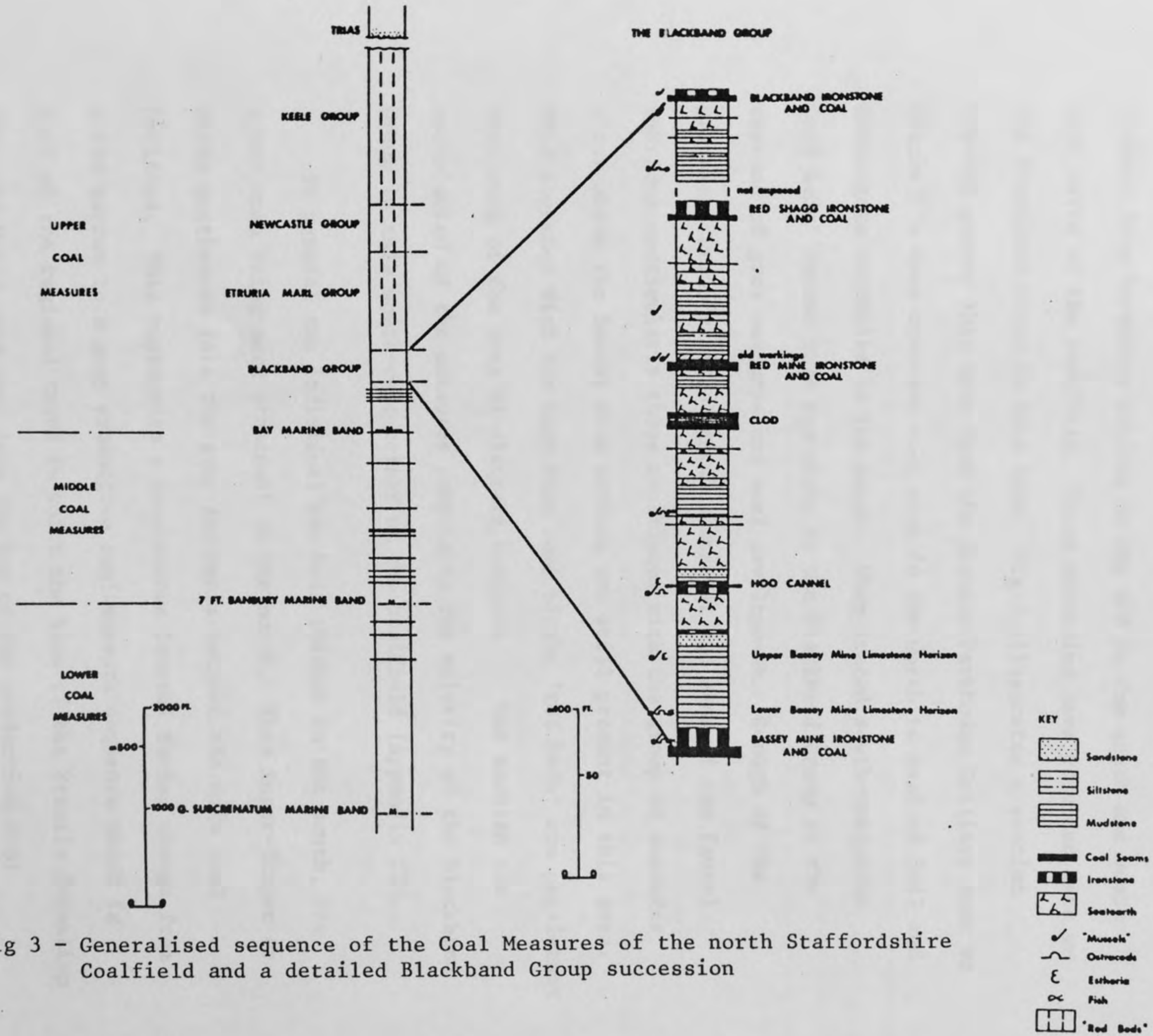


Fig 3 - Generalised sequence of the Coal Measures of the north Staffordshire Coalfield and a detailed Blackband Group succession structurally distinct, the eastern area corresponds to an anticlinal region whereas the central area approximates to the axis of the Potteries Syncline which forms the dominant structural element of the coalfields. A less rapid thinning of the Coal Measures is also evident from boreholes drilled by the NCB in the south and south-west parts of the coalfield. These boreholes have provided data on the Blackband Group in this area. Fig 4 illustrates a section NNW-SSE across this area from the disused Parkhouse Colliery near to Mitchell's Wood opencast coal site in the north to Meaford Hall and Hobbergate boreholes in the south. When traced south-westwards 'red beds' become more prevalent in the Blackband Group at the expense of grey measures and coal development. Enough of the Blackband Group's lithological character and some of the faunal horizons particularly those associated with the group of measures close above the Bassey Mine horizon are still present in this area. This together with the fact that some of the 'red beds' are persistent over much of the area at discrete horizons has enabled the correlation of the measures comprising the majority of the Blackband Group in this south-west corner of the coalfield (Appendix II).

In general the individual 'red-beds' thicken to the south, the upper ones being more prominent in the north. They inter-finger or wedge northwards into the grey sediments between the main coal horizons. This represents a diachronous lateral facies change from a red barren to a grey productive coal measure sequence which is part of the regional trend in which the base of the Etruria Formation (Etruria Marl) cuts down into the top of the productive coal measures when traced southwards towards the then existing Midland Land Mass. The general plan form of the 'red bed' wedges was investigated in this restricted south-west part of the coalfield and although the northerly limit of the wedges could in most cases be fairly well defined their individual plan forms appeared rather irregular (Fig 4, Appendix I). Some of the wedges appear to be convex north and others convex south. Further work regarding the extent of the wedges by Besley (personal communication) over a larger area of the coalfield has established that all are generally convex northwards representing a prograding of 'red beds' from south to north. A study of the sedimentary structures in some of the Westphalian C sand bodies by Besley has also indicated a northerly palaeocurrent direction.

The 'red beds' are demonstrably primary and indicate sedimentation under oxidising conditions and subsequent oxidation of the sediment during diagenesis. In recent years a process involving the intrastratal dissolution of unstable ferromagnesian minerals and the consequent precipitation of a suite of authigenic minerals including haematite, have been invoked for the origin of 'red beds' of moist tropical climates (Walker, 1974). There is however a lack of detailed studies of the transport and diagenesis of iron in humid tropical climates and also of examples in the geological record. Recent work by Besley and Turner (1981) has shown convincing evidence for the reddening of the Etruria Marl facies to have originated at or soon after deposition by the dehydration of detrital ferric hydroxides and the oxidation of ferrous iron associated with organic material; the oxidation taking place during the development of well drained soils on an alluvial surface, preserved in the sediment as complex palaeosols.

The blackbands occur in the Blackband Group which forms the

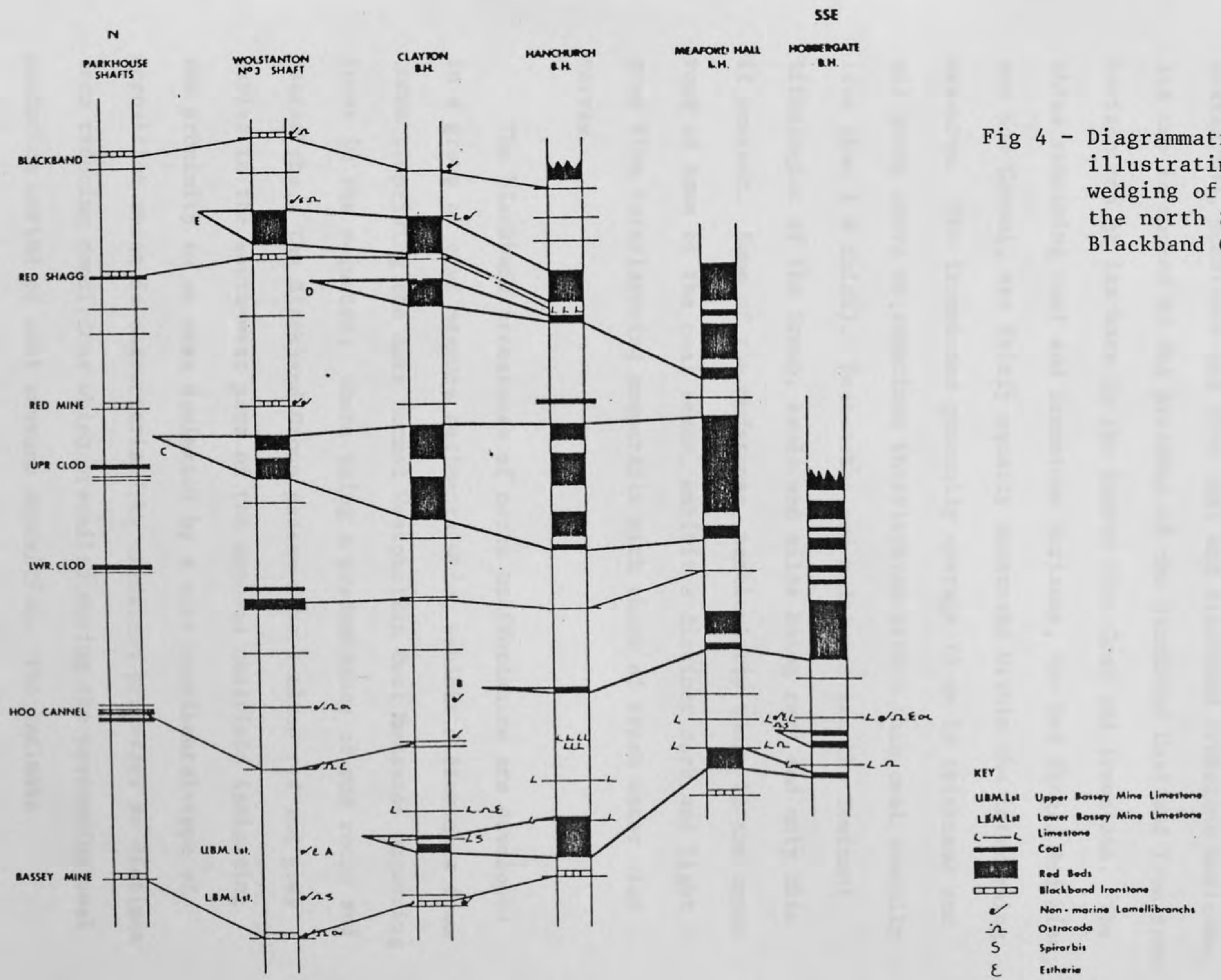


Fig 4 - Diagrammatic cross-section illustrating the inter-wedging of 'red beds' into the north Staffordshire Blackband Group succession uppermost grey Coal Measures in the Westphalian of north Staffordshire. In the Mitchell's Wood opencast coal site the Blackband Group is about 85 m (280 feet) in total thickness, and comprises mainly grey seatearths, mudstones and five coal and blackband ironstone horizons. Its top is marked by the presence of the Blackband Coal and Ironstone horizon and at its base is the Bassey Mine Coal and Ironstone. The three remaining coal and ironstone horizons, the Red Shagg, Red Mine, and Hoo Cannel, are fairly equally separated within the intervening measures. The ironstones generally average 75 cm in thickness and all occur above or sometimes interlayered with a thin coal (usually less than 1 m thick). Seatearths and mudstones are the dominant lithologies of the Group, sands and silts being rare and only thin if present. Some of the mudstones, particularly those in the upper roof of some of the coal seams, exhibit a distinct dark and light grey fine interlayering comparable with those of fresh water clay varves.

The blackband ironstones of north Staffordshire are developed in a group of coal measure sediments which exhibit differences from those comprising the more normal Westphalian Coal Measures occurring lower in the sequence; there being a predominance of mud rocks and seatearths. The Blackband Group passes into a mixed red and grey series in the south-west part of the exposed coalfield indicating the proximity to an area dominated by a more continental-type of deposition which is characterised by oxidation processes as distinct from reducing conditions which prevailed during the preceeding coal producing period of coal measure deposition. The intimate association of the ironstones with a coal seam horizon strongly suggests a common generic link between their respective environments of formation. The sedimentary evidence particularly the varve-like appearance of many of the mudstones, points to a lacustrine environment within and upon the main coal forming peat blankets.

Chapter Two

The Detailed Mineralogy and Petrology of the Blackband Ironstones of the North Staffordshire Coalfield

Blackband Ironstones of North Staffordshire - Their Detailed Petrology and Mineralogy

2.1 Introduction

Historically, ironstones of Carboniferous age have played an important part in the industrial development of this country. They have attracted the attention of geologists and mining engineers who have commented on their physical and chemical characteristics and have suggested modes of formation as a result of their observations. The clay-ironstones, being the most common, as would probably be expected, have attracted the most attention, whereas, in contrast, the blackband ironstones have been subjected to much less detailed scrutiny.

The blackband ironstones appear to have been restricted in economic development in the United Kingdom to the coalfields of the Midland Valley of Scotland and North Staffordshire. Those of the latter coalfield have been found to differ very markedly in texture, mineralogy and faunal and lithological associations from the clay-ironstones.

During the summer of 1976, the Shirland Fireclay Co Ltd of Chesterfield commenced work on an opencast coal site at Mitchell's Wood (E3832 N3509), Red Street, near Stoke-on-Trent in North Staffordshire, providing an opportunity to study freshly exposed blackband ironstones of this coalfield for the first time in many years.

The following is an account of the detailed petrology and mineralogy of the ironstones exposed in this quarry. Blackband ironstones from Apedale Colliery a nearby private mine, Hem Heath Colliery (NCB) 6 km (3¾ miles) south-east of Newcastle-under-Lyme, and two NCB deep boreholes in the south-west of the coalfield (Fig 1) have also been sampled and studied.

2.2 Sample Collection and Preparation

Mitchell's Wood opencast coal site is situated some 7 km (4½ miles) north-west of Stoke-on-Trent. Overburden stripping commenced in June 1976 at the southern end of the site exposing the uppermost of the four main blackband ironstone horizons, the Blackband Coal and Ironstone outcropping under a thin (approx 3 metres) cover of Boulder Clay. The coal was worked in a series of 'lifts' down dip to a total depth of about 21m (70 ft) below original ground level; the seam dipping at 22° to the south-south-east. The Red Shagg Coal and Ironstone outcrop was then located and was similarly worked, as were the Red Mine, Hoo Cannel and Bassey Mine coal seams; the ironstones forming the immediate roof measures of the seams being discarded (Fig 5).

Complete representative samples, pillar samples, were obtained from each of the ironstones. The intervening measures were logged in detail in order to establish the correlation of the coal and ironstone horizons with those of the surrounding coalfield.

Care had to be exercised in the selection of sampling locations as some of the ironstones and coals had previously been extensively worked. Sampling in the active opencast site was also made difficult by the excessive scree cover of many parts of the pit sides and poor exposure in the active scraping area itself. Pillar

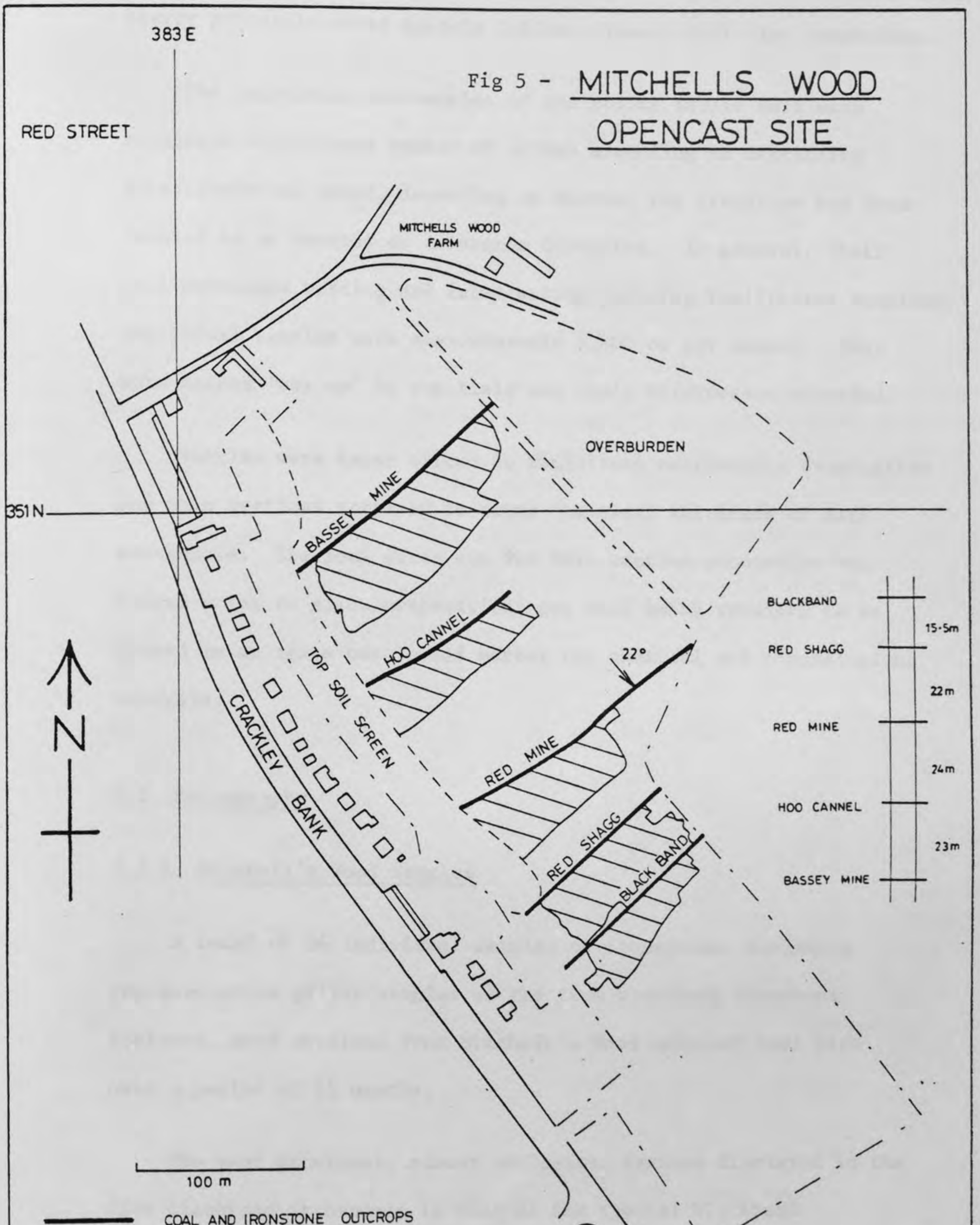


Fig 5 - MITCHELLS WOOD OPENCAST SITE

samples of the Bassey Mine Ironstone were also obtained from the nearby privately owned Apedale Colliery (see 2.3.2) for comparison.

The individual sub-samples of the pillar sample were each allocated a reference number of either ascending or descending stratigraphical order, depending on whether the ironstone had been sampled in an upwards or downwards direction. In general, their well-developed bedding and intersecting jointing facilitated sampling. Individual samples were approximately 1,000 cc per sample. They were marked 'way up' in the field and their thicknesses recorded.

Samples were later sliced to facilitate macroscopic examination and thin sections prepared to cover the total thickness of each sub-sample. The rock slice cut for thin section production was halved prior to slide preparation; one half being retained to be ground in an agate pestle and mortar for chemical and mineralogical analysis.

2.3 Petrography

2.3.1 Mitchell's Wood Samples

A total of 86 individual samples of ironstones, including representative pillar samples of the five blackband ironstone horizons, were obtained from Mitchell's Wood opencast coal site over a period of 11 months.

The most prominent, almost exclusive, texture displayed in the five blackband ironstones is that of the typical blackband character - a fine interlayering of grey, dark grey and pale brown layers, averaging 7 mm in thickness, ranging from 1-15 mm (Plate 1).

It is not surprising that past researchers have drawn analogy between this marked fine interlayering and the varve-like texture produced in some Lacustine environments (Stout 1944). In many cases the mudstones close above the coal and ironstone horizons are very markedly finely laminated with alternating dark and light grey laminae (Plate 2). These very closely resemble lacustrine clay varves (Bradley 1929, Picard and High 1972). All the blackband ironstones sampled rested directly on a coal seam, usually with a sharp planar base, although some very fine interlamination was noted at the base of the Bassey Mine Ironstone at one sampling location.

The detailed veritical sections of the five major coal and ironstone horizons exposed in Mitchell's Wood opencast site are shown in Table 1.

Blackband		Red Shagg		Red Mine		Hoo Cannel		Bassey Mine	
M		SE/M		Old Workings		M		M	
IS	10	IS	149	IS	45	IS	19	IS/M	13
C	18	C	72	C	38	IS/M	38	IS	20
IS	73	SE/M		IS/CC	23	IS	10	C	1
C	40			Floor not seen		C	9	IS	8
SE/M						SE/M		CC	2
								C	20
								M/C/CC	15
								C	53
								M/C	3
								SE/M	

Table 1 - Details of the five major coal and ironstone horizons Mitchell's Wood, north Staffordshire

Abbreviations:- M - mudstone, IS - ironstone (blackband), C - coal, CC - cannel coal, SE - seatearth.

(thicknesses in cm)

The Blackband Ironstone differs from the other ironstone horizons in containing a thin coal towards its top. The immediate 35.5 cm of ironstone below this coal has a very disturbed seatearth texture, a 'seatearth' ironstone (Plates 3 and 4). This texture passes down into a layered nodular texture for 21 cm, the nodules themselves exhibiting an internal layering similar to that of the typical blackband layering mentioned above. Below, the layered/banded texture is again dominant but in places is disturbed by sub-vertical discontinuities which are interpreted as disturbances resulting from root penetration. These reduce in intensity downwards and are peculiar to this ironstone.

The Red Mine Coal seam at Mitchell's Wood contains a 23 cm thick cannel layer within the seam and in this layer occurs elongate lenticular and discretely nodular layers of siderite (Plate 5) very similar in appearance to those of the nodular layer below the Blackband 'seatearth' ironstone referred to above. The mode of formation of this intra-seam ironstone texture appears to be very similar to that of the nodular layer in the Blackband Ironstone, ie formed by the penetration of rootlets breaking up the discrete siderite layers into a series of nodular bodies or lenticles.

The ironstone above the Red Mine Coal, the Red Mine Ironstone, on the other hand, exhibits the typical blackband layered character exlcusively as also do the Red Shagg and Bassey Mine Ironstones.

In thin section, the ironstones are in the main composed of light brown peloids of siderite ranging in size up to 150 μm, often exhibiting a paler coarser overgrowth (Plate 6). The banded or layered macro-texture of the ironstone can be seen to be the result of a variation in the density of the siderite peloids in a spore-rich, carbonaceous matrix (the large spores being flattened with their long axes parallel to the bedding). The siderite is always exclusively observed in association with this type of matrix which represents a sapropelic coal development. This is in sharp contrast to the bright and dull humic coals forming the bulk of the coal seams immediately underlying each of the ironstones.

Many of the ironstone subsamples contain bright yellow oval-shaped oil algae comparable with those previously described from algal cannel coals and torbanites (Sprunk 1941, Trotter 1950). The occurrence of these algae varies considerably from rare to abundant. The Red Mine Ironstone, in particular, contains a thin layer with many oil algae towards the top of the sampled section (Plate 7). Oil algae are also common throughout the Hoo Cannel Ironstone in both the carbonaceous and siderite-rich layers. Further evidence of algal activity is furnished by the presence of very small ($< 50\mu m$) algal borings at one horizon in the Blackband Ironstone (Plate 14). Neither the likely genus nor its environment of life are known for this algae and therefore no significant conclusions can be reached concerning its presence.

Both these algal forms are very distinct from those described by Pollard and Wiseman (1971) occurring at the base of the Newcastle-under-Lyme Formation (Westphalian D) some few hundreds of metres higher in the Upper Coal Measure sequence at the nearby Metallic Tileries quarry, Chesterton (E3839 N3499). These Westphalian D algae have been ascribed to the genus Girvanella which has marine affinities.

In addition to its peloidal mode of occurrence, siderite is also present spasmodically in small (up to a few mm in diameter) microcrystalline aggregates in all the ironstones sampled from Mitchell's Wood site. In many of these aggregates the outlines of the cells making up fragments of planty tissue are preserved in a dark brown carbonaceous residue (Plate 8).

Poorly preserved rounded 'ghosts' are also present (Plates 9 and 10). These occur as larger rounded siderite bodies set in a fine grained matrix and they are commonly associated with large plant or animal fragments. Such bodies have often been interpreted as faecal pellets (Pettijohn 1957, Bathhurst 1971) although in this case the lack of consistent size, their varying shape and absence of any convolutions or axial elongation would appear to rule out such an interpretation for their origin. Similar 'ghosts' have been observed in a blackband-type ironstone from Nottinghamshire and the details of this, and the possible mode of formation of these 'ghosts' are discussed later.

With regard to macro-fauna, sideritised non-marine lamellibrachs (commonly including Anthraconauta phillipsi) and ostracod shells and fragments are occasionally present, particularly in the uppermost subsections of the ironstones. Some of the non-marine lamellibranch valves are articulated and comprise chains of prismatic crystals. These are remnants of the middle prismatic layer or ostracum of the original three-layer mollusc shell (Fig 6 and Plate 11). In addition fish fragments have also been identified including occasional spines and scales.

To summarise, then, the blackband ironstones sampled from this opencast coal site in north Staffordshire exhibit dominantly the typical layered blackband character resulting from alternating

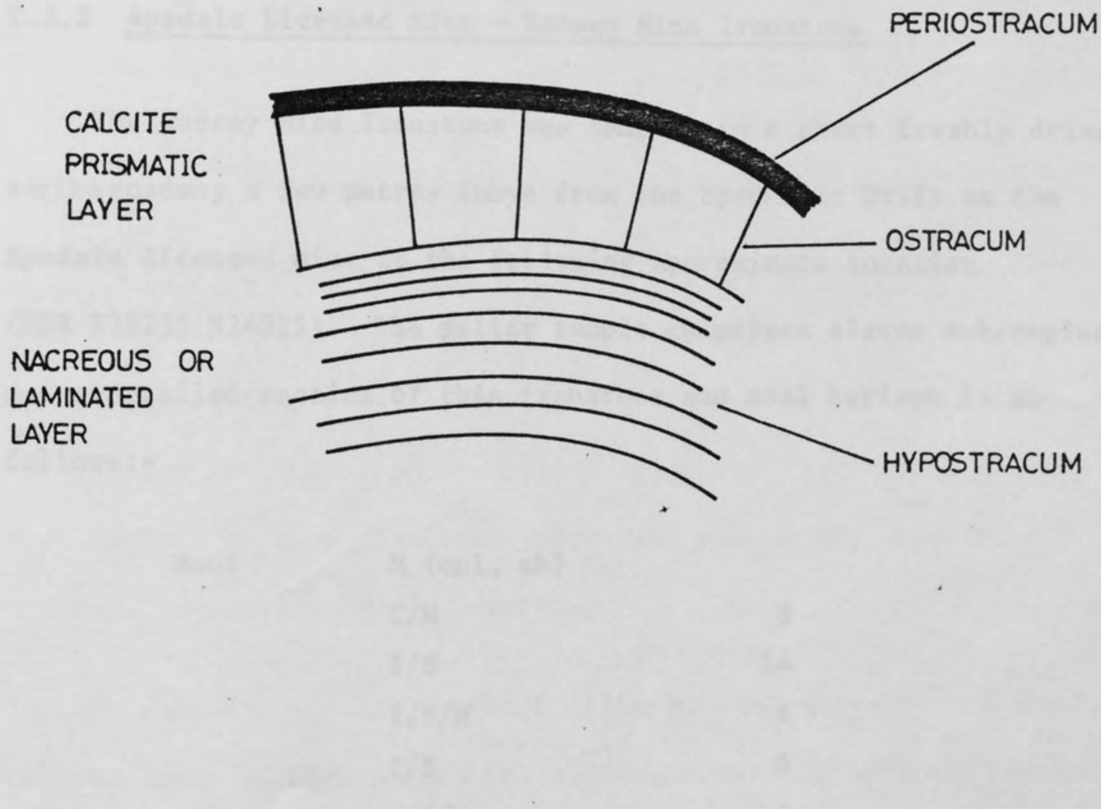


Fig 6 - Non-marine lamellibranch shell structure (cross-section) siderite and carbonaceous rich layers; the siderite occurring commonly as peloids in the carbonaceous, sapropelic matrix which also contains some oil algae, occasional mollusc tests and fish fragments. Planty tissue together with the mollusc and fish debris is associated with small micritic aggregates.

It is interesting to compare the detailed features exhibited in these ironstones with those of the Bassey Mine Ironstone at the nearby Apedale licensed mine.

2.3.2 Apedale Licensed Mine - Bassey Mine Ironstone

The Bassey Mine Ironstone was sampled in a short freshly driven strike roadway a few metres inbye from the Spencroft Drift at the Apedale licensed mine at the following approximate location (NGR E38235 N34815). The pillar sample comprises eleven subsamples and a detailed section of this ironstone and coal horizon is as follows:-

Roof	M (cnl, cb)	
	C/M	8
	I/S	14
	I/S/M	4
	I/S	5
	I/S/M	6
	I/S	5
	M (with lenticular I/S)	33
	I/S	14
Bassey Mine Coal	C	79
Bassey Mine Coal	SE/M	10
Bassey Mine Coal	C	30
Floor		

I/S = ironstone, C = coal, M = mudstone, SE = seatearth, cnl = cannel, cb = carbonaceous.

X-ray diffraction analysis of powdered samples from these subsections revealed a more complex mineralogy than any of the Mitchell's Wood samples previously described. Several carbonate species were identified and as a consequence one half of each thin section was treated with a solution of Alzarin Red S and potassium ferricyanide (Dickson 1965) for carbonate identification. The different carbonate species are identified as follows:-

carbonate	stain
calcite	pink
ferroan calcite	mauve to Royal Blue
ferroan dolomite	pale to deep greenish-blue
dolomite	unstained
siderite	unstained

In hand specimen the Bassey Mine Ironstone from Apedale differs from the Mitchell's Wood samples in that much calcareous shell debris is present forming discrete layers and the characteristic blackband layering or banding is not so well developed. The Apedale samples also contain more argillaceous layers and some large, very fine grained lenticular siderite masses.

In thin section the striking difference between the samples is the abundance of layers rich in calcareous non-marine lamellibranch shell debris and the absence of a dominant peloidal texture. Peloids are, however, occasionally developed in thin layers where they grade into the carbonaceous matrix. Many of the shells are articulated and many exhibit a calcareous prismatic layer (Plates 11 and 12) as previously noted in a few of the Mitchell's Wood samples. Here, though some of the larger prismatics bear evidence of growth in the form of fine growth lines (Plate 13). Many of these chains of prismatic crystals are associated with a thin layer of ferroan calcite which is usually restricted to either the upper or the lower margin of the chain. Isolated articulated lamellibranchs show this to be a replaced remnant of part of the original shell structure (nacreous layer). The association of the ferroan calcite and the prismatics can be observed in a cross-section of one of the articulated shells.

Starting from the outside of the shell the following sequence is observed: 1. calcareous prismatic layer, 2. ferroan calcite layer, 3. internal fill (usually fine grained siderite with voids filled with ferroan calcite), 4. ferroan calcite layer, and 5. calcareous prismatic layer (Plate 15). The ferroan calcite layer clearly represents the inner nacreous layer of the lamellibranch shell. Ferroan calcite also occurs in sub-vertical veins truncating many of the Apedale Bassey Mine sub-samples. It cuts across all layers and clearly represents a later, post depositional phase of mineralisation. The nacreous layers also occasionally contain localised patches where they have been bored by algae (Plate 14) similar to those already observed from Mitchell's Wood.

Small lenticular patches of small calcareous nodules also occur in this ironstone. These exhibit an extinction cross under crossed nicols indicating radial arrangements of crystals.

Like the Mitchell's Wood samples, scattered oil algae, flattened spores and fish debris are also present. In addition, the Apedale samples contain thin lenticular layers of fine grained siderite containing scattered mollusc shells, chains or aggregates of shell prisms, ostracods and occasional Spirorbis.

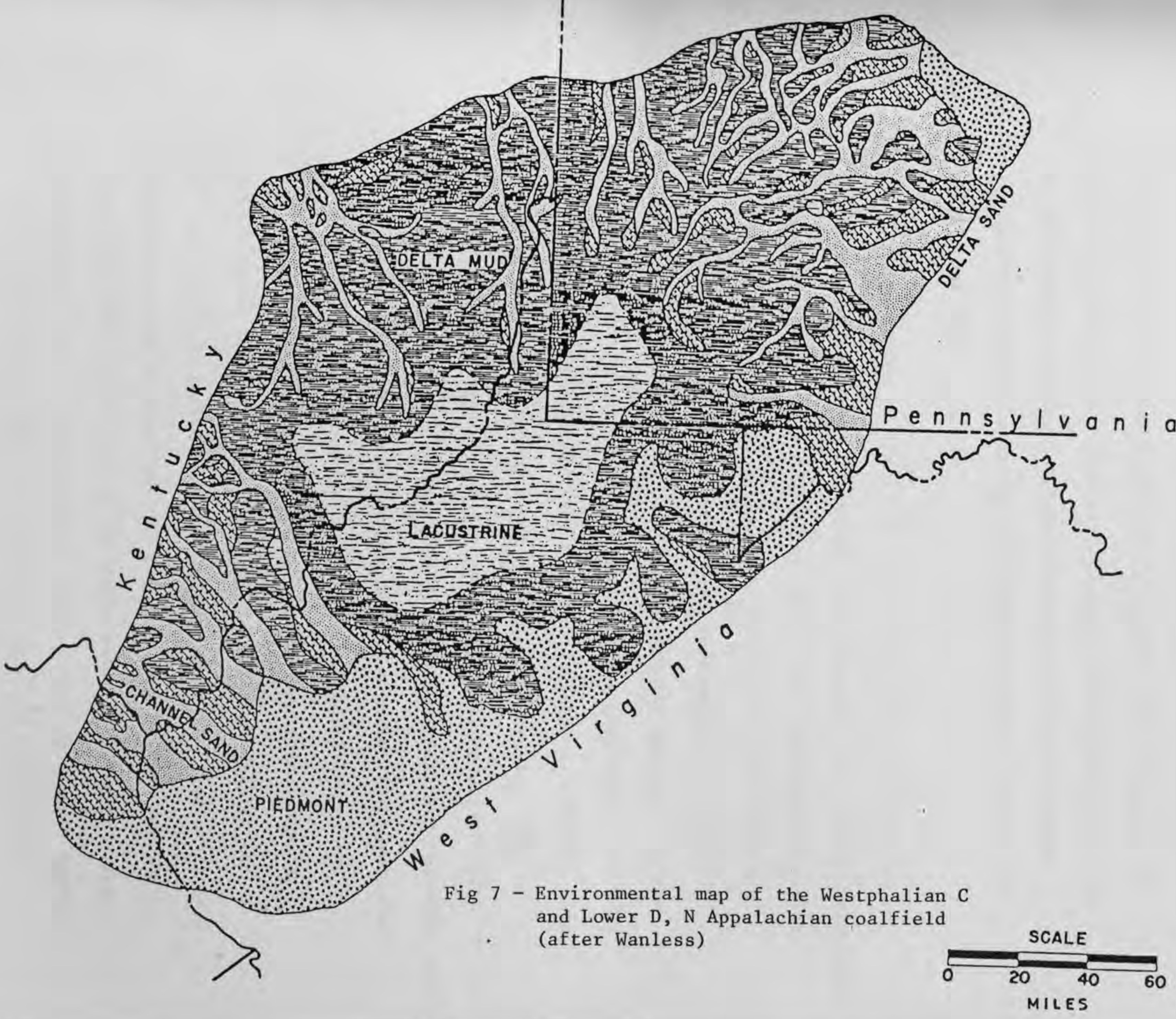


Fig 7 - Environmental map of the Westphalian C and Lower D, N Appalachian coalfield (after Wanless)

2.4 Comparison of the Apedale and Mitchell's Wood Samples

The mineralogy textures and abundant fauna of the Apedale samples contrasts markedly with the Mitchell's Wood samples. The former are argillaceous, shelly, calcareous ironstones with a rich lamellibranch and *Spirorbis* fauna as opposed to the dominantly carbonaceous siderite ironstone as exemplified by the latter, the typical blackbands.

The association of lime-rich rocks with siderite ironstones of a blackband character has previously been recorded from the Pennsylvanian of Ohio, USA (Westphalian C/D)(Stout 1944). The limestone occurring in association with the ironstones was considered to be the result of deposition in a deeper portion of the sedimentary basin where the water was 'clearer'. No petrological details of the limestone or ironstones nor their faunal associations are published. The term 'shell ore' used to describe some of these ironstones, however, does suggest an ironstone similar to that sampled at Apedale. The sedimentological evidence from the group of strata associated with these 'shell ores' and a description of the ironstones does indicate a blackband-type of ironstone development in a lacustrine environment (Fig 7). The evidence for the environment of deposition of the north Staffordshire blackbands including the lacustrine varving, attenuation of the Blackband Formation and the interrelation of 'red beds' clearly indicates that the developments of the calcareous facies was on the landward edge of the grey Coal Measure forming basin, presumably in an area of shallower water with higher oxygen availability nearer to the sediment source. This conclusion appears to be at variance with the interpretation proposed for the Ohio calcareous ironstones - if indeed they can be compared - a fact which on the published evidence must still remain in doubt.

The Ohio State University was approached in the course of this study but were unable to provide material for examination.

2.5 Detailed Mineralogy

The sub-samples of each ironstone sample were cut perpendicular to the bedding and a representative slice produced from each. The slice was then cut into two roughly equal portions again in a direction normal to the bedding but at right angles to the original cut producing two thin slices each representing a very similar representative sample of the subsection of the ironstone. One was mounted for the production of a thin section and the other powdered to facilitate X-ray diffraction and atomic absorption analysis.

2.5.1 X-ray Diffraction Analysis

This was carried out using Ni filtered $CuK\alpha$ or $CoK\alpha$ radiation on powders of the duplicated halves of the subsection slices. Scanning was generally carried out over the range $2\theta = 20\text{-}35^{\circ}$ for the main carbonate peaks, although some samples were scanned at lower angles.

As anticipated, the dominant mineral species in most cases was identified as siderite (Fig 8) with an average d-spacing for the major peak (211) of 2.81 Å for the four Mitchell's Wood blackband ironstones and 2.82 Å for the Apedale sample. In the Mitchell's Wood samples only occasional minor peaks for quartz, dolomite and calcite were identified in addition to the siderite peaks. Rarely goethite peaks were also noted for samples which exhibited some

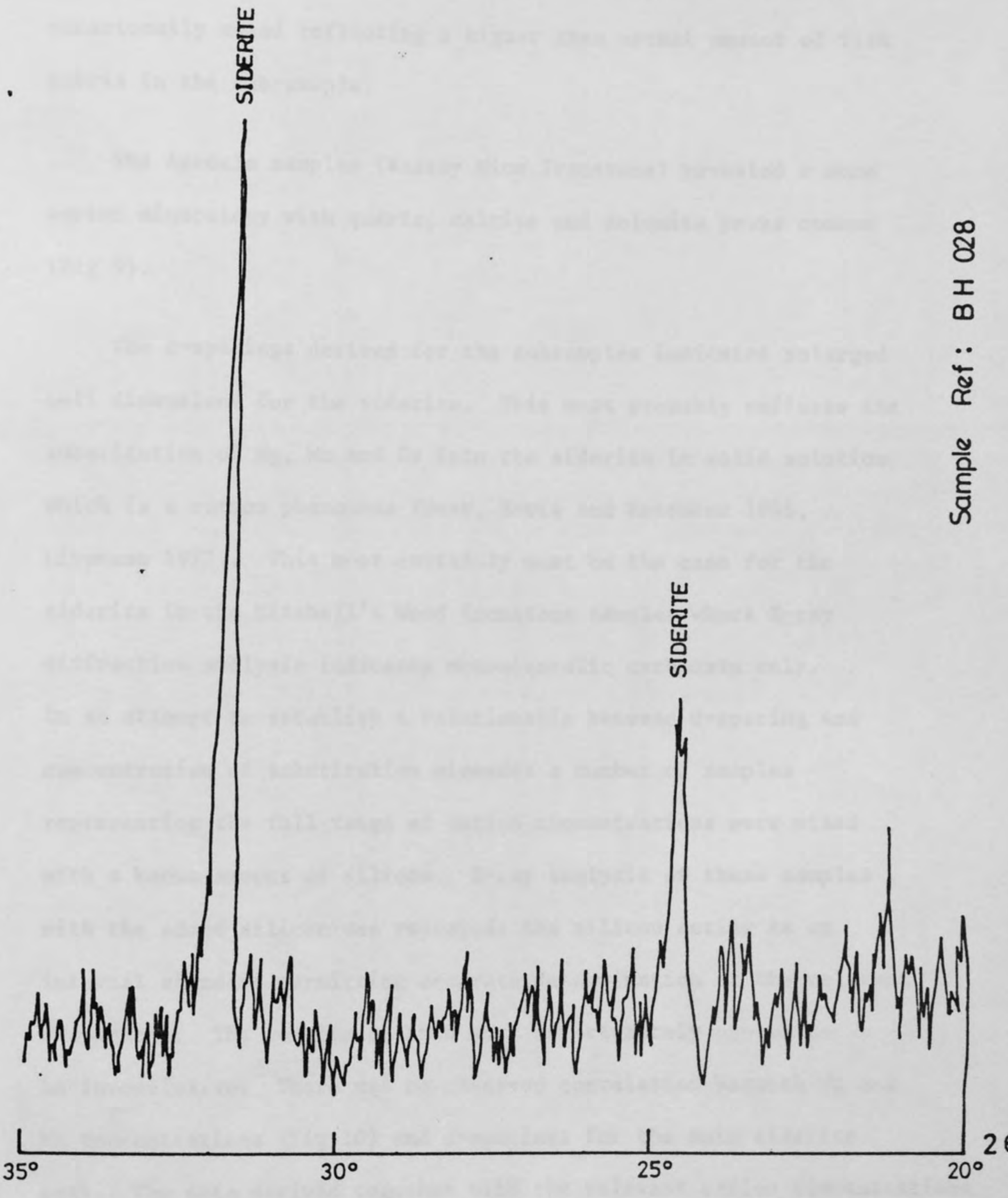


Fig 8 - X-ray diffraction graph (CuKα) Red Shagg Ironstone, Mitchell's Wood, north Staffordshire oxidation in hand specimen. The presence of apatite was also occasionally noted reflecting a higher than normal amount of fish debris in the sub-sample.

The Apedale samples (Bassey Mine Ironstone) revealed a more varied mineralogy with quartz, calcite and dolomite peaks common (Fig 9).

The d-spacings derived for the subsamples indicates enlarged cell dimensions for the siderite. This most probably reflects the substitution of Mg, Mn and Ca into the siderite in solid solution which is a common phenomena (Deer, Howie and Zussmann 1966, Lippmann 1973). This most certainly must be the case for the siderite in the Mitchell's Wood ironstone samples where X-ray diffraction analysis indicates monomineralic carbonate only. In an attempt to establish a relationship between d-spacing and concentration of substitution elements a number of samples representing the full range of cation concentrations were mixed with a known amount of silicon. X-ray analysis of these samples with the added silicon was repeated; the silicon acting as an internal standard permitting accurate determination of the relevant d-spacings. The results of this work unfortunately proved to be inconclusive. There was no observed correlation between Mg and Mn concentrations (Fig 10) and d-spacings for the main siderite peak. The data derived together with the relevant cation concentrations is tabulated below (Table 1). One can only presume that i) the variations observed were not sufficiently above the levels of experimental error, or ii) other sources of Mg and Mn are present in the ironstones other than that substituted in the siderite eg in the argillaceous matrix, or iii) a combination of these two

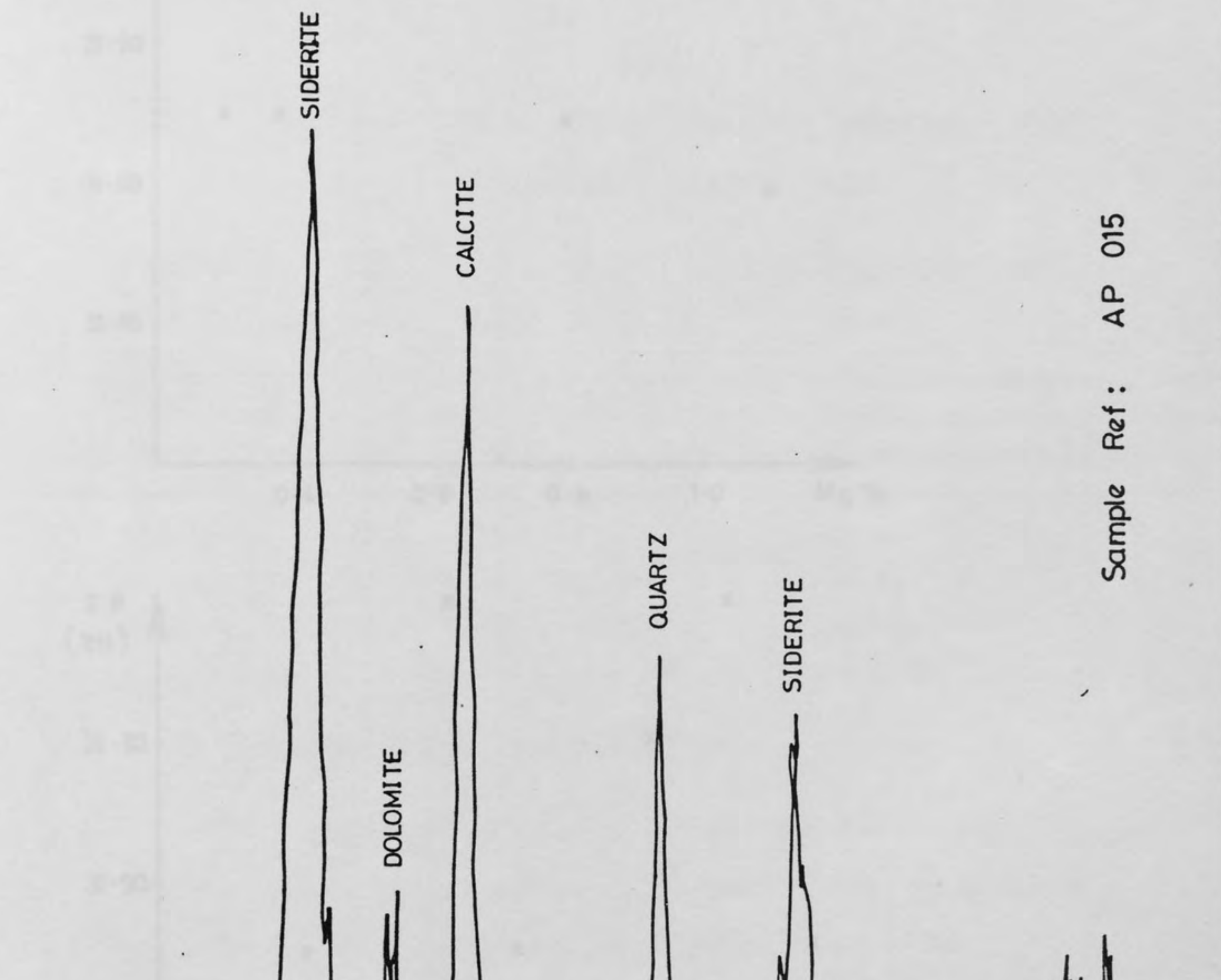


Fig 9 - X-ray diffraction graph (CuK∝) Bassey Mine Ironstone, Apedale licensed mine north Staffordshire

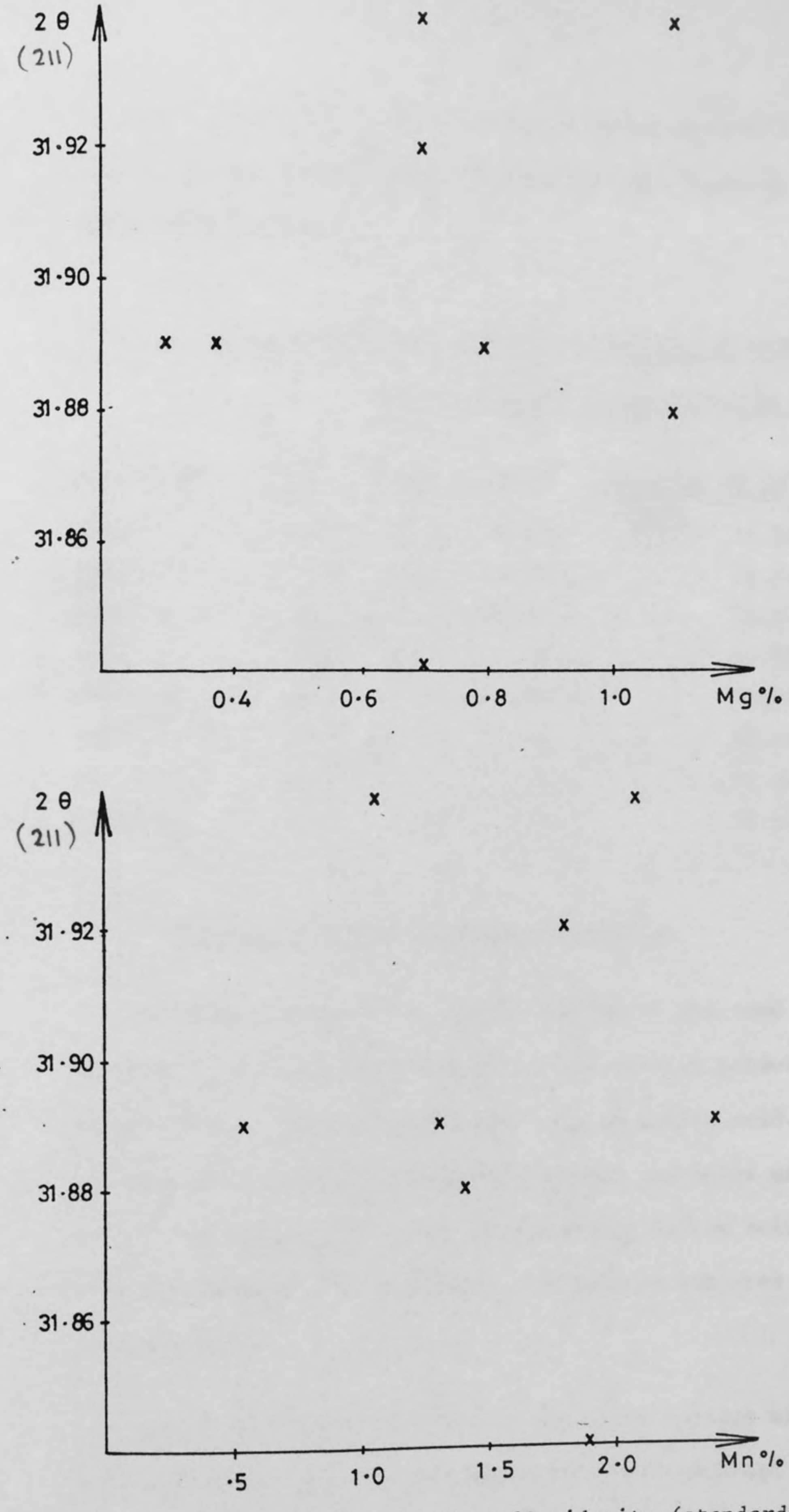


Fig 10 - Plot of Mg% and Mn% vs 2θ siderite (standardised) for selected blackband ironstone samples factors. Further work on a separated siderite fraction of these ironstones may prove useful in shedding more light on their detailed mineralogy.

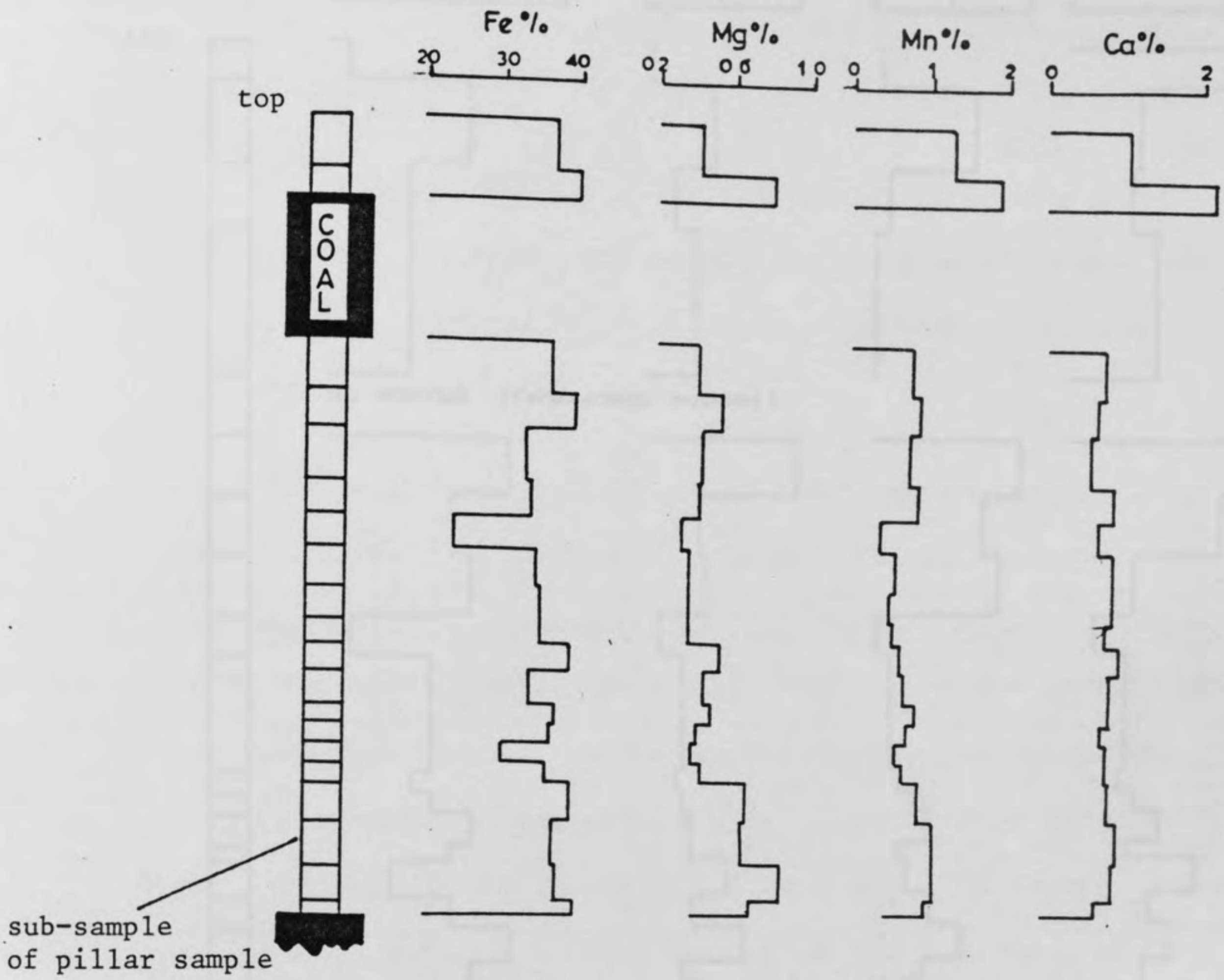
Table 1 - Data from X-ray diffraction analysis of selected samples with a silicon internal standard

Sample Ref	Fe%	Mg%	Mn%	Siderite 2θ (standardised) (211)
BH007	34.8	0.38	0.53	31.89
BH014	39.8	0.70	1.05	31.94
BH002-1	39.6	0.70	1.88	31.84
BH036	20.0	0.30	1.30	31.89
BH034-2	32.5	1.10	2.10	31.94
BH0236-2	25.0	0.70	2.40	31.89
BH030	17.5	1.10	1.40	31.88
BH031-1	32.5	0.70	1.80	31.92

2.5.2 Results of Atomic Absorption Analysis

A Perkin-Elmer 460 AA spectrophotometer was used for the analysis. Analyses were carried out by firstly producing a lithium borate fusion and then dissolving this in nitric acid. For calcium determinations lanthanum chloride was added as a spike to both standards and solutions of the sample before being introduced into the oxygen/acetylene flame. A N_2O flame was used for Mg determinations.

The detailed distribution of the major cations within the four ironstones sampled from Mitchell's Wood opencast site are detailed in Figs 11a and 11b. All the ironstones exhibit an increase in iron, manganese and magnesium towards the underlying or enclosed coal seam or carbonaceous layers. Calcium on the other



Blackband Ironstone, Mitchell's Wood
Vertical distribution of cations

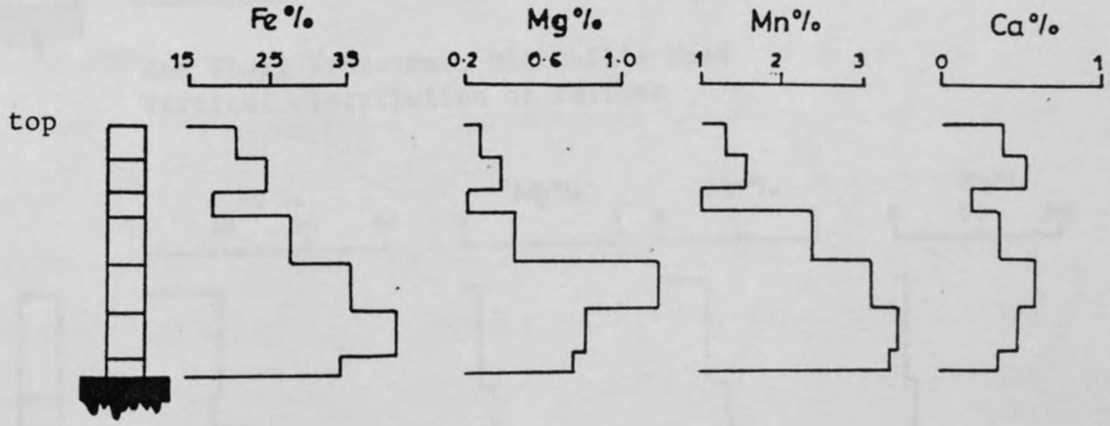
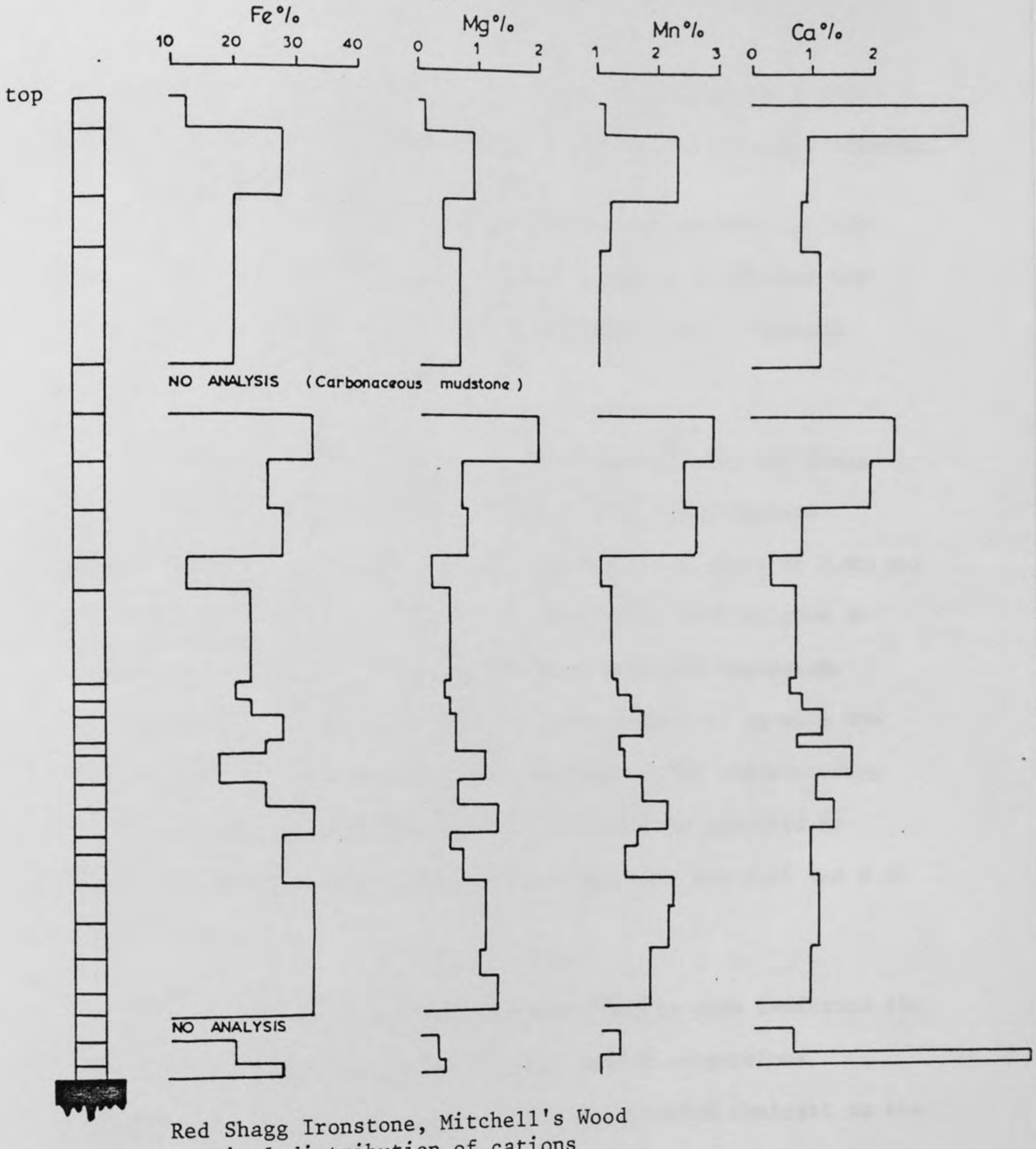


Fig 11 a)

VERTICAL SCALE 10cm

Red Mine Ironstone,
Mitchell's Wood



Red Shagg Ironstone, Mitchell's Wood
Vertical distribution of cations

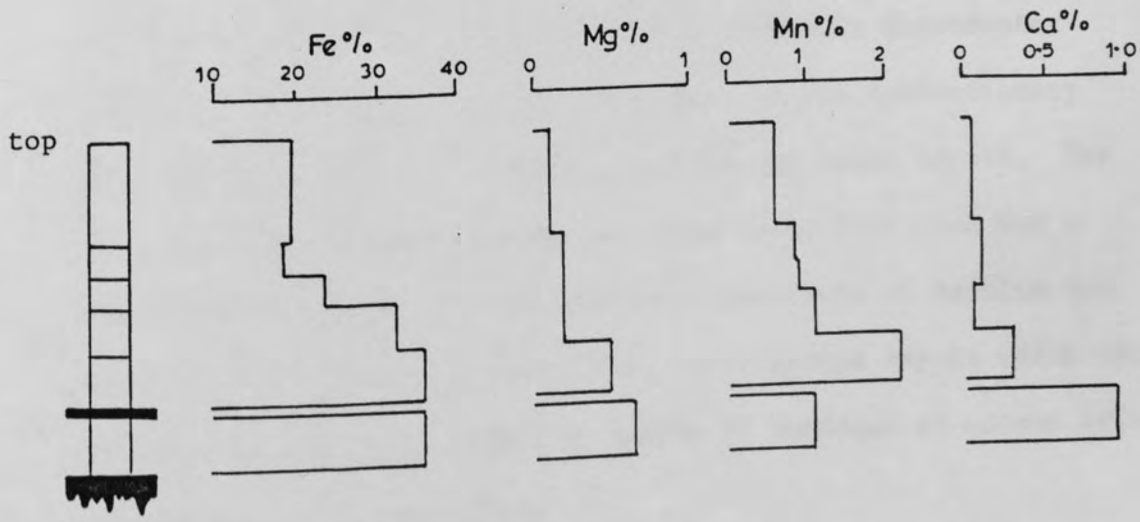


Fig 11 b)

Bassey Mine Ironstone,
Mitchell's Wood

hand appears to be more randomly distributed although to a first approximation there is a similarity in the shape of its distribution.

Statistical analysis of the atomic absorption data for the two thickest blackbands was carried out using an HP-85 desk top calculator. A paired sample analysis program from a standard statistics pack was utilised.

The results of the analysis of the Blackband and Red Shagg data confirms a good correlation between iron and manganese concentrations with a coefficients of correlation (Rxy) of 0.65 and 0.67 for the respective ironstones. Rxy values were as good at 0.60 and 0.68 for the correlation between iron and magnesium. Fig 12 shows the plotted data for Fe vs Mn and Fe vs Mg with the line of best fit for the Blackband Ironstone. The corresponding figures for iron vs calcium, however, as would be expected by inspection of Fig 11a are poorer, these are only Rxy 0.31 and 0.25 respectively.

The similarity in shape of the distribution also indicates the existence of fairly consistent relative cation proportions throughout the sampled sections. This is in marked contrast to the analyses from a clayband ironstone from the Westphalian of Yorkshire (Curtis et al 1975). These indicate a change in groundwater chemistry with time, with the inner part of the concretionary band having a different composition from the outer layers. The inner earlier formed siderite was found to be iron rich but a progressive increase in the relative proportions of calcium and magnesium was evident in the outer, later formed layers which were presumed to have been formed at depths of hundreds of metres below the sediment water-interface.

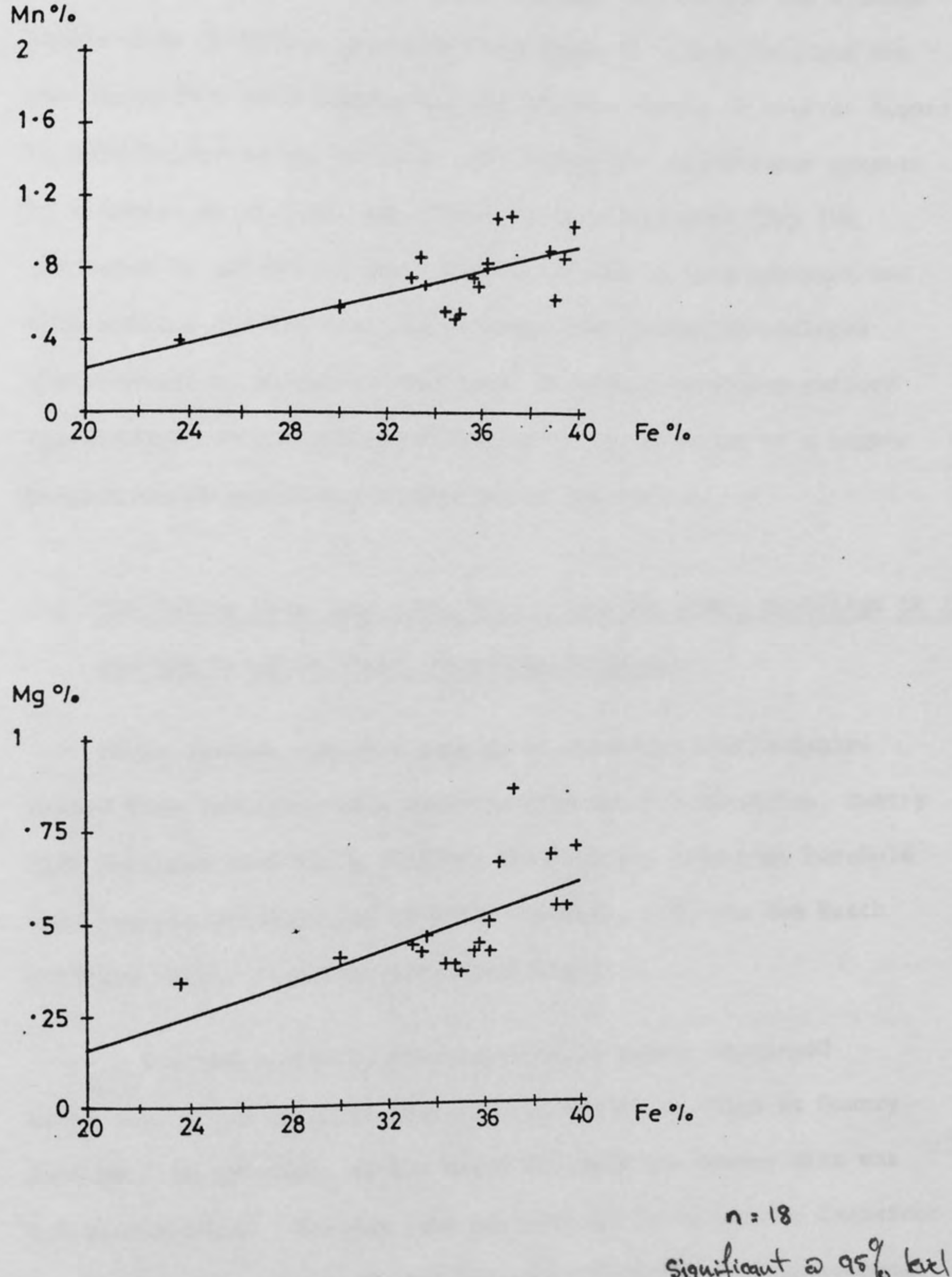


Fig 12 - Plot of Mn% and Mg% vs Fe% with best fit line for Blackband Ironstone, Mitchell's Wood

The average iron and manganese concentrations for the Apedale Bassey Mine Ironstone are within the range of values obtained for the Mitchell's Wood samples but the Apedale sample is however higher in both magnesium and calcium. The latter is considerably greater by a factor of at least ten. This is to be expected from the abundance of calcareous shell debris evident in hand specimen and thin section and the increase in magnesium presumably reflects the presence of dolomite. The lower iron concentrations reflect the dilution of the ironstone samples by the presence of a higher proportion of argillaceous material in the matrix.

2.6 The Bassey Mine Ironstone, Quarry Bank BH (NCB), Seabridge BH (NCB), and Hem Heath Colliery, North Staffordshire

Three further complete samples of the North Staffordshire Bassey Mine Ironstone were obtained from two NCB boreholes, Quarry Bank Borehole near Keele (E381061 N345646) and Seabridge Borehole near Newcastle-under-Lyme (E383472 N342866), and from Hem Heath Colliery (NCB), Trentham (E388 N341)(Fig 1).

In the two boreholes the ironstone is poorly developed being only 25 cm thick at Seabridge BH and 29 cm thick at Quarry Bank BH. In contrast, at Hem Heath Colliery the Bassey Mine was 1.2 metres thick. Besides this contrast in thickness the ironstone at the colliery and in the two boreholes differs in other respects. In both of the boreholes the ironstone occurs in a nodular or irregular pseudo-nodular form with poorly developed banding or layering (Plates 17 and 18). At the colliery on the other hand, the ironstone is a well developed blackband with a peloidal micro-texture. Both borehole samples are similar to the Apedale Bassey Mine sample in thin section. They contain abundant shell debris and are highly carbonaceous and argillaceous with scattered oil algae in the carbonaceous layers. The Seabridge BH sample in addition displays an unusual siderite texture in some of the carbonaceous layers in its lower part. The siderite here occurs occasionally with a colloform texture. The individual rounded aggregates making up the texture are small but in the upper part of the ironstone they are more abundant and larger. Here they take on the appearance of ooids (Plates 19 and 20). Many concretionary and oolitic textures are believed to be characteristic of minerals of colloidal origin (Pettijohn 1957) formed directly by crystallisation from a gel as indeed could also be the case for some or all of the common peloidal texture exhibited by many of the blackbands. The ooids may indicate a shallow water environment where direct precipitation in a "free-rolling" environment could have produced such textures.

An attempt to investigate the detailed morphology of the peloids using a scanning electron microscope (SEM) was made during the course of this study (see section 2.7).

XRD analysis shows that mineralogically the two borehole samples are similar to the Apedale Bassey Mine containing a little dolomite and calcite in some of the sub-samples. Most of the shell debris, however, is sideritised resulting in a low overall calcium concentration (Ca 0.89-3.88% by weight). The Hem Heath samples though rarely contain any shell debris and in overall composition are very similar to the blackbands described from

Mitchell's Wood. All the major cation concentrations (Fe, Mg, Mn and Ca), with the exception of one of the Hem Heath sub-samples, which on AA analysis yielded 44.25% by weight. Fe, fell within the ranges of concentrations obtained from the other north Staffordshire blackbands.

2.7 Scanning Electron Microscopy

In an attempt to investigate the micro-peloidal texture of the siderite in more detail than was possible using the conventional petrological microscope, small chips of material comprising a representative selection of the various types of ironstone were broken off the specimens and coated in carbon. These were then investigated using the scanning electron microscope (SEM) and scanned at different resolutions.

Unfortunately, despite repeated attempts, it was not found possible to observe any detailed morphological features of the siderite. Any features that may have been present were masked by clay minerals, mainly flaky illite. Only rarely were there obvious features such as large shell fragments observed. To try to alleviate this problem small pieces of uncovered thin sections were similarly coated in carbon and again scanned using the SEM. The problem of the masking by the flaky clay still persisted however.

It may be possible to devise some technique to leach away the clay minerals to uncover the siderite enabling a detailed examination of its micro-texture to be made. This may well be an avenue worth pursuing in any further study.

Chapter Three

Coal Petrography - The Bassey Mine Seam

Mitchell's Wood, North Staffordshire

3. Coal Petrography - The Bassey Mine Coal Seam, Mitchell's Wood, North Staffordshire

In addition to sampling the ironstones and associated strata in Mitchell's Wood opencast site a pillar sample of the Bassey Mine coal seam lying immediately beneath the Bassey Mine blackband ironstone was taken.

This seam was selected as it displayed the most diverse petographic macro-textures including both dull, bright and cannel coals and a transition layer between the base of the ironstone and the top of the coal seam in which diffuse and thin lenticular layered siderite occurred. From the individual coal sub-samples polished sections were prepared and these were examined using an oil-immersed objective to increase the contrast of the images. The sub-sections were examined in order to determine whether there were any significant features displayed in the coal microlithotype profile that would indicate changes in the palaeoenvironment.

The details of the sampled section are as follows:-

	thickness (cm)
I/S, blackband	
CC/I/S	15
CC	2.5
C, bright	20
M,cb, listric	48
C, fusainous	12.5
M,cb, listric	15
C, dull	7.5
C, bright	45
M,cb, listric	2.5
SE/M pale grey-brown	

I/S = ironstone
CC = cannel coal
C = coal
M = mudstone
SE = seatearth
cb = carbonaceous

Polished sections of the individual coal layers were prepared and their microscopic textures observed using an oil-immersed objective. The basal 45 cm of bright coal was found to be composed of trimacerite, clarite and vitrinite with interspersed lenses of semi-fusinite. Pyrite was common, occurring in both framboidal form and occasional small lenses of individual crystals. The overlying dull coal was found to be part carbonaceous shale (carbargilite) and part trimacerite, clarite and fusite with clay and quartz interspersed throughout. Pyrite was again abundant in this layer which also contained a 4 mm thick cannel/boghead. The succeeding bright and fusainous coal layers were of similar composition to those already described from the basal coal layer. The cannel coal next in the upward sequence of layers marks a change from the more normal bright and banded coal to a predominantly sapropelic development. The presence of siderite is first noted here and it becomes more prominent in the overlying cannel/ironstone subsection of the seam profile. This was found to be canneloid clarite and trimacerite impregnated with granular amorphous siderite.

A number of round sideritised spores (Plate 21) were noted to occur in the cannel/ironstone layer which formed the passage junction between the coal and the overlying Bassey Mine Ironstone. The form of these spores is in sharp contrast to that of those occurring in the carbonaceous-rich layers of the ironstone, where the spores are flattened with their long axes parallel to the bedding planes.

The dominance of clarite and trimacerite in the coal probably reflects a peat derived essentially from ferns and pteridosperms whose spores characterise the Upper Coal Measures (Crookall 1929). The peat evidently accumulated under fairly constant conditions since the general petrographic profile shows no marked change in microlithotype composition. Vitrinite, the dominant maceral, suggests an anaerobic environment of deposition for the peat. The obvious change at the top of the seam with the establishment of a cannel coal - a sapropelic facies - is of particular significance. It indicates the commencement of a distinct period of deposition. Cannel coal is massive and unlaminated in hand specimen and breaks with a conchoidal fracture. It is composed of much altered plant material containing variable quantities of spore cases, resin and cuticle. It is generally considered to have been transported and deposited as an organic sediment (Smith 1968, Moore 1968). This is in contrast to the bright and dull bituminous coals which have developed in situ and possess well developed seatearths at their bases, unlike the cannel coals.

The presence of cannel indicates formation by accumulation of allochtonous material in some form of depression within the peat swamp. The carbonaceous/canneloid matrix of the ironstone, therefore, is likely to have been formed in the same way. An inverse proportional relationship between the thickness of the ironstone and its underlying coal seam has been noted in Staffordshire (Homer 1875) as has also the tendency for the ironstone and coal to pass laterally into a normal coal seam. Cannel coal developments within coal seam profiles also exhibit this kind of relationship. The cannel is developed at the expense of the underlying or enclosing bituminous coal and eventually passes laterally, at the edge of the area of cannel development, into a normal bituminous coal seam.

The development of discrete water bodies on the top of the peat swamp is consistent with this and other evidence presented in previous chapters and reinforces the conclusion that the ironstones were most probably developed in cannel pools or depressions in the peat swamp surface in a lacustrine environment. The presence of round uncrushed sideritised spores in the upper layers of this coal seam also provides important evidence as to the time of siderite formation, demonstrating, quite clearly, a phase of siderite development prior to the compaction of the peat.

Chapter Four

The Fauna of the Blackband Group, North Staffordshire, and its Significance

4. Associated Fauna and its Significance

The blackband ironstones of north Staffordshire occur in the Blackband Group of the Upper Coal Measures (Westphalian C). The north Staffordshire coalfield is one of many which comprise the Pennine Province of coalfields which includes those of the Midlands, North Wales, Yorkshire and Lancashire.

The fauna of the Blackband Group is dominated by the non-marine lamellibranch *Anthraconauta phillipsi* which together with the presence of *Torispora securis* in the miospore assemblages of the coals occurring in the Group (Smith and Butterworth 1967) confirms a Westphalian C age. The majority of the faunal horizons which often include the ostracod *Carbonita* as well as *Anthraconauta* usually occur in the mudstones forming the immediate roof measures above the main ironstone and coal horizons. In the case of the shelly ironstones of the Apedale and Silverdale areas (Appendix I) the ironstones themselves contain many laminae composed of the flattened tests of *Anthraconauta*. Some of the fine grained siderite layers also contain uncrushed ostracods and occasional *Spirorbis*. In Mitchell's Wood opencast site '*Estheria*' was also recorded together with *Anthraconauta* and ostracods at three horizons; one just above the Hoo Cannel coal and ironstone and the others at the Bassey Mine Limestone horizons.

The majority of the coal measure faunas of Great Britain are considered to have existed in a dominantly non-marine paralic-type environment (Calver 1968), the general term 'non-marine' embracing several distinct habitats ranging from brackish to fresh-water. The precise niche of particular species is not readily determinable, but certain of the individual genera have a consistent relationship to one another in both space and time. This enables links to be made between certain groups of individuals and the interpreted environments of their enclosing sediments. The presence of Anthraconauta, Carbonita, 'Estheria', Spirorbis and fish, however, is more consistent with an existence in inland lakes rather than a paralic environment (Calver 1968). Anthraconauta is thought to have appeared at a time of fundamental change in the coal measure palaeogeography when the whole environment took on a more 'continental' aspect. Its most likely habitat appears to have been large inland lakes or lagoons cut off from the sea as evidenced by the lack of marine horizons in the Upper Coal Measures (Westphalian Upper C and D). According to Calver (1968) Anthraconauta attains its largest size in the north Staffordshire Blackband Group and this may well indicate an acme in the development of this type of environment. The presence of boghead cannels with their oil algae is a further indication of a lacustrine habitat (Yen and Chiliugarian 1976). The dominantly paralic environment of the Lower and Middle Coal Measures appears to give way than to a limnic environment in Upper Coal Measure times in north Staffordshire.

The presence of 'Estheria' could be taken to imply that the environment was, in contrast, somewhat brackish. There is a tendency for 'Estheria' to occur at discrete horizons analogous to the behaviour of the marine faunas and it often is present in the beds immediately preceding or following a marine incursion (Calver 1968). However, the presence of 'Estheria' at numerous horizons in the Upper Coal Measures, a demonstrably more continental facies, appears to conflict with the concept of a brackish-water habitat. The

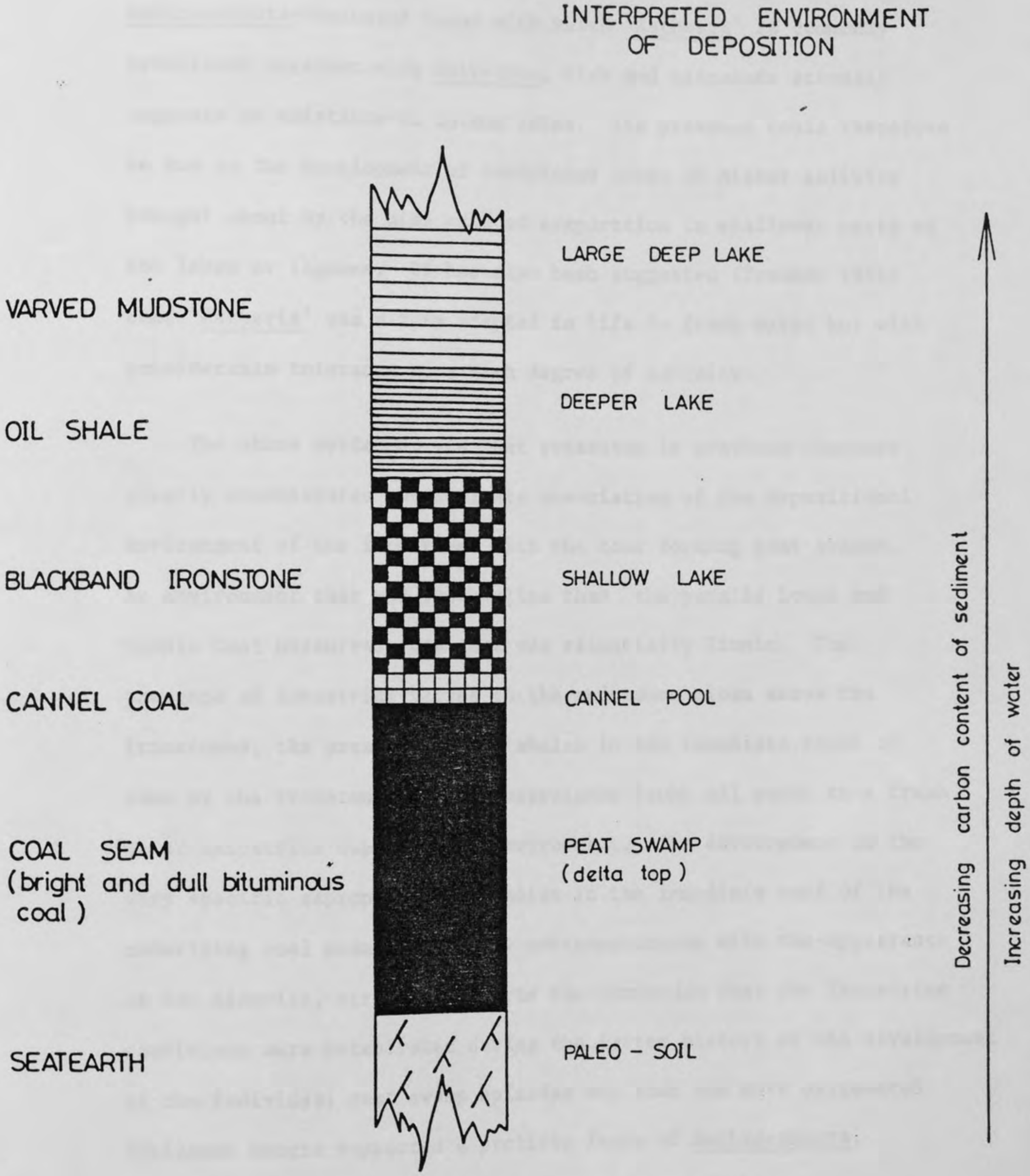


Fig 13 - Typical blackband ironstone development with interpretation of environments of depcsition

Scale~50cm

Anthraconauta-dominated fauna with which '*Estheria*' is commonly associated together with *Spirorbis*, fish and ostracoda strongly suggests an existence in inland lakes. Its presence could therefore be due to the development of restricted areas of higher salinity brought about by the high rate of evaporation in shallower parts of the lakes or lagoons. It has also been suggested (Trueman 1946) that '*Estheria*' was a form adapted to life in fresh water but with considerable tolerance to a high degree of salinity.

The above evidence, and that presented in previous chapters clearly demonstrates the intimate association of the depositional environment of the ironstones with the coal forming peat swamps. An environment that was less saline than the paralic Lower and Middle Coal Measures. One that was essentially limnic. The presence of lacustrine varves in the mudstones close above the ironstones, the presence of oil shales in the immediate roofs of some of the ironstones and the associated fauna all point to a fresh water lacustrine depositional environment. The development of the very specific sapropelic coal facies in the immediate roof of the underlying coal seams apparently contemporaneous with the appearance of the siderite, strongly supports the conclusion that the lacustrine conditions were established during the latter history of the development of the individual peat swamp episodes and that the more oxygenated shallower waters supported a prolific fauna of *Anthraconauta*, *Spirorbis*, '*Estheria*', oil algae, ostracods and fish.

Chapter Five

Blackband-type Ironstones from other British Coalfields

Blackband-type Ironstones from other British Coalfields

5.1 Nottinghamshire

5.1.1 Sunrise Borehole (NCB)

During the course of the exploration of the coal reserves for Newstead Colliery (NCB) Sunrise Borehole (E457288 N354796) was drilled near Blidworth, Nottinghamshire. This borehole encountered a blackband ironstone just above the horizon of the Main Bright Seam (Westphalian B). In this borehole the coal horizon itself is poorly developed, being only represented by very thin seams of cannel coal; the basal one occurring at a depth of 456.13 m below surface.

The complete core sample of 870 mm diameter core of the ironstone and a few centimetres of its enclosing sediments, in total length amounting to 92 cm of core, was collected for study. A detailed description of this sample is as follows:-

	Thickness (m)	Depth (m)
Top of core		455.10
Mudstone, dark grey, fish scales and fish debris, carbonaceous, ?siderite matrix; 'mussel' fragment at 455.24 and below to 455.26; very small siderite aggregates at base	0.33	455.43
CANNEL COAL	0.04	455.47
Mudstone, dark grey, canneloid, ostracod at 455.55; some diffuse siderite layering	0.13	455.60
Ironstone, layered pale brown siderite; some thin COAL layers and laminae in lower half	0.40	456.00
Mudstone, dark grey, coalified plants	0.02	456.02

The core was cut and samples were prepared for microscopic examination, XRD and AA analysis in the same way as for the Staffordshire samples.

In hand specimen the ironstone exhibits a distinctive layered texture (Plate 22). The dark and light grey 'varve-like' lamination is also evident in the canneloid mudstone forming the immediate roof of the ironstone. Diffuse siderite laminae are also developed here, particularly towards the contact between the roof measures and the top of the ironstone. Three centimetres below the top a 3.5 cm layer appears different from the rest of the ironstone. Unlike the blackband-like layered texture exhibited by the bulk of the ironstone, this thin layer appears to be very fine grained and contains lens-like patches of very small oval carbonate concretions or ooids ($<$ 0.5 mm). Some have been dissolved out leaving small solution cavities. The remaining ironstone below is layered and lenticular pale brown and grey-brown siderite with occasional coaly laminae and thin layers, particularly in the basal 15 cm. The floor measures below are of a dark grey planty mudstone.

The fine grained nature of the distinctive layer in the upper part of the ironstone can be seen in thin section. It contains abundant plant fragments, some with their cell structure still preserved. Non-marine lamellibranch shell fragments are also present within this layer, some with the prismatic layer of their shell still evident, as was found in some of the Staffordshire blackbands. Occasionally these shells are articulated and some have their internal voids filled with rounded siderite aggregates which often exhibit a thin paler overgrowth. This also develops into a matrix when a few of the aggregates are in juxtaposition. The thin section of the ooid bearing layer does not unfortunately reveal any internal structure as the ooids were destroyed during slide preparation and are represented only by voids in the section. This layer is separated from the more typical peloidal siderite (Plate 23) below by a carbonaceous rich layer. Again, like the Staffordshire blackbands this contains flattened spores and occasional orange and yellow oil algae. The peloidal siderite below contains occasional non-marine lamellibranch shell fragments and in places also contains small areas made up of round or oval shaped darker siderite bodies which resemble the 'ghosts' identified in the Mitchell's Wood samples. In one case (Plate 23) the area occupied by these rounded aggregates is surrounded by planty tissue with its cell structure preserved. The rows of cells are arranged in such a way as to appear to be forming an outer wall surrounding and containing the aggregates in the way a spore case would surround and contain its spores or a seed case its seeds. Alternatively these aggregates may have been formed during the decomposition around centres of rotting matter within the voids formed in the larger pieces of plant material. As discussed previously the lack of consistency of shape and any axial elongation would appear to rule out faecal pellet origin for these aggregates or 'ghosts'. Their common association with plant and animal remains supports the latter interpretation, ie concentrated decomposition of larger pieces of plant and animal debris forming areas of sustained reducing conditions.

The concentrations of the four main cations in this ironstone were found to be within similar ranges to those of the blackbands from Mitchell's Wood, north Staffordshire. Their average compositions are as follows:-

Fe 28.8%, Mg 1.5%, Mn 0.71%, and Ca 0.71%. The analyses for each subsection is plotted in Fig 14 in a similar way as those for the Mitchell's Wood samples. Again by visual inspection the similarity in shape of the Fe, Mg and Mn vertical distributions are similar and that of Ca more random.

X-ray diffraction analysis confirms the dominant carbonate mineral as siderite together with smaller amounts of quartz.

5.1.2 Radcliffe By-pass Borehole (NCB), Nottinghamshire

During the course of the exploration of the potential operating coal reserves to the east of Cotgrave colliery (NCB) south Nottinghamshire in the early part of 1978 a diffuse blackband-type ironstone development was encountered in one of the boreholes (Radcliffe By-pass borehole, E463895 N338484) at a depth of 509.53 m below surface a short distance below the Hospital coal horizon (Westphalian A).

The core sample of the ironstone exhibited a blackband development over a length of 1.21 m, the ironstone resting directly on a thin (6 cm) intraformational mudstone breccia. The contrast between the dark grey argillaceous matrix and the layered and lenticular siderite is most pronounced (see Plate 25). Because of the highly argillaceous nature of this ironstone some difficulty was experienced in producing thin sections from the core. However those that were produced showed a peloidal siderite micro-texture very similar to that already described from other blackbands. Some scattered quartz grains were also evident.

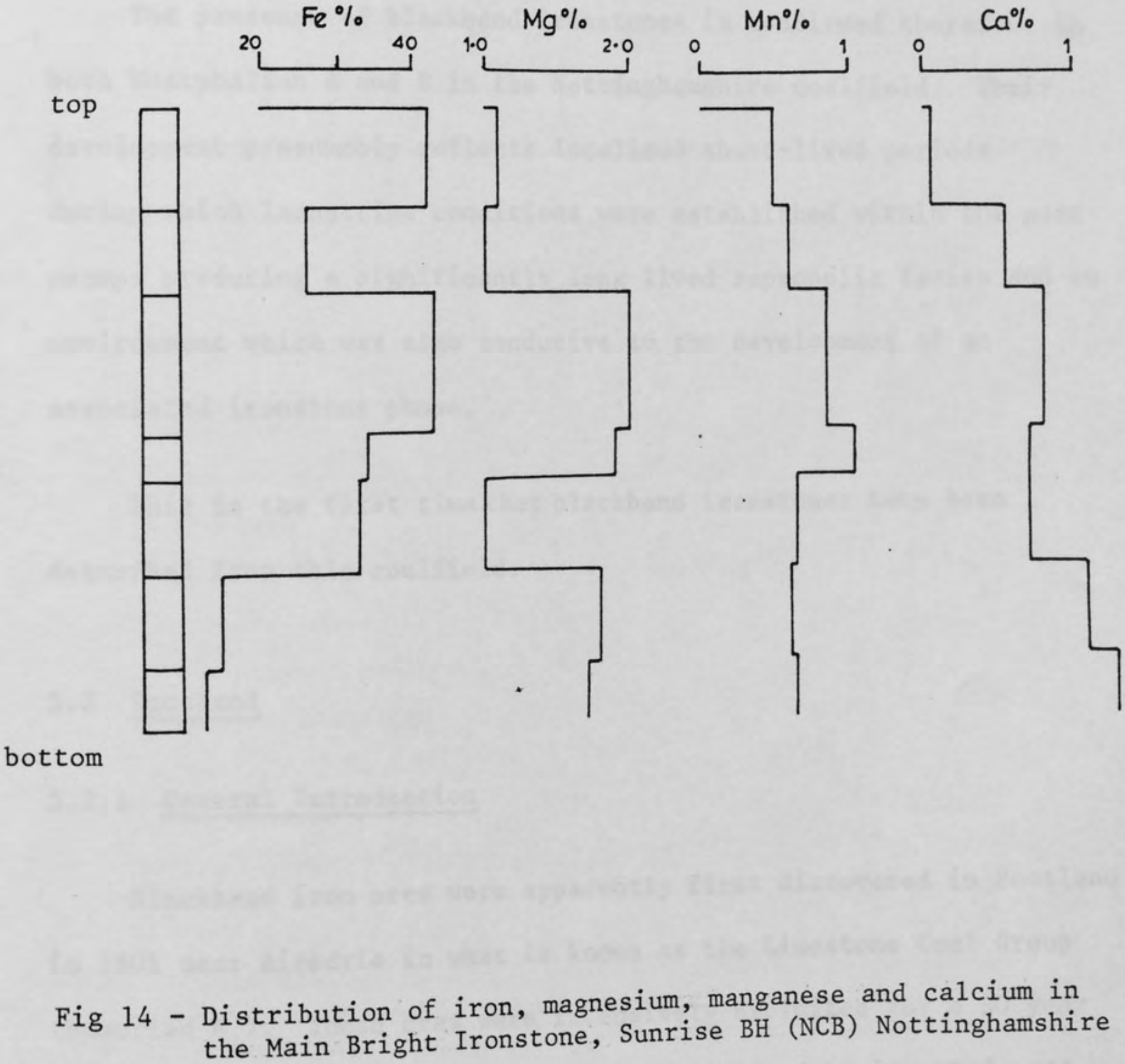


Fig 14 - Distribution of iron, magnesium, manganese and calcium in the Main Bright Ironstone, Sunrise BH (NCB) Nottinghamshire

X-ray diffraction analysis of the powdered ironstone samples confirmed the presence of quartz and siderite and no other mineral species were indicated. AA analysis produced figures indicating a very similar cation concentration as for other blackbands both from Nottinghamshire and Staffordshire, ie Fe 17.7-26.26%, Mg 1.43-1.7%, Mn 0.27-0.65% and Ca 0.17-0.98%.

The presence of blackband ironstones is confirmed therefore in both Westphalian A and B in the Nottinghamshire coalfield. Their development presumably reflects localised short-lived periods during which lacustrine conditions were established within the peat swamps producing a significantly long lived sapropelic facies and an environment which was also conducive to the development of an associated ironstone phase.

This is the first time that blackband ironstones have been described from this coalfield.

5.2 Scotland

5.2.1 General Introduction

Blackband iron ores were apparently first discovered in Scotland in 1801 near Airedrie in what is known as the Limestone Coal Group (Namurian E_1). These ores were intensively exploited for a 30 year period up to 1860 before being gradually replaced by imported ores (Macgregor, Lee and Wilson 1920). Their occurrence in the Glasgow-Stirling area is confined to about ten horizons distributed throughout the Limestone Coal Group. Like their Staffordshire counterparts they are developed in a cannel or cannelly mudstone facies at a coal seam horizon (Forsyth and Read 1962).

The published bulk analyses show that the occurrence and concentrations of the major cations in the ironstones are very similar to the typical blackbands already described from Staffordshire and Nottinghamshire.

Blackbands have also been recorded from the underlying Calciferous Sandstone Series in the Glasgow-Stirling area. One recorded from Muiredge occurs close below an oil shale (cf the Red Mine and Bassey Mine Ironstones of Mitchell's Wood) and is developed together with calcareous rocks. The detailed section is quoted as follows:-

		Thickness	
		ft	ins
Limestone			
Blaes		0	3
Limy blaes		0	3
Oil shale	10 in to	1	3
Limestone fakes		2	0
Brown irony limestone		0	6
Blackband ironstone		0	5
Irony Parrot Coal		0	3
Dough holing		0	3
Coarse fireclay with hard balls	1ft 3in to	2	0
Foul Coal		0	7

Blaes = fine grained argillaceous grey sediments or mudstones
fakes = thin bedded argillaceous sandstone
Parrot = cannel
Dough = black fireclay

A borehole put down in the near vicinity of this section recorded 'hard limestone' at this horizon. Another blackband in this Series mentioned by the same authors was noted to pass laterally into a normal coal seam. Both these characteristics have been noted in blackbands described previously.

The blackbands of the Central Coalfield are postulated to have accumulated "in more or less isolated lagoon-like areas of deposition" (Macgregor, Lee and Wilson 1920).

5.2.2 The Calpatie blackband ironstone, Monktonhall Colliery (NCB), Midlothian

During the course of this work it has been possible to obtain a complete core of the Calpatie blackband ironstone from the Midlothian Coalfield. The core of this blackband was obtained from No 7/78 Underground Borehole (E333329 N671655) during the proving of the Coronation Seam from existing workings in the Gillespie Seam (Namurian E_1)(Plate 26), Monktonhall Colliery (NCB).

A lithological description of the core and its contained ironstone is as follows:-

		Thickness (cm)
	Siltstone/Sandstone, medium grained grey siltstone with irregular, fine, off-white sandstone laminae, roof disturbed thin layers, micaceous	top not seen
	Ironstone, siltstone, fine matrix, dark grey, slightly carbonaceous. Thin, finely nodular layers of siderite in top 5 cm, layered siderite below with some layers comprised of packed lens-shaped siderite bodies (5x1 cm); massive in basal 5 cm.	25
	Mudstone, dark grey, silty	28
	Ironstone, dark grey, muddy, sideritic, poorly laminated	13
	Siltstone, dark grey, fine	02
	Mudstone, dark grey, carbonaceous	08
Calpatie Seam	COAL	18
Calpatie Seam	CANNEL COAL	06
Calpatie Seam	COAL	52
	Seatearth/Mudstone, grey, silty.	

In thin section this ironstone exhibits a dominant well developed peloidal texture (Plate 27). The fine grained part near the top however is similar to the fine grained ostracod rich layers noted in the Apedale samples of Staffordshire. In this part the 'ghost-like' siderite development is also well developed (Plate 28). Oil algae and spores are present in the carbonaceous laminae and rare lamellibranch fragments have also been identified in this ironstone.

Like the Nottinghamshire samples only siderite and quartz was identified by XRD analysis and the shells in the main must therefore be sideritised.

The AA results again fall within the well established ranges for the major cations (Table 2).

In all respects, apart from its lower stratigraphical occurrence, this Scottish blackband ironstone is identical to those described from Staffordshire and Nottinghamshire.

	Subsection thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref
Top						
	5	13.05	3.1	0.35	0.51	CAL004
	4	11.8	2.4	0.30	0.38	CAL003
	5	17.4	2.9	0.35	0.51	CAL002
	M_z	not sampled	28 cm thick			
	6	10.8	2.2	0.29	0.29	CAL001
Bottom						

Table 2 - Analyses of major cations, Calpatie Ironstone, Monktonhall Colliery Underground Borehole 7/78

Chapter Six

The Mode of Siderite Formation in Blackband Ironstones

The Mode of Siderite Formation in Blackband Ironstones

6.1 General Considerations

Blackband ironstones are together with Clayband ironstones the two types of ironstone which commonly occur with measures containing coals in grey coal measure sequences. Examples of the former have been described earlier from the Namurian coal measures of Scotland and coal measures of Westphalian A, B and C ages in the Midlands. The Claybands are thin (a few cm thick) nodular or tabular concretionary micritic siderites whereas Blackbands are up to a few metres thick and are usually layered carbonaceous siderites.

Blackband ironstones have been shown herein to be texturally and mineralogically distinct from claybands. Hitherto, however, the two were considered by many researchers to be very closely related (W Gibson 1925, A Trueman 1954, J L James 1966, Trotter 1953) the former being presumed to be nothing more than just a carbonaceous rich variety of the latter. Their modes of formation were accordingly considered analagous, the blackbands differing only from the claybands in having a closer association with the coal forming environment.

Details of both ironstone types are discussed below and a different mode of formation for the blackbands is proposed.

The Claybands and Blackbands

Recent work on a Yorkshire Clayband ironstone (Curtis 1967, Curtis and Spears 1968, Oertel and Curtis 1972, Curtis, Pearson and

Somogyi 1975) indicates a protracted history of diagenetic growth, often involving the formation of nodular micritic or stratiform concretions. This is in sharp contrast to the many primary textures demonstrated by the blackbands as previously described herein.

The work by Curtis and Spears (1968) concluded that virtually all the sedimentary iron minerals in their Yorkshire clayband had been formed in diagenetic rather than depositional environments. The diagenetic history originated, they proposed, in a period of rapid growth within the uppermost few metres of unconsolidated sediment where organic detritus is present and bacteria thrive. Oxidative bacteria close to the sediment - water interface and fermentation bacteria produced bicarbonate which found its way into diagenetic carbonates. The long history of diagenetic growth was illustrated by changes of chemical composition observed within the concretions. The early inner carbonates were found to be iron rich, whereas the later outer carbonates demonstrated increases in relative percentage of other cations, particularly Ca and Mg.

The fine interlayering common in the blackbands contrasts markedly with the homogeneous micro-crystalline texture of the claybands. The blackbands also exhibit other primary textures including root disturbed layers below coal beds, sideritised unflattened spores and preservation of plant cell detail, all pointing to a very early, in some cases pre-compaction formation of the siderite. Localised small masses of micrite are associated with the larger plant and animal remains (mainly mollusc shells). The only suggestion of any late diagenetic phase of sideritisation is represented possibly by the thin paler coarser outer margins to some of the peloids making up the bulk of the iron rich layers.

Unlike the claybands, the blackbands do not exhibit changes in relative cation concentrations that would indicate possible changes in groundwater chemistry with time. On the contrary the blackbands demonstrate a consistency in relative composition of their major cations Fe, Mg and Mn. All three in most ironstones sampled also show a general increase towards the base of an individual ironstone, ie towards the roof of the underlying coal seam.

6.2 Palaeogeographical Setting

The Blackbands of north Staffordshire occur in the Blackband Group, in the lower part of the Upper Coal Measures (upper Westphalian C).

In the exposed coalfield around Stoke-on-Trent, the Blackband Group is underlain by a thick productive grey coal measure sequence. In the upper part of the Group we have seen that there are intercalations of red-beds which become thicker and more numerous occurring at lower horizons in the formation towards the south. The measures comprising the Blackband Group pass upwards gradationally into the Etruria Marls which consist entirely of red mudstones and subordinate sandstones.

The Etruria Marl Formation has recently been interpreted (Besley 1979) as representing deposits of a complex of alluvial channels and flood plains lying between a source area to the south of Birmingham dominated by a continental-type depositional environment and coastal plain swamps and delta areas in which the productive Coal Measures were being formed.

The measures of the Blackband Group are therefore likely to have been deposited in a sedimentary environment intermediate and transitional between the two above mentioned environments. This is likely to have been one in which small areas were subject to significant periods of lacustrine deposition.

6.3 Dimensions of the Depositional Basin

In an attempt to determine the dimensions of the lacustrine basins in which the ironstones were probably deposited the Abandoned Mines records of the National Coal Board which are held at the Area Headquarters at Stoke-on-Trent were consulted. The object of the exercise was to abstract thickness data for the ironstones from the old mining records of ironstone workings in the north Staffordshire coalfield which would then enable the construction of isopach maps for each ironstone. A considerable amount of very localised rapid variation was evident however in many of the records, the ironstone increasing or decreasing in thickness by more than 50% in a few hundred metres lateral distance. This rapid change was documented in the following example quoted by Dewey (1920), although the extent of the variability was not quantified:-

> "In thickness the bed (Bassey Mine Ironstone) is extremely variable. At Great Fenton (colliery) on a working face in the first hundred yards it varies from 4 ft 6 in to 2ft 9 in in the next 50 yards it varies from 3 ft to 9 inches. The top of the bed suffers more changes than the base which maintains fairly even lie".

At first it was thought that this variation was only a local phenomena, a conclusion which was initially further supported by observations in the opencast coal quarry at Mitchell's Wood where direct observations revealed little variation. It is possible that some of the recorded variation has resulted from the fact that some data may refer to a thickness for the ironstone which was that portion that was worked rather than the total thickness including the part of the ironstone left up in the roof or in the floor of the working being a portion that was considered at the time to be uneconomic to work. The variability is so well documented, in restricted areas that have been worked continuously over a relatively short period of time that locally this source of variability must be insignificant. However, it should be borne in mind that when comparing data from different areas and different collieries that this source of variation could well be an important factor. The variation therefore would appear to be a common feature of the ironstone development throughout the coalfield.

In general the top three ironstones appear to be well developed in the Wolstanton and Holditch areas but they thin rapidly to the south of Silverdale and Stoke-on-Trent suggesting an overall basin of deposition with a radius of about 3 km. The lowest ironstone, the Bassey Mine would appear to be developed over a larger area in the western part of the exposed coalfield being over 1.00 m thick within an elongate north-south area of approximately 13 km x 4 km. Much of the available data, however, is old and unreliable and fairly sparse in the north of the coalfield.

6.4 Results of a Study of the Carbon and Oxygen Stable Isotopes of Blackband Ironstones

In an attempt to answer the question as to the precise mechanism of the siderite formation and the origin of the carbonate or bicarbonate precursor in the blackbands a study of the stable carbon and oxygen isotopes was undertaken at the I.G.S. Isotope Geology Unit.

Bicarbonate is commonly formed by the degradation of organic matter in one of the following three ways (Curtis 1977):-

i) by oxidative bacteria

ii) by fermentation bacteria

iii) by sulphate reducing bacteria.

Stable isotope studies are able to distinguish between some of these contributions and this study was undertaken in order to attempt to define more precisely the mode of siderite formation.

Twelve subsamples chosen from a cross-section of the different ironstones were selected for this study. A few hundred milligrams of the samples were initially reduced to a fine powder by grinding in an agate pestle and mortar. These were then placed in a Nanotech Plasmaprep P.100, a low temperature oxygen plasma, for about 24 hours to oxidise all the free carbon. These samples were then reacted with 100% phosphoric acid at a temperature of 95^{o}C (similar to the method described by McCrea (1950)). When reaction had reached completion the carbon dioxide evolved was purified by passing it through a trap cooled to -100^{o}C. The resulting gas was then analysed for $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios using a Micromass 903 mass spectrometer.

Carbon and oxygen isotopic compositions are conventionally expressed in δ notation:

$$\delta^{13}C = \left(\frac{^{13}C/^{12}C \text{ (unknown)}}{^{13}C/^{12}C \text{ (standard)}} - 1 \right) \times 1000$$

For carbonates it is convenient to use the same PDB standard for carbon and oxygen. PDB was a Cretaceous belemnite; its isotopic composition being $\delta^{13}C = 0$, $\delta^{18}O = 0$ by definition. This is close to that of many marine carbonates where values are thus small positive or negative numbers. The ratios are reported as per mil (%o) difference between the sample and the PDB standard.

The results for the twelve ironstone samples analysed are given in Table 3 and their $\delta^{13}C$ PDB and $\delta^{18}O$ PDB ratios are plotted against each other in Figure 15. The reproducibility of these figures was determined experimentally to be possible to 0.1%o $\delta^{13}C$ and 1.6%o $\delta^{18}O$. It should be noted, however, that because a calcite and not a dolomite standard was used the $\delta^{18}O$ results are likely to be approximately 0.8%o too heavy, the more important $\delta^{13}C$ determinations though remain unaffected.

Unlike the results of previous work on Carboniferous siderites by Curtis et al (1972) and those of Fritz and others (1971) on early diagenetic fresh-water siderites from the Cretaceous of Western Canada where values of $\delta^{13}C$ in excess of +7 were obtained, no unusually heavy carbon isotopic ratios were found to occur in the samples analysed. An enrichment of ^{13}C may come about as a result of the decomposition of organic matter by fermentation bacteria; ^{13}C rich carbon dioxide and ^{13}C depleted methane being produced (Cheney and Jensen 1965, Sass and Kolodny 1972).

Some of the higher ^{13}C values in Table 3 (Monktonhall Colliery) may indicate a contribution from such fermentation reactions, a

Horizon and Location	Sample Ref	^{13}C PDB	^{18}O PDB
Mitchell's Wood N Staffs Blackband I/S	BH004 BH010	-6.3 -4.4	-5.4 -5.9
Red Shagg I/S	BH035	-0.8	-5.7
Red Mine I/S	BH069 a) BH069 b)	-0.9 -2.1	-7.3 -7.5
Apedale Licensed Mine N Staffs Bassey Mine I/S	AP004	1.9	-6.0
Hem Heath Colliery NCB, N Staffs Bassey Mine I/S	HH007	-3.1	-6.0
Seabridge BH, NCB N Staffs Bassey Mine I/S	SB001	-1.9	-6.5
Sunrise BH, NCB S Notts	SR009	1.3	-8.4
Radcliffe By-pass BH NCB, S Notts	RAD001 a)	-0.7	-8.8
Monktonhall Colliery NCB, Scotland Calpatie I/S	CAL002 CAL003	2.4 3.9	-6.0 -7.3

Table 3 - Results of Carbon and Oxygen Stable Isotope Analyses for various Blackband Ironstones

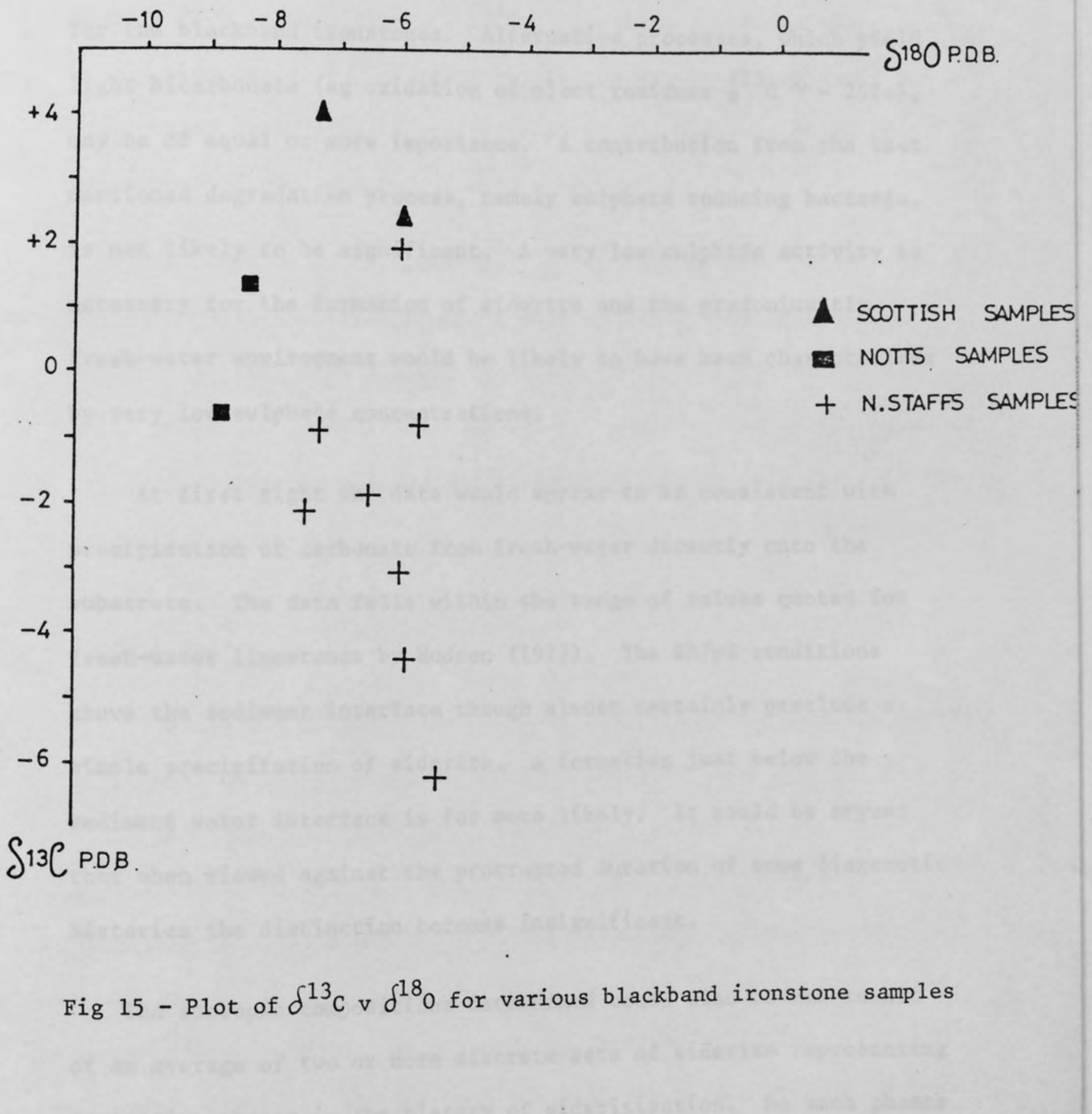


Fig 15 - Plot of δ^{13}C v δ^{18}O for various blackband ironstone samples mechanism which both the above authors considered responsible for their high carbon fractionations. The predominance of this process, however, must be ruled out by the main body of the data derived for the blackband ironstones. Alternative processes, which yield light bicarbonate (eg oxidation of plant residues $\delta^{13}C \sim -25‰$), may be of equal or more importance. A contribution from the last mentioned degradation process, namely sulphate reducing bacteria, is not likely to be significant. A very low sulphide activity is necessary for the formation of siderite and the predominantly fresh-water environment would be likely to have been characterised by very low sulphate concentrations.

At first sight the data would appear to be consistent with precipitation of carbonate from fresh-water directly onto the substrate. The data falls within the range of values quoted for fresh-water limestones by Hudson (1977). The Eh/pH conditions above the sediment interface though almost certainly preclude a simple precipitation of siderite. A formation just below the sediment water interface is far more likely. It could be argued that when viewed against the protracted duration of some diagenetic histories the distinction becomes insignificant.

The isotopic compositions determined could also be the result of an average of two or more discrete sets of siderite representing successive phases in the history of sideritisation. No such phases however have been identified in either thin section or by mineral composition variations. Only occasional overgrowths to some of the siderite peloids are evident and these could well be nothing more than local recrystalisation. The main bulk of the ironstones is apparently the result of one main phase of sideritisation.

The situation could possibly be further complicated by the incorporation of carbon dioxide derived from ^{13}C depleted methane or the reaction of bicarbonate solutions with dissolved carbon dioxide from the atmosphere ($\delta^{13}C$ - 7). This could explain the fairly wide range of $\delta^{13}C$ values exhibited by these ironstones and fresh-water carbonates in general. There is, however, no evidence in support of the presence of such a mechanism.

The range of values obtained for the $\delta^{18}O$ is more restricted having a small deviation around a mean of -7. These values are not incompatible with a fresh-water origin for the siderite. The small spread of values also suggests the preservation of the original oxygen isotopic composition and presumably reflects similarly on the carbon ratios also.

Conclusions

The absence of heavy carbonate strongly suggests that fermentation reactions, do not predominate and they could be less important in blackband ironstone formation than in early diagenetic processes previously investigated. Contributions from other bicarbonate producing mechanisms may be as or more important. The process could further be complicated by reactions with CO_2 derived from the atmosphere or oxidation of methane. A fresh-water affinity for the siderite however is not incompatible with the data presented above.

6.5 A Model for Blackband Ironstone Formation

There are two principal sources of iron at the Earth's surface. One is brought about by continental erosion and the other is provided by volcanic activity. As there is no evidence of contemporary vulcanism within the Staffordshire Westphalian C sediments nor any volcanic rock detrital fragments in the coarser sediments a direct source of such iron can be ruled out.

Ideal conditions for the supply of iron are found though in tropical areas of low relief and intense chemical weathering. Here complexes of iron with organic ligands, absorption of iron on fine particle organic fragments as a constituent of fine clay substituting in the clay lattice or as a coating on the surface of the mineral platelets (egkaolinite often contains large quantities of impurities, adsorbed iron is commonly between 1% and 3%), and fine particulate iron hydroxide as suspended sediment all contribute to iron availability.

Ferric iron, however, is practically insoluble in the presence of oxygen, when its maximum solubility is of the order of 1g/cu m, but in the ferrous state and in acid solutions in the absence of oxygen its solubility may reach 50 mg/cc. The accumulation of plants and humus in swamps and marshes produces acidic reducing conditions in the surface waters and such environments are very favourable for the solution of iron and manganese. The partial decomposition of the vegetable matter will also produce abundant carbon dioxide. This results in high iron bicarbonate concetrations in the swamp groundwaters.

It appears likely therefore that an adequate iron source would be available in the delta top clay sediments upon which the peat blanket is developing. A lacustrine environment developed on top of this blanket being the result of differential subsidence will undoubtedly have bicarbonate rich waters draining into it from the slightly higher surrounding bog. On coming into contact with the oxygenated near surface waters the iron bicarbonate will be immediately oxidised to ferric oxyhydroxides and precipitated. The following equation summarises the general process:-

$$Fe^{2+} + 3OH^{-} \rightarrow Fe(OH)_3 + e^{-}$$

This phenomena is analogous to that observed when iron-rich mine waters are discharged into a settling lagoon or surface water course. A turgid precipitate of colloidal hydroxide is formed - often termed 'ochre'. This ochre will slowly settle to the bottom of any still body of water and may be covered from time to time, or partially mixed with, influxes of sediment.

In a lacustrine environment established on a peat blanket sedimentation is dominated by organic debris accompanied by a minimal amount of clay minerals. Periodic influxes of surface waters containing a carbonaceous-rich sediment would produce a fine interlayering of carbonaceous-rich and iron-rich layers. The matrix of the ironstone bears evidence to the type of sediment being formed in this environment and clearly shows a generally mud-free sediment. The surrounding peat presumably acted as a mud filter allowing through only the iron-rich bicarbonate waters and fine organic debris. The iron was clearly derived directly from the bicarbonate waters draining into the lake and not directly from any clay minerals. The absence of siderite in the underlying bituminous coals (except that associated with short lived sapropelic episodes) clearly precludes the post depositional derivation of iron from the clay sediment below the coal seam (being more permeable this would have been a more likely host rock for post depositional siderite accumulation).

The establishment of an oxygenated lacustrine environment immediately over potentially coal forming peats and fed by iron-rich surface waters from the surrounding penecontemporaneous peats would produce the conditions necessary for the formation of an ironstone/ cannel alternation overlying a bituminous coal seam. This is the common configuration of ironstone and coal found at the blackband coal and ironstone horizons. The oxygenated water of the lake is essential to this mechanism as it is the means by which the iron is initially precipitated and hence concentrated. This situation is identical to the formation of bog iron ores as described by many authors in Scandanavia (eg James 1966).

Neither the substrate nor the overlying waters in this lacustrine environment would be likely to be conducive to the development of anything other than microscopic life. Evidence of algal activity in the blackbands is demonstrated by the presence of small yellow or orange oil algae and occasionally preserved algal borings. In shallower water with less iron input, however, more oxygen could be available and a more amenable environment for macro life could exist. The shallower waters around the margins of the lagoons are likely to have provided such an environment.

Once the oxyhydroxides have been incorporated into the carbonaceous rich sediment the conditions then prevail for the reduction and precipitation of the iron as siderite. Bacterial activity associated with the partial degradation of the planty material probably contributed considerably to this process. Many micro-reducing environments where plant and animal breakdown was more concentrated than others could have produced the peloidal micro-texture common in most of the blackbands. Pisolitic, oolitic and colloform textures are common in bog iron ores. It is possible that the peloidal texture is a result of iron hydroxide precipitation subsequently preserved during sideritization. The more concentrated fine-grained siderite accumulations could have been formed in a similar way at the sites of much larger scale bacterial breakdown of plant and animal tissue. The partial degradation of the planty tissue is evidenced by the preservation of the outlines of the plant cells in some of the more carbonaceous ironstone sub-samples.

The following type of reaction would characterise the processes involved:-

$$4Fe(OH)_3 + 3C_{org} \longrightarrow 4Fe^{2+} + 3CO_2 + 6H_2O - 4e$$

The influx of argillaceous sediments, likely to increase with time and deepening of the water of the lake prior to burial by mudstones, would tend to dilute the iron precipitates producing leaner (or muddier) ores towards the top of the ironstone profile and 1
drainage into the lake would also eventually stop. Finally a cover of argillaceous sediment would inhibit further ironstone formation. Increased input of carbonaceous sediments and depth of water would also prevent oxidation continuing in the near-surface waters causing the cessation of concentrated iron precipitation.

Documented observations of siderite formation at such shallow depths within modern sedimentary sequences are few but they suggest that suitable environments do exist and that it is taking place in contemporary peat bogs. One studied recently in Denmark (Postma 1977) showed the presence of iron carbonate within the top metre of peat in a low-moor type peat bog with a composition between siderite and rhodochrosite/calcite and rarely pure siderite. Siderite has also been identified at shallow depth in Recent fluviatile sediments of the Atchafalaya Basin, USA (Ho and Coleman 1969). The preferential formation of carbonates as opposed to sulphides results from the low dissolved sulphate concentrations in the dominantly non-marine depositional environment. Ristvet (1978) noted siderite only 75 cm sub-bottom depth in sediments off Hawaii, siderite appearing only after dissolved sulphate had been removed by reduction and growth of earlier pyrite. Hemingway (1974) cites evidence for the pre-compaction development of siderite from the study of the compaction of mudstones around irony concretions and the composition of some coal measure breccio-conglomerates. Many concretions show evidence of compaction around the body and where laminations pass through the body they invariably have greater spacing inside than outside. Shells enclosed in ironstone are also found commonly uncrushed whereas outside they are flattened. The common occurrence of ironstone pebbles in conglomerates with little or no other extra-formational material is also strong evidence for early siderite formation in coal measures.

The distribution of the cations within the ironstones ie their relative concentrations within the lower portion of the ironstone profile is compatible with the above model as is also the distribution of the macrofauna; the shelly ironstones being restricted to the shallower water areas where the ironstones are more

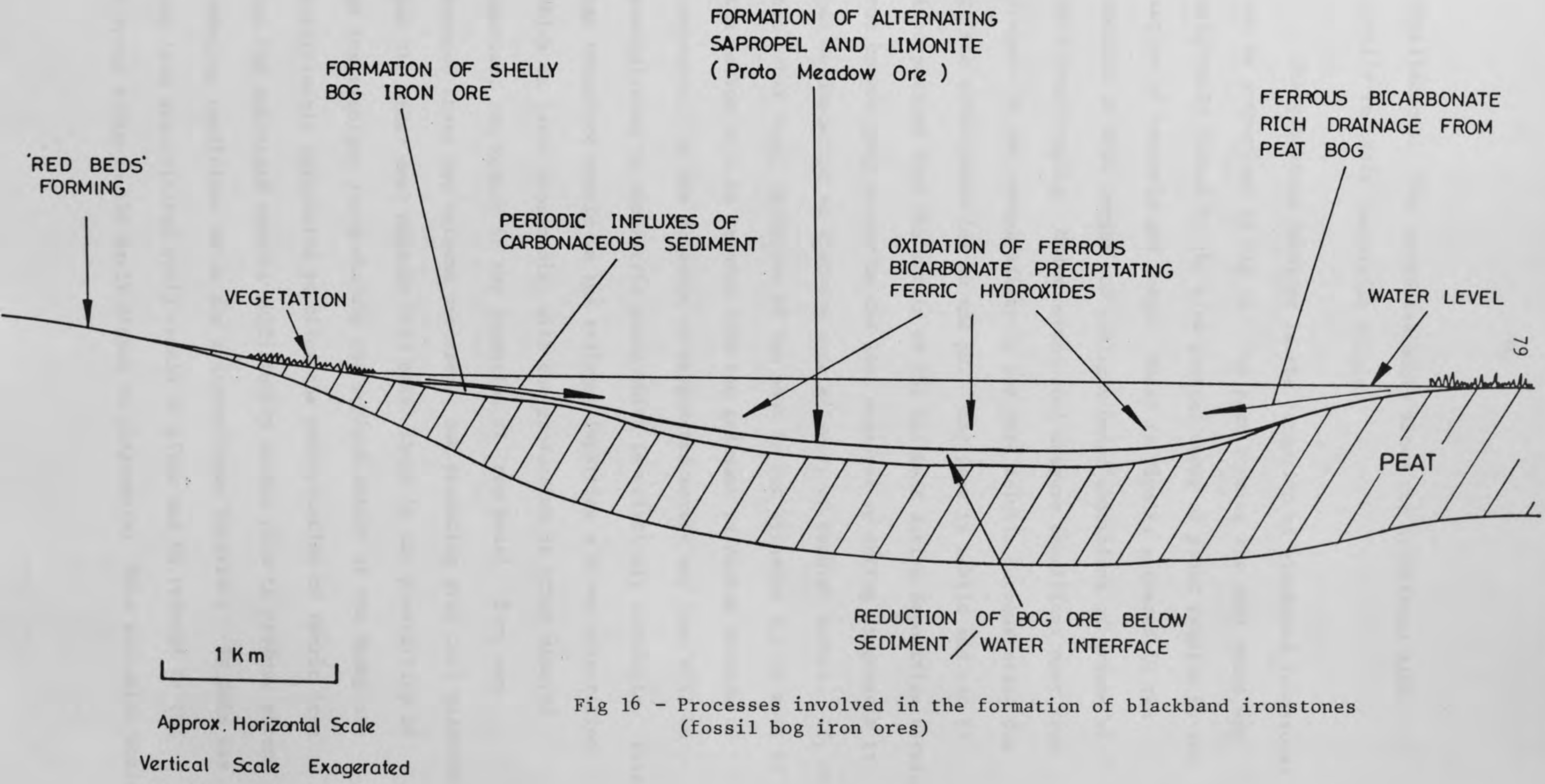


Fig 16 - Processes involved in the formation of blackband ironstones
(fossil bog iron ores)

argillaceous. The varved sediments above the ironstones also testify to their lacustrine origin.

The processes involved in the formation of blackband ironstones can be summarised in Fig 16. The peat forming the coal seams was originally formed by the slow partial decay of plant remains by the action of bacteria and fungi. Decay is finally arrested in the absence of free oxygen and sunlight under conditions of ground or soil waterlogging. Under normal coal measure conditions most iron present in the swamps exists in the more soluble ferrous state due to the established low Eh and pH. The iron is mobile and can be incorporated into the matrix of the sediment during deposition forming the common grey colour to the coal measures or during diagenesis it can be deposited as discrete concretionary or nodular bodies. If, on the other hand, oxidation of the peat is not arrested all or most of the carbon will be removed from the sediment as carbon dioxide or carbonate. In the presence of oxygenated waters any iron will be precipitated in the ferric state which is relatively insoluble. This can therefore remain in the sediment imparting a brown colouration which on later diagenesis, with the production of other mineral species, can result in the formation of 'red beds'. Part way between these two extreme processes, one producing grey coal measures and the other coal measure 'red beds' there is the possibility of an intermediate state whereby the surface waters of the swamp are sufficiently oxygenated to allow the precipitation of ferric iron but the substrate remains sufficiently carbon rich to produce strong reducing conditions below the sediment/water interface. In this way any iron precipitated would remain in place and be reduced to the ferrous state in the early stages of diagenesis. This situation would be possible in the circumstances just described in detail where the presence of a body of oxygenated water is developed upon a peat blanket within a coal measure swamp. As a result of such a situation, the conditions for the accumulation of precipitated iron and its subsequent reduction analogous to the formation of a bog iron ore would be possible.

These conditions would therefore be likely to be at an optimum towards the end of a coal forming period prior to a change to more a 'continental' period of sedimentation. It is not surprising to find blackbands well developed therefore at the top of a thick productive coal measure sequence in north Staffordshire prior to the onset of the red beds and the Etruria Marl Formation.

The genesis of the blackband ironstones and associated facies can be summarised therefore as follows:-

1. Development of a large lake with oxygenated surface waters on a peat blanket as a result of differential subsidence.

2. The lake receives iron rich bicarbonate waters draining from the higher surrounding peat bog.

3. Precipitation of ferric hydroxides brought about in the oxygenated surface waters of the lake. From time to time carbonaceous rich sediments are also brought into the lake. These together with the iron precipitate form alternating iron and carbonaceous rich layers on the lake bottom. (- Prolific shelly fauna existing in the shallower parts).

4. Cessation of drainage into lake due to drowning of surrounding peat blanket. Slight increase in argillaceous content of available sediment.

5. Period of almost very quiet sedimentation except for fine organic debris and a little clay minerals resulting in an accumulation of oil algae which have been living in the oxygenated surface waters.

6. Eventual influx of pro-deltaic muds, slowly at first with the development of fresh water varves.

Chapter Seven

Conclusions

7. Conclusions

All the evidence collected during the course of this study points to there being a distinctive, easily recognised layered sideritic carbonaceous ironstone known as a blackband ironstone which is developed to a greater or lesser degree in grey coal measure sequences. It is restricted in development to a sapropelic facies at a coal seam horizon or is formed in place of a coal seam. Blackband ironstones are often succeeded in the coal measure succession by oil shales and/or varved mudstones or shales of a lacustrine affinity. This ubiquitous association of facies together with evidence from the contained faunas and the presence of many primary textures all demonstrate a lacustrine environment of deposition. In the case of the north Staffordshire blackbands the relationship of the depositional environment to the other nearby marginal coal measure facies ie the calcareous ironstones and 'red beds' has been well established.

Their formation can be compared with Recent bog iron ores where iron is precipitated in the trivalent state often in colloidal form and is subsequently reduced in the top of the sediment pile. Oxygen is therefore a fundamental ingredient in their formation, the presence of which would at first sight appear to be excluded by the sapropel and coal developments which are intimately associated with the ironstones. However, the balance between oxygen availability and reducing conditions appears to have been extremely fine during Coal Measure times particularly in the Upper Coal Measures (although for the most part reducing), the controlling factor most likely being the relative position of the water table in relation to the top of the sediment pile. The presence of paleosols and partially oxidised coal seams and ironstones in the Upper Coal Measures bears witness to this fine balance (Besley personal communication).

Early diagenetic reduction of the precipitated ferric hydroxides appears to have taken place in the reducing conditions established in the top few metres of the sediment of the marsh lake bottoms. The presence of round sideritised spores, some uncrushed shells, the development of a seatearth profile in one ironstone (Blackband, Mitchell's Wood) under a thin rider coal seam, the intimate nature of the layering of the siderite and the carbonaceous rich layers of the ironstone all testify to a pre-compaction early diagenetic siderite formation. Much of the characteristic peloidal texture of the ironstones may well be the result of micro-reducing environments established within the sapropelic milieu, probably resulting from concentrations of bacterial activity around centres of rotting organic debris. The colloform textures and the presence of ooliths strongly suggest development from a colloidal precipitate.

The blackbands undoubtably represent fossil bog iron ores a genesis already ascribed by one author (Stanton 1972) although as with many previous authors no detailed petrographic or mineralogic evidence is cited in support of such a conclusion. Their development owes its origin to the establishment of a lacustrine environment with oxygen availability in the surface waters high enough to allow the oxidation and hence precipitation of complex iron hydroxides which are subsequently reduced to form siderite in the top few metres of the substrate.

Although carrying considerable high concentrations of iron (over 40%) in some sub-samples, the north Staffordshire blackband ironstones are generally thin and only the Bassey Mine appears to constitute an ore reserve over any considerable part of the coalfield. Most of the reserves in the upper three main ironstones in the exposed coalfield have been extensively worked and are now exhausted. There appears to be very little economic importance to be attached therefore to these ironstones.

If blackband type ironstones are present in a productive coal measure sequence at a target seam horizon (a seam of economic importance) their presence may herald the onset of or accompany changes in the quality of the seam due to the presence of cannel coal in part or all of the seam section, being the result of the establishment of an oxygenated body of water within the proto-coal peat swamp, precluding normal peat development. This process which is analagous to the formation of present day bog iron ores is more likely to be developed towards the top of a productive coal measure sequence during the final stages of the filling of the sedimentary basin when the probability of the establishment of significant lacustrine basins with oxygenated surface waters is higher than during the more normal coal measure forming conditions.

Chapter Eight

Recent New Provings of Blackband Ironstones in North Staffordshire

8. Recent New Provings of Blackband Ironstones in North Staffordshire

In the latter part of 1979 during the drivage of the new surface drifts (inclined access tunnels from the surface) at Silverdale Colliery, Silverdale, north Staffordshire for the Silverdale New Mine, the Blackband and Red Mine Coal and Ironstone horizons were encountered. In due course these two horizons were examined and pillar samples taken (approx location E3807 N3455).

The Blackband Ironstone was found to be approximately 50 cm thick passing upwards into a cannelly coal. Although well layered the ironstone is considerably more argillaceous than that sampled at Mitchell's Wood and contains many thin laminae packed with sideritised shell debris (Plate 29). The Red Mine Ironstone closely resembles the Bassey Mine as sampled at Apedale. It is extremely shelly with many of the shelly layers in the upper part of the ironstone being calcareous rather than sideritic (Plate 30).

These provings provide further visual evidence of the lateral change of the ironstones into a shelly argillaceous facies.

References

References

Bathurst, R G C 1971 Carbonate sediments and their diagenesis. Developments in Sedimentology 12, Elsevier.

Besley, B M 1979 Late Carboniferous sediments of north Staffordshire. North Staffordshire Group of the Geologists Association. Field meeting notes, May 1979.

Besley, B M and Turner P 1981 Origin of red beds in a moist tropical climate (Etruria Formation, Upper Carboniferous. UK)(in press).

Boardman, E L 1978 Blackband ironstones of the north Staffordshire coalfield. Trans North Staffs Journ Field Studies, 18, 1-13.

Borchert, H 1960 Genesis of marine sedimentary iron ores. Bull Inst Min Metal, 69, 261-279.

Bradley, W H 1929 The varves and climate of the Green River Epoch. Prof Paper 158-E, US Geol Surv. Washington DC.

Calver, M A 1968 Coal measure invertebrate faunas in 'Coal and Coal Bearing Strata', Oliver & Boyd, Edinburgh.

Cheney, E S and Jensen, M L 1965 Stable carbon isotope compostion of biogenic carbonates. Geochim et Cosmochim Acta, 20, 1331-1346.

Crookall, R 1929 Coal Measure Plants, Arnold, London.

Curtis, C D 1967 Diagenetic iron minerals in some British Carboniferous sediments. Geochim et Cosmochim Acta, 31, 2109-2123.

Curtis, C D 1977 Sedimentary geochemistry : environments and processes dominated by involvement of an aqueous phase. Phil Trans R Soc Lond A, 386, 353-372.

Curtis, C D, Pearson M D, and Somogyi, V A 1975 Mineralogy, chemistry and origin of a concretionary siderite sheet (clay-ironstone band) in the Westphalian of Yorkshire. Min Mag, 40, 385-393.

Curtis, C D, Petrowski, C, and Oertel, G 1972 Stable carbon isotope ratios within carbonate concretions, a clue to place and time of formation. Nature, 235, 98-100.

Curtis, C D and Spears, D A — 1968 — The formation of sedimentary iron minerals. Econ Geol, 63, 257-270.

Deer, W A, Howie, R A and Zussman, J — 1966 — An introduction to the rock forming minerals. Longmans.

Dewey, H in Strahan et al — 1920 — Carboniferous bedded ores, north Staffordshire. Special reports, mineral resources of Great Britain. Mem Geol Surv, 64-86.

Dickson, J A D — 1965 — A modified staining technique for carbonates in thin section. Nature, 205, 587.

Forsyth I H and Read, W A — 1962 — The correlation of the Limestone Coal Group above the Kilsyth Coking Coal in the Glasgow-Stirling region. Bull Geol Surv, 19, 29-52.

Fritz, P, Binda, P L, Folinsbee, F E, and Krouse, H R — 1971 — Isotopic composition of diagenetic siderites from Cretaceous sediments in western Canada. Journ Sed Pet, 41, 282-288.

Gibson, W — 1925 — The geology of the country around Stoke-on-Trent. Mem Geol Surv.

Hemingway, J E — 1968 — Sedimentology of coal bearing strata in Coal and Coal Bearing Strata (Edit Murchison D G and Westoll T S). Oliver & Boyd,London.

Ho, C and Coleman, J M — 1969 — Consolidation and cementation of Recent sediments in the Atchafalaya basin. Bull Geol Soc Amer, 80, 183-192.

Hoare, R H — 1960 — Red beds in the coal measures of the West Midlands. Trans Inst Min Eng, 119, 185-198.

Homer, C J — 1875 — The north Staffordshire coalfield with the ironstones contained therein. Trans North Staffs Inst Min and Mech Eng, 2, 1-11.

Hudson, J D — 1977 — Stable isotopes and limestone lithification. Journ geol Soc Lond, 33, pt 6, 637-658.

James, H L — 1966 — Chemistry of the iron-rich sedimentary Rocks in Data of Geochemistry. US Geol Surv Prof Paper 440-W.

Lumsden, G I	1964	The Limestone Coal Group of the Douglas coalfield, Lanarkshire Bull Geol Surv, 21, 37-61.
Macgregor, M, Lee, G W and Wilson, G V	1920	Special reports of the mineral resources of Great Britain. Vol 2, Iron Ores. The iron ores of Scotland Mem Geol Surv.
Macgregor, M and Macgregor A C	1948	Midland Valley of Scotland. British Regional Geology, 2nd Edit (revised) Geol Surv.
Malkin, A B	1961	Contributions to the study of the stratigraphy of the north Staffordshire coalfield. Unpubl MSc Thesis, Univ of Manchester.
McCrea, J M	1950	On the isotopic chemistry of carbonates and a palaeotemperature scale. Journ Chem Phys, 18, No 6, 847-857.
Moore, D D and Bellamy, D J	1974	Peatlands. Elek Science, London.
Moore, L R	1968	Cannel coals, bogheads and oil shales in 'Coal and Coal-bearing Strata' Edits Murchison, D G and Westoll, T S. Oliver & Boyd, London.
Oertel, G and Curtis, C D	1972	Clay-ironstone concretions preserving fabrics due to progressive compaction. Bull Geol Soc Amer, 83, 2597-2606.
Pettijohn, F J	1957	Sedimentary Rocks. Harper, New York.
Picard, M D and High, C R	1972	Criteria for recognising lacustrine rocks in 'Recognition of Ancient Sedimentary Environments', Ed Rigby et al. Soc Econ Palaeont & Min, Sp Pub 16.
Pollard, J E, and Wiseman J F	1971	Algal Limestones in the Upper Coal Measures (Westphalian D) at Chesterton, north Staffordshire. Proc Yorks Geol Soc, 38, Pt 3, No 15, 329-342.
Postma, D	1977	The occurrence and chemical composition of Recent Fe-rich carbonates in a river bog. Journ Sed Pet, 47, No 3, 1089-1098.
Ristvet, B L	1978	Reverse weathering reactions within Recent nearshore marine sediments. Kaneohe Bay, Oahu. Doctoral Thesis, Northwestern Univ, Evanston, Illanois.

Sass, E and Kolodny, V 1972 Stable isotope chemistry and petrology of carbonate concretions (Mishah Formation, Israel). Chemical Geology, Elsevier, Amsterdam.

Shrock, R R and Twenhofel, W H 1953 Principles of Invertebrate Palaeontology. McGraw Hill, New York.

Stanton, R L 1972 Ore Petrology. McGraw Hill, New York.

Smith, A H V 1968 Seam profiles and seam characters in Coal and Coal-bearing Strata' Edits Murchison, D G and Westoll, T S. Oliver & Boyd, London.

Smith, A H V and Butterworth, M 1967 Miospores in the coal seams of the Carboniferous of Great Britain. Special Papers in Palaeontology No 1, Palaeontological Assn, London.

Stout, W 1944 The iron ore bearing formations of Ohio. Geol Surv Ohio, 4th series, Bull 45.

Sprunk, G C 1941 Influence of physical constitution of coal upon its chemical, hydrogenation and carbonization properties. Univ Chicago 5th Anniversary Celebration, p 411-420.

Trotter, F M 1950 Genesis of a fuel series of rising rank : top peat to fat bituminous coal. Proc Yorks Geol Soc, 28, 152-156.

Trotter, F M 1953 Reddened beds of Carboniferous age in north-west England and their origin. Proc Yorks geol Soc, 29 Pt 1, No 1, 1-20.

Trueman, A E 1946 Stratigraphical problems in the coalfields of Great Britain. Q Jl geol Soc Lond, 103, 65-104.

Trueman, A E 1954 Coal in Great Britain. Arnold, London.

Walker, T R 1967 Formation of red beds in modern and ancient deserts. Bull geol Soc Amer, 78, 353-368.

Walker, T R 1974 Formation of red beds in moist tropical climates : a hypothesis. Bull geol Soc Amer, 85, 633-638.

Wanless, H R 1969 Marine and non-marine facies of the Upper Carboniferous of north America. Compte Rendu, Vol 1, 293-328.

Yen, T F and Chilingarian, G V 1976 Oil Shale. Developments in petroleum science, 5. Elsevier, Amsterdam.

Zitzmann, A (Ed) 1978 The iron ore deposits of Europe and adjacent areas, Vol 2. Fed Inst Geosci & Nat Res, Hanover.

Appendix I

Blackband Ironstones of the North Staffordshire Coalfield

North Staffordshire Journal of Field Studies
Vol 18, 1978, 1-13

Reprinted from The North Staffordshire Journal of Field Studies, Volume 18, 1978

THE BLACKBAND IRONSTONES OF THE NORTH STAFFORDSHIRE COALFIELD

E. L. BOARDMAN

The north Staffordshire coalfield has long been an area of intense mining and industrial activity. The wealth of the district was founded on the easily accessible clays, coals and ironstones of the exposed part of the coalfield. During the mid-nineteenth century, ironstones, particularly those of black-band character, the blackband ironstones, formed the mainstay of a thriving iron industry. Little detailed investigation has been carried out regarding the mineralogy of these ironstones and the limited published information is supplemented only by a few bulk chemical analyses. Recent exposures in a coal opencast site at Mitchell's Wood, Red Street, 4½ miles northwest of Stoke and a privately owned coal mine at Apedale, Chesterton, some 1½miles further southwest, together with information from recent National Coal Board deep boreholes, have provided an opportunity to study the ironstones and their associated measures in more detail (Fig. 1).The following is an account of the history of research, together with a

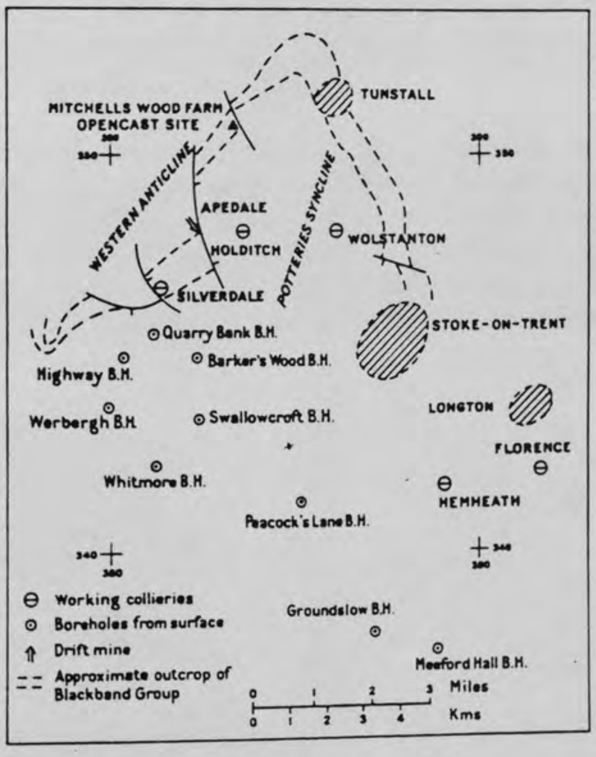


FIGURE 1. Location of recent provings in the Blackband Ironstone, north Staffordshire coalfield.

contribution to the stratigraphy of the blackband ironstones and some preliminary results of a more detailed examination of their occurrence.

HISTORY OF RESEARCH

Stratigraphy

The results of the first geological survey of the north Staffordshire coalfield were published in map form during the years 1852-1864, the Coal Measures having been mapped by Smyth, who, during this period (Smyth, 1862) published a memoir on the ironstones. He divided the Coal Measures into four groups, in descending order: first, Upper Measures; second, Pottery Coals and Ironstone Measures; third, Lower Thick Measures; and fourth, Lowest Measures.

The blackband ironstones were included, with the clay ironstones occurring lower in the sequence of strata, in his second group, the Pottery Coals and Ironstone Measures. Considerable variability of the ironstone development was noted but some of this can be explained by inconsistencies in the naming of the same ironstones in different parts of the coalfield. He was, however, the first to document that the ironstones are not individually developed over the whole of the coalfield and was also the first to describe the 'typical' black-band character. Regarding the Red Shag (Shagg) Ironstones, he states:

> This bed, at Shelton, lies immediately upon a foot coal and is 15 to 17 inches thick, exhibiting numerous laminae of deposition which, in the transverse section, give a multitude of brown and black stripes, generally from 1/20 to 1/4 of an inch in thickness.

The presence of *Anthracomya (Anthraconauta)* in abundance in some laminae was recorded, together with Stigmariae, *Spirorbis*, fish remains and coprolites.

Despite the correlation problems evident in Smyth's work, Bradbury (1861) recognised that the highest ironstone, the Blackband Ironstone, was being worked at several collieries in the north, west and southeast of the exposed coalfield and he published the first generalised succession of the blackband ironstone measures:

	Yd.	*Ft.*	*Ins.*
Blackband Ironstone		1	6
Strong Bass	14	0	0
Red Shagg Ironstone 4ft. Coal, 1ft. 9ins.	1	2	9
Rocks, Binds and Bass	24	0	6
Red Mine Ironstone 2ft. 9ins. Coal 2ft.	1	1	9
Metal, Coal and Bass	10	1	6
Coal		1	8
Rock, Binds, Coal and Bass	19	0	0
Coal		1	0
Rock, Linsey and Bass	25	0	6
Coal		1	0
Warrant, Rock and Strong Metal	24	0	0
Bassey Mine Ironstone 4 ft. Coal 1ft. 6ins.	1	2	6

Homer (1875) later published details of his provings at Chatterley Collieries, Tunstall, in the north central part of the coalfield, and Cadman (1901) examined the mode of working and treatment of the ironstones. Their findings are summarised in Table 1.

TABLE 1

Details of the blackband ironstone horizons in the Tunstall area

Horizon	*Depth in yards below (Blackband) Half-Yards*	*Remarks*
Half-Yards (Blackband) Ironstone and Coal	0	1ft. 6ins. to 5ft. 6ins. 1st class quality ironstone overlying a moderately good household coal (1ft.—2ft. 6ins.) with a seatclay floor averaging 3ft. of excellent quality; used largely for brickmaking or as a fireclay. Contains larger *Anthraconauta phillipsi* than usual, although not so abundant as in the Red· Mine.
Red Shagg Ironstone and Coal	21	Seatearth roof with an oil shale immediate roof to the ironstone, yielding 12-15 gallons heavy oil/ton. Ironstone 2ft. 6ins. to 6ft. of excellent quality overlying a coal (1ft. 6ins.—2ft.) of inferior quality. *Stigmaria* common on bedding planes.
Red Mine Ironstone and Coal	40	Oil shale (1ft. 6ins.) roof yielding 28 gallons oil/ton; ironstone 2-4 ft. extremely rich overlying a coal (2ft.) of moderate quality.
Coal (Clod)	60	3-4 ft. fair quality.
Hoo Cannel	77	Cannel yielding 25-30 gallons oil/ton, with a coal 8ins. thick and a band of ironstone 9ins. thick.
Bassey Mine Ironstone and Coal	101	Ironstone 1ft. 6ins—5ft., rich in quality, overlying a coal(8ins.—2ft.); used as a fuel in brickmaking and other common purposes.

Sources: HOMER (1875); CADMAN (1901)

In various sections published prior to this date. a thin bed of impure limestone had been recognised, containing *Spirorbis* at a position close above the Bassey Mine horizon, and Ward (1890) suggested its usefulness as a palaeontological marker. In his treatise he suggested a tripartite division for the Coal Measures into Upper, Middle and Lower; the Upper division embracing a considerable portion of the uppermost measures of the coalfield, 'consisting an alternating series of red, purple and variegated marls, several thin coals and three or four seams of blackband carbonaceous ironstone, together with a thin band of limestone'. The subdivision was generally on a lithological basis and was the first recognition of a group of strata containing ironstones with the distinctive black-band character. However, Ward excluded from this Upper division the Bassey Mine Ironstone and Coal, preferring to draw a base at the Spirorbis limestone close above the Bassey Mine horizon.

Following the re-survey of the coalfield by Gibson and Wedd during the years 1898-1901, the Carboniferous measures above the Bassey Mine were grouped into four divisions, local names being given as follows: (4) Keele Group; (3) Newcastle-under-Lyme Group; (2) Etruria Marl Group; and (1) Blackband Group.

This subdivision now provided a separate group for the blackband ironstones and their associated measures exclusively. Gibson and Wedd (1905) defined the base of their Blackband Group as the easily mappable Bassey Mine horizon, in contrast to Ward's Spirorbis limestone (Malkin (1961) having shown that this limestone horizon is composed of two distinct beds separated by some 20 to 25 ft. of mudstone and shale), and the upper junction of the Group taken at the base of a green sandstone occurring a short distance above the Blackband Coal and Ironstone. It is not clear why this was chosen in preference to the more readily defined Blackband horizon. Gibson (1905) stated that the subdivision was based on distinct lithologies with characteristic faunas and floras. However, the groups were not well defined and lacked a palaeontological framework, making inter-coalfield correlation impossible. Hind (in Kidson, 1905) attacked this work and showed that there was no palaeontological break at the Bassey Mine horizon. Gibson (1925) later recognising this fact, suggested that the base of his Blackband Group could be lowered to the Cannel Row horizon.

Work on the non-marine lamellibranchs by Davies and Trueman (1927), refining the zonal scheme originally proposed by Hind, confirmed the continuity of fauna from below the Bassey Mine through the Blackband Group and up into the Etruria Marl Group. The

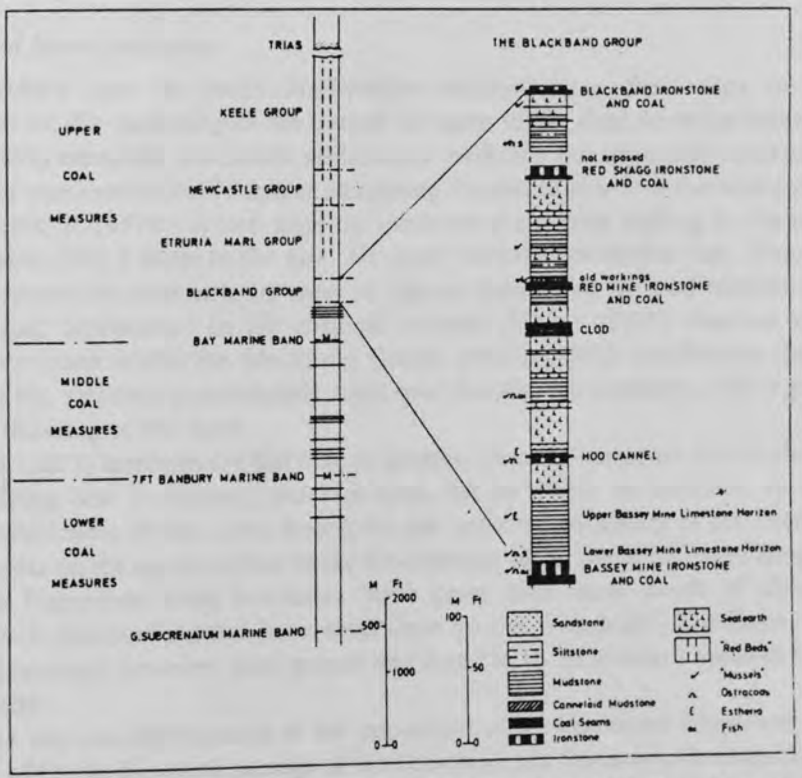


FIGURE 2. Generalised sequence of the Coal Measures of the north Staffordshire coalfield and a detailed Blackband Group succession (based on Mitchell's Wood opencast site (upper 200 ft.) and Wolstanton Colliery no. 3 shaft).

Blackband Group subdivision is, therefore, one of lithostratigraphic significance only, composed of a succession of measures including ironstones exhibiting a black-band character. As is present day practice, its limits can best be defined as the dominant uppermost and lowermost blackband ironstones, namely, the Blackband and Bassey Mine Ironstones. Other localised minor occurrences of poorly developed ironstones with black-band character, or semi-blackbands, have been recorded from within the Blackband Group and both the Etruria Marl Group and the upper part of the Middle Coal Measures (Gibson, 1905 and 1901; Malkin, 1961).

More recently, Malkin (1961), drawing his material from the reconstruction shaft sinking at Wolstanton Colliery, supplemented by data from quarries and underground at various collieries in the district, concentrated on the description and correlation of the minor seams between the major coal and blackband ironstone horizons, and Earp (1961) recorded the findings of the post-war N.C.B. drilling programme up to 1954. Both authors contributed to the palaeostratigraphy of the Blackband Group. In Figure 2 the general stratigraphy of the Blackband Group is outlined at its best development in the centre of the exposed coalfield and its relative position in the north Staffordshire Coal Measures succession.

Vertical and lateral variation

Researchers into the north Staffordshire coalfield have, from time to time, commented on the variability of the overall thickness of the Coal Measure succession. Gibson (1901) noted the association of thickness variations and structural variation; the thickness of productive Coal Measures composing the anticlinal area to the west differing by some 1,500 ft. (457m) in total from the thickness of measures making up the central synclinal area only 3 miles to the east. He drew the valid conclusion that 'This great variability seems to show separate areas of deposit marked out by local movements of elevation and depression.' In his coalfield memoir, Gibson (1905) observes similar thickness variation within the Blackband Group. Malkin (1961) corroborates this and shows that the variation is particularly rapid over the Western Anticline, with a general less rapid thinning to the south.

Homer (1875) mentions the fact that, in general, when the ironstone is at its thickest, the underlying coal is thinnest, and vice-versa, but he makes no comment as to the possible significance of this. Like Smyth, he also notes the variability of the ironstones and comments on the southern limit to the development of the Blackband, Red Shagg and Red Mine Ironstones: these ironstones 'have never been found south of Cobridge, although their indicated position has several times been sunk through'. The Bassey Mine Coal and Ironstone, however, were proved and found to be 'of ordinary uniform quality and thickness'.

Besides this non-development of the uppermost of the blackband ironstones in the area south of Stoke, the lateral passage of the ironstones into limestones towards the west and extreme south has been noted by several authors (Cadman, 1901; Gibson, 1905 and 1925; and Dewey, 1920). No details of this facies change have been published but Gibson (1925) suggested the possibility that the blackband ironstones represent an original calcareous rock in which the calcium has been replaced by iron. Trotter (1953), however, regarded the interbedding of the ironstones with coal 'a clear indication of contemporaneous deposition'. Cadman (1901) also noted lateral changes into cannel and canneloid ironstones.

Malkin (1961) noted the persistence of certain beds of red or mottled mudstone in the coalfield, and that, in general, these 'red beds' were more frequent in the southern part of the coalfield and absent in the lower part of the Blackband Group in the northern part. He comments that their variability and colour point to a secondary origin and he suggests, like Hoare (1960) an origin dependent on the variation in the level of the water table after deposition.

Ironstone mineralogy

Various bulk chemical analyses of the blackband ironstones have been published, those of Dewey (1920) being the most comprehensive. The ironstones are carbonaceous siderites and have been found to average 37% iron in the raw stone, with a range from 29 to 42% iron; the Red Mine Ironstone being the richest. They vary in thickness up to 6 ft. (1.8m) exceptionally 14 ft. (4.3m) thick, with an average thickness of 2 ft. 6 ins. (0.76m). Carbonaceous matter content in some instances is as high as 30%. MnO and CaO concentrations vary from 1 to 2.5% and 0.5 to 16% respectively, the higher CaO percentage being in samples from the Silverdale area, presumably reflecting the increase in lime content in that area. Cadman (1901) notes the presence of 'minute crystals of galena and zinc blend very sparingly diffused through the ore'. The relative occurrence of other cations can be seen from Table II.

TABLE II

Chemical analyses of some blackband ironstones

	Silverdale seam name				*Chatterley seam name*			
Chemical element	*Black-band*	*Red Shagg*	*Red Mine middles*	*Red Mine bottoms*	*Black-band*	*Red Shagg*	*Red Mine*	*Bassey Mine*
Fe	34.42	35.17	32.56	41.80	39.10	35.40	39.58	38.71
CaO	3.00	2.34	3.02	2.24	0.53	0.64	2.07	2.23
MgO	1.08	1.34	2.41	1.01	0.25	0.20	0.80	1.94
MnO	1.70	2.50	1.10	1.26				
P_2O_5	0.61	0.51	0.60	0.54	0.83	0.99	0.62	0.51
H_2SO_4	trace	0.28	—	nil	trace	0.32	0.10	0.48
Al_2O_3	1.45	1.20	0.51	1.00	0.20	0.32	0.73	0.45
SiO_2	2.20	2.00	4.07	0.51	0.15	0.50	1.11	0.27

Source: CADMAN (1901)

The ironstone, in general, decreases in iron quality in an upward direction. This is exemplified in the above table in the Red Mine, where the 'middles', the middle portion of the seam, as worked, has a lower iron concentration than the 'bottoms', the basal part of the worked section.

MATTERS ARISING FROM PAST RESEARCH

The Blackband Group (defined as the measures between the Blackband and Bassey Mine horizons) exhibits thickness variation—a general southerly thinning with a much more rapid thinning over the Western Anticline. The Blackband Group contains four prominent ironstones of black-band character-banded canneloid-carbonaceous siderites, all occurring above and sometimes interlayered with a coal seam. The upper three (Blackband, Red Shagg and Red Mine Ironstone) are not developed south of Stoke-on-Trent, but the lowest, the Bassey Mine, is present. The ironstones have also been noted to pass laterally into limestones in the area of the Western Anticline and in the extreme south. The fauna is dominated by *Anthraconauta phillipsi* and plant fragments, with some occurrences of *Estheria, Spirorbis,* ostracods and fish remains.

Seatearths and mudstones are the dominant lithologies of the group, with 'red beds' developed at distinct horizons, particularly in the south in the coalfield. Sand and silt grades are generally rare and thin and impure *Spirorbis* limstones are developed at certain horizons. The ironstones each average 2ft. 6ins. thick, with 37% metallic iron content and up to 30% carbonaceous matter, the richer part of the seam being that near the base. Their possible origin in calcareous rocks subsequently replaced by iron has been suggested (Gibson, 1925). However, Trotter (1951) regards their interbedding with coal 'a clear indication of contemporaneous deposition'.

PRELIMINARY RESULTS OF PRESENT RESEARCH

Lateral passage of ironstones into limestones

Results of a records search at the National Coal Board's Western Area Geological Service has revealed documentation of the facies change of the Bassey Mine Ironstone into limestone in the Silverdale and Apedale areas. A vertical section compiled from data collected in the Great Row Back Crut (cross-measure drivage) dated 1945-6 (E.381730m, N.345972m, to E.381700m, N.345620m), which proved the measures between the Clod and Spencroft seams, records the following lithological detail at the Bassey Mine horizon:

		Thickness ft.	ins.
	Mudstone	1	2
	Mudstone with *Carbonicola vintii*	0	8
	Limstone	1	3
	Blackband ironstone	1	3
	Cannel and brazels (nodular ironstone and coal)	2	3
	Ironstone with ostracods *Carbonita sp.*	0	2
BASSEY	COAL	2	10
MINE	dirt	0	11
COAL	COAL	0	9

Comparison with surrounding borehole sections confirms this as the Bassey Mine horizon.

A drawn section of Forge Pit, Chesterton, (E.382700, N.349600 approx.) obtained from information from the Shelton Iron & Steel Co. Ltd. by F. W. Cope and dated 25 November 1946, records 'Limestone 31'0"?' close above the Bassey Mine horizon. This sinking also proved the Blackband, Red Shagg and Red Mine Ironstones but there is no evidence of this facies change affecting these upper ironstones.

Further details of the facies change are afforded by borings for the Spencroft Surface Return Drift at Silverdale Colliery drilled in 1973. Three boreholes proved the Bassey Mine horizon, Silverdale Return Drift Borehole Nos. 3, 4 and 5. All three proved the Bassey Mine seam overlain by 12 to 13ft. (4m) of limestones and calcareous shales with an *Anthraconauta* and ostracod fauna.

Samples of the Bassey Mine Ironstone have recently been obtained from the privately owned Apedale Colliery. These constitute continuous 'pillar' samples of the ironstone and complement spot samples taken in October 1976, when the Bassey Mine was first accessed. Some preliminary results are presented below.

Lateral passage into 'red beds'

Exploration by the National Coal Board during the past 11 years has provided borehole data which has enabled the identification of the Blackband Group in the south and southwest of the known coalfield. The Blackband Group in these new boreholes has been correlated in detail and compared with the successions well documented in the coalfield to the north. As a result, information concerning the disposition of the 'red beds' within the Blackband Group has come to light.

Figure 3a illustrates a section NNW-SSE across the central and southern parts of the coalfield, from the disused Parkhouse Colliery in the north to Meaford Hall and Hobbergate boreholes in the south. No 'red beds' are recorded in the Blackband Group at

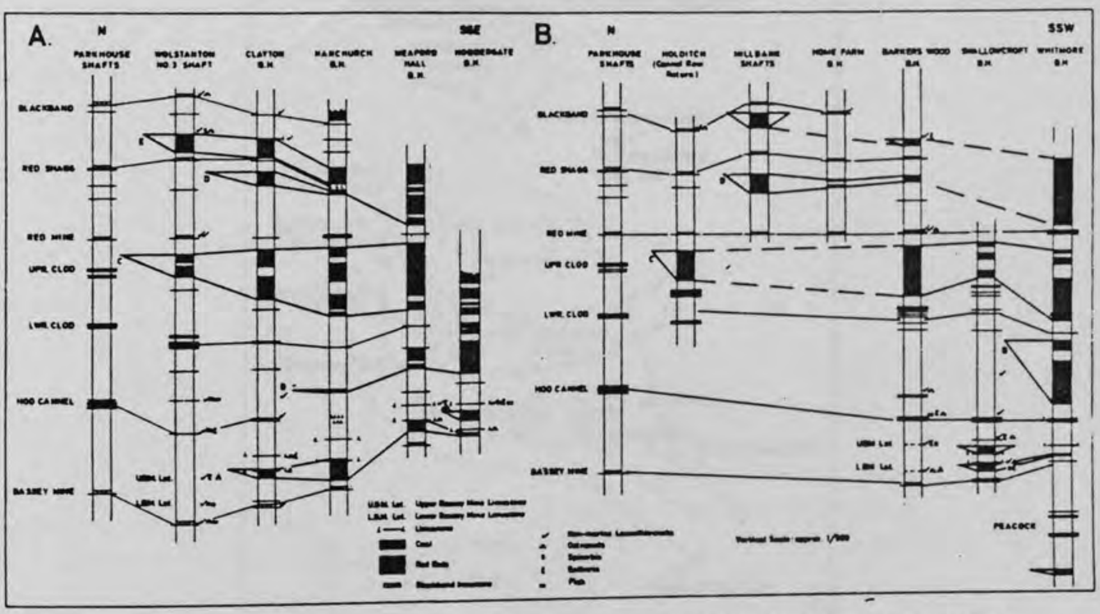


FIGURE 3. Diagrammatic cross-sections of the interwedging of red beds into the north Staffordshire Blackband Group succession.

Parkhouse Colliery, a fact which is confirmed by the author's recent observations in Mitchell's Wood opencast site about ¾ mile to the northwest. 'Red beds' are recorded at two distinct horizons in Wolstanton No. 3 Shaft. The upper horizon is 8ft. 3ins. (2.5m) above the Red Shagg Coal and Ironstone and consists of 9ft. (2.7m) of unbedded mottled red-brown mudstones, and the lower horizon of similar lithology, some 24ft. (7.3m) below the Red Mine and 12ft. (3.65m) thick. These two horizons can be correlated in Clayton and Hanchurch boreholes to the south and the lower horizon can be recognised in Meaford Hall borehole in the far south when nearly all the Red Mine-Clod internal is occupied by poorly bedded khaki, chocolate and brown mottled mudstones. The lateral persistence of these and other coloured beds, together with the presence, though poorly developed, of the main coal horizons, has allowed the Blackband Group, with the exception of the uppermost Blackband Coal, to be correlated with confidence, even though many of the faunal marker horizons recognised in the coalfield to the north are absent.

In general, the individual 'red beds' thicken to the south, the upper ones being more prominent in the north. They interfinger or wedge northwards into the grey sediments of the Blackband Group between the main coal horizons. The tops of the 'wedges' (A-E, Fig. 3) are generally at a constant horizon, whereas their bases cut down progressively into lower horizons within the adjacent grey measures when traced southwards before joining with a lower group of 'red beds'.

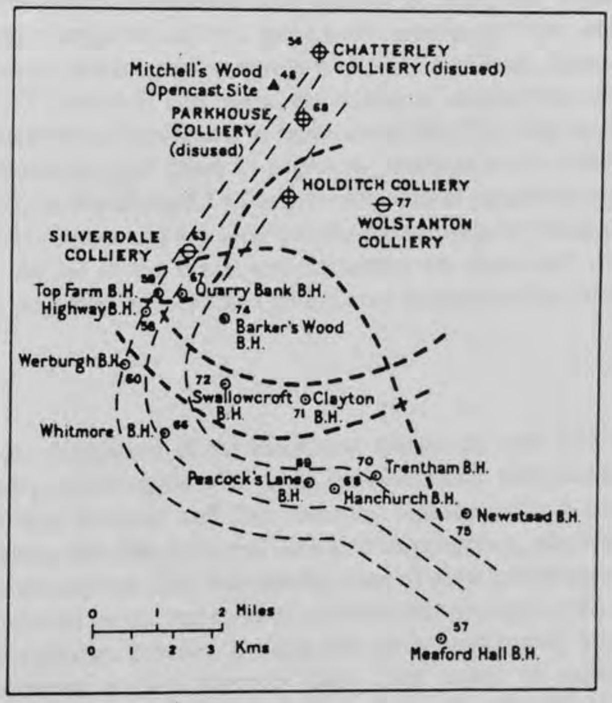


FIGURE 4. Red Mine—Bassey Mine interval (metres). Corrected for dip where appropriate with approximate maximum extent of red bed wedges.

The presence of 'red beds' within a deltaic sequence is indicative of sedimentation under oxidising conditions and subsequent oxidation of the sediment during diagenesis. Most continental 'red beds' are now thought to be reddened by the diagenetic breakdown of iron silicate minerals into hematite plus clay minerals (Walker, 1967). This is so for both the arid climate (red beds with evaporites) and the humid climate (red beds with Coal Measures) associations recognised by Walker (1974). Hoare (1960) and Malkin (1961) have suggested relative movements of the water table after deposition as a possible mechanism for the formation of 'red beds' within typical grey Coal Measures. Hoare specifically linked this movement with phases of emergence during the first stages of the Malvernian earth movements in the west Midlands.

The wedge shaped interfingering of the red and grey measures exhibited in Figure 3 is typical of a major diachronous lateral facies change and represents the base of the Etruria Marl facies of the Upper Coal Measures cutting down into the grey measures of the Blackband Group in a general southerly direction. The common horizon of the tops of the 'wedges' indicates rapid and laterally extensive periodic halts to the red bed forming process; the top of the wedge marking the beginning of a period of established reducing conditions during which the succeeding coal is laid down. This could represent a period of submergence, as opposed to emergence during which the underlying coloured rocks were formed. The submergence could possibly be due to a rise in sea level some distance away from the area of grey bed deposition affecting the water level and extending the area of grey bed development southwards into the area in which the Etruria Marl facies was established; these changes in sea level being a continuation of those which had previously produced temporary marine environments within the coal basin forming the well-known 'marine bands'. The vertical and lateral association of sedimentary environments of the Upper Coal Measures is interpreted as representing the final stages of the 'silting up' of the north Staffordshire coal basin in a general south to north direction. This simple picture, however, is complicated by the presence of local positive areas, e.g. the Western Anticline, and fluctuations in sea level producing an irregular wedging of red and grey facies (Fig. 4). As far as the blackband ironstones are concerned, there is therefore a possibility that they may be associated with a very distinctive and restricted depositional environment.

Sedimentology

The intimate association of the blackband ironstones with coal and cannel coal, a fauna composed predominantly of mussels *(Anthraconauta phillipsi)* and ostracods, with some *Spirorbis* and *Estheria* and fish remains, together with a consistent mudstone lithology with some very fine light and dark grey interlayering, all point to a very specific environment of deposition. The fine interlayering of some mudstones with a 'varve-like' appearance, produced by the variation of carbonaceous content in the thin layers, closely resembles lacustrine clay deposits. Besides this finely interlayered lithology, some of the blackband ironstones studied recently have been noted to exhibit other primary structures, including seatearth textures and root disturbed laminae subjacent to a coal bed, and also interlayering of ironstone and coal, indicating that the environment was

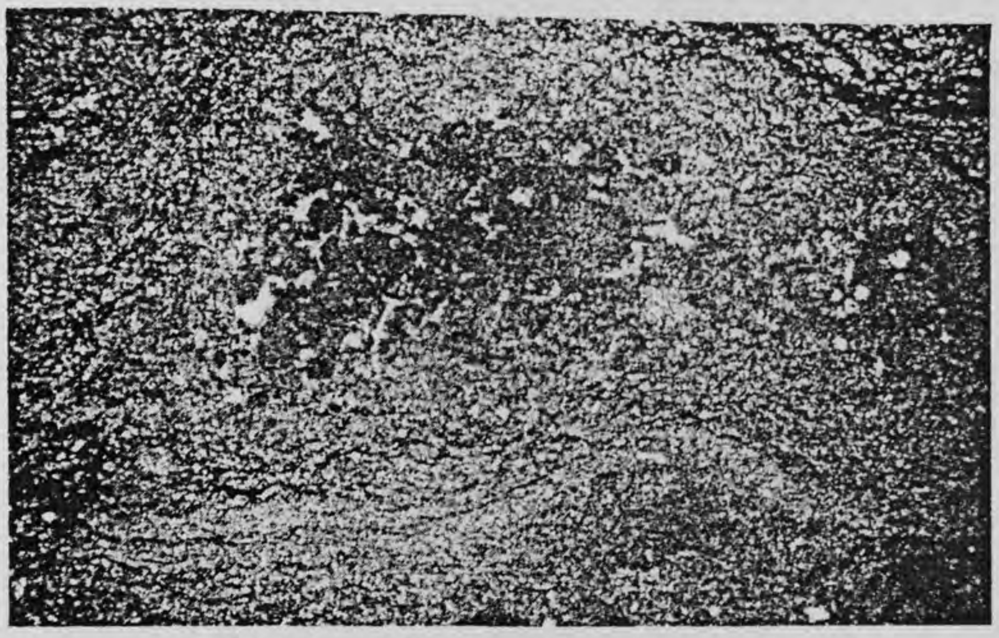


PLATE 1. Nodule of microcrystalline siderite with peloidal texture, Blackband Ironstone, Mitchell's Wood opencast site. Note sideritised non-marine lamellibranch shell towards bottom of photomicrograph. Thin section in plane-polarized light (x 50).

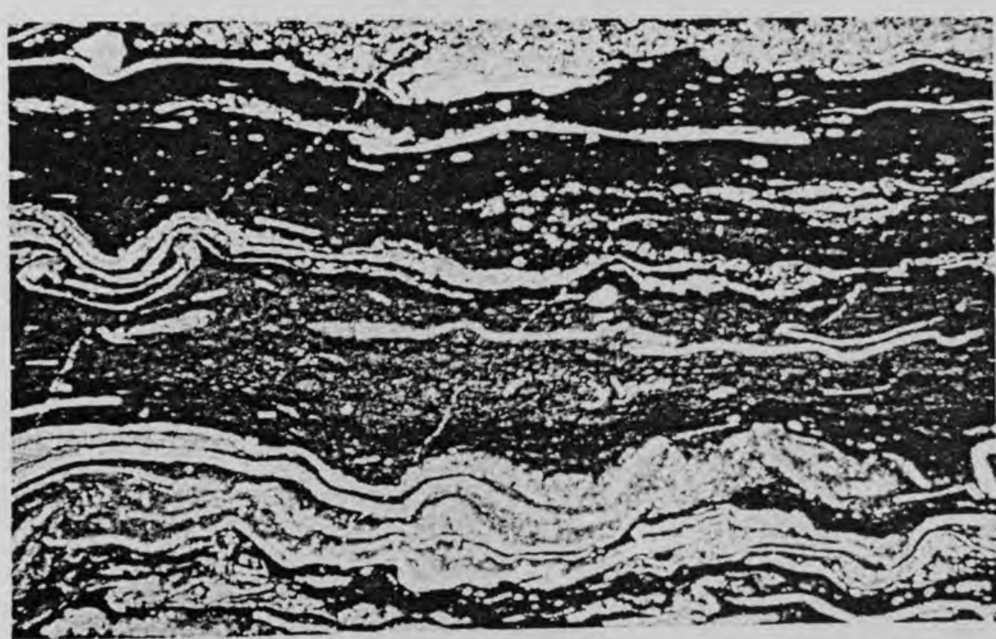


PLATE 2. Laminated calcite (non-marine lamellibranch shells), siderite and organic material, Bassey Mine Ironstone, Apedale. Thin section in plane-polarized light (x 50).

locally colonised by plants.

Thin sections show the blackbands to be predominantly siderite mudstone with a distinctive peloidal texture. The siderite is interlayered with carbonaceous laminae; the varying proportion of siderite and matrix producing the black and grey banded nature from which the ironstone acquires its name (Plate I). The Bassey Mine Ironstone from Apedale, a private colliery near the area in which the ironstones pass into limestones, is textually and mineralogically the most varied of the ironstones so far investigated. Siderite, calcite and dolomite occur in intimate association. The peloidal texture is still apparent but calcite shell debris (ostracods and 'mussels') is common, filled with clay or dolomite (Plate 2).

The blackband ironstones show many features which indicate that they are a distinctive lithology produced in a specific depositional environment. The evidence suggests that siderite was produced during early diagenesis, possible just below or at the sediment/water interface. They are thus in sharp contrast to the well-known Carboniferous clayband-ironstones. These occur in a variety of mudstone or shale sequences and vary from sheet-like to nodular bodies. They show no specific textural features and their mineralogy is quite different from that of the blackband ironstones. The claybands are interpreted by Curtis *et al* (1975) as diagenetic segregations produced during burial.

CONCLUSIONS

The Blackband Group of the north Staffordshire coalfield can, as is present day practice, be conveniently defined as the measures between the Blackband and Bassey Mine Coal and Ironstone horizons being a useful lithostratigraphic subdivision of the Upper Coal Measures in the exposed part of the coalfield containing carbonaceous ironstones commonly exhibiting a distinctive banded appearance; the blackband ironstones.

These ironstones are without exception intimately associated with coal and cannel coal and often carry a rich mussel and ostracod fauna, together with *Estheria, Spirorbis* and fish remains. Detailed examination of their petrography has revealed that the siderite is present in a peloidal form, set with varying density in a carbonaceous matrix, unlike the more common fine grained discretely banded or nodular concretionary clay ironstones. They have also been noted to exhibit primary structures such as root disturbed laminae and occur in close association with finely interlaminated 'varve-like' mudstones.

The preliminary evidence suggests a very early diagenetic siderite formation possibly in a lacustrine environment; an environment which may have been one marginal to a positive area to the south associated with the northerly advance of the 'Etruria Marl' facies during the later stages of the filling of the north Staffordshire coal basin.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of the National Coal Board both for their financial support and permission to utilise records held at their Western Area Geological Service, Stoke-on-Trent, and would also like to thank Dr. P. Turner, Aston University, and Mr. R. H. Hoare, N.C.B., for helpful criticisms of the original manuscript. The author also acknowledges the research facilities granted by the University of Aston.

REFERENCES

BRADBURY, J. (1861). The north Staffordshire coalfield. *Trans. Manchester geol. Soc.* 3, 255-276.

CADMAN, J. (1901). The occurrence, mode of working and treatment of the ironstones found in the north Staffordshire coalfield. *Trans. Fed. Inst. Min. Eng.* 22, 89-112.

CURTIS , C. D., PEARSON, M. J. and SOMOGY, V. A. (1975). Mineralogy, chemistry and origin of a concretionary siderite sheet (clay-ironstone band) in the Westphalian of Yorkshire. *Min. Mag.* 40, 385-393.

DAVIES, J. H. and TRUEMAN, A. E. (1927) A revision of the non-marine lamellibranchs of the Coal Measures, and a discussion of their zonal sequences. *Q. Jl. geol. Soc. Lond.* 83, 210.

DEWEY, H. (1920). Carboniferous bedded ores, north Staffordshire in STRAHAN *et al. Special reports, mineral resources of Great Britain.* Mem. geol. Surv. 64-86.

EARP, J. R. (1961). Exploratory boreholes in the north Staffordshire coalfield. *Bull. geol. Surv.* 17, 153-190.

GIBSON, W. (1901). On rapid changes of thickness and character of the Coal Measures of north Staffordshire. *Geol. Mag.* 8, Pt. 4, 79-80.

GIBSON, W. (1901). On the character of the Upper Coal Measures of north Staffordshire, Denbighshire, south Staffordshire and Nottinghamshire and their relation to the productive series. *Q. Jl. geol. Soc. Lond.* 57, 251-266.

GIBSON, W. (1905). *The geology of the north Staffordshire coalfields.* Mem. geol. Surv.

GIBSON, W. and WEDD, C. B. (1905). *The geology of the country around Stoke-upon-Trent.* Mem. geol. Surv.

GIBSON, W. (1925). *The geology of the country around Stoke-upon-Trent.* 3rd Edit., Mem. geol. Surv.

HIND, W. (1896). Zonal divisions of the Carboniferous systems. *Geol. Mag.* 3, 255.

HOARE, R. H. (1960) Red beds in the Coal Measures of the west Midlands. *Trans. Inst. Min. Eng.* 119, 185-198.

HOMER, C. J. (1875). The north Staffordshire coalfield with the ironstones contained therein. *Trans. North Staffs. Inst. Min. & Mech. Eng.* 2, 1-11.

KIDSON, R. (1905). On the divisions and correlation of the upper portion of the Coal Measures, with special reference to their development in the midland counties of England. *Q. Jl. geol. Soc. Lond.* 61, 308-323.

MALKIN, A. B. (1961). *Contributions to the study of the stratigraphy of the north Staffordshire coalfield.* Unpubl. M.Sc. Thesis, Univ. of Manchester.

SMYTH, W. W. (1862). *Iron ores of Great Britain, pt. 4, iron ores of north Stafforshire.* Mem. geol. Surv.

TROTTER, F. M. (1953). Reddened beds of Carboniferous age in north-west England, and their origin. *Proc. Yorks. geol. Soc.* 29, 1-20.

WALKER, T. R. (1967). Formation of red beds in modern and ancient deserts. *Bull. geol. Soc. Am.* 78, 353-368.

WALKER, T. R. (1974). Formation of red beds in moist tropical climates: a hypothesis. *Bull. geol. Soc. Am.* 85, 633-638.

WARD, J. (1890). The geological features of the north Stafforshire coalfield. *Trans. N. Staffs. Inst. Min. & Mech. Eng.* 10.

Appendix II

Condensed Lithological Logs of the

Blackband Group

Provings in the North Staffordshire Coalfield

1965-1977

CONDENSED LITHOLOGICAL LOGS OF BLACKBAND GROUP PROVINGS IN THE NORTH STAFFORDSHIRE COALFIELD 1965 - 1977

N.C.B. Meaford Hall Borehole (1965)

Location:- National Grid Reference E.388491 m, N.337157 m

Starting Level:- 310.5 ft. Above Ordnance Datum

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
	Coring commenced at 1,322 ft.				
	Siltstone, grey	2	6	1324	6
	Sandstone, thin silty mudstone partings, pale grey-green	21	6	1346	0
	Measures, mainly grey mudstones	50	5	1396	5
	Mudstone and seatearth, mottled grey, red-brown and khaki	57	4	1453	9
	Mudstone, grey and black	5	11	1459	8
RED MINE	Coal	0	3	1459	11
	Seatearth and mudstone, grey	8	10	1468	9
	Mudstone, mottled brown-grey and khaki; poorly bedded, occasional grey planty layers, sphaerosideritic in part	59	3	1528	0
	Mudstone, dark grey, seatearth in part, sphaerosideritic	14	11	1542	11
CLOD	Coal	0	3	1543	2
	Mudstone and seatearth, grey	17	10	1561	0
	Mudstone, grey with khaki mottling, sphaerosideritic	15	9	1576	9
	Sandstone, pale grey, fine grained	2	0	1578	9
	Measures (mainly grey mudstones)	18	5	1597	2
	Seatearth, dark grey	0	10	1598	0
HOO CANNEL (	Coal	0	3	1598	3
HOO CANNEL (	Mudstone and seatearth, grey	1	1	1599	4
HOO CANNEL (	Coal	0	5	1599	9
	Mudstone and seatearth, grey	10	1	1609	10
	Mudstone, grey, calcareous in part with <u>Estheria</u> ostracods, <u>Spirorbis</u> and mussels	1	3	1611	1
	Limestone, black with <u>Estheria</u> and plant fragments	0	6	1611	7
	Seatearth/Mudstone, dark grey with calcareous nodules	1	5	1613	0

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
	Mudstone, grey, poorly bedded	9	9	1622	9
	Limestone, pale brownish-grey, with ostracods	1	3	1624	0
	Mudstone, grey	2	0	1626	0
	Mudstone, grey and red-brown	11	6	1637	6
	Mudstone, grey	6	0	1643	6
BASSEY MINE	Ironstone, black-band, brownish-grey, hard massive, with black carbonaceous layers	2	1	1645	7
BASSEY MINE	Mudstone, iron rich, pale brown	0	3	1645	10
BASSEY MINE	COAL	1	8	1647	6

Borehole continues.

N.C.B. Barker's Wood Borehole (1966)

Location:- National Grid Reference E.382211 m, N.345163 m

Starting Level:- 658 ft. Above Ordnance Datum

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
	Fault			1592	10
	Mudstone, greenish-grey	5	2	1598	0
	Mudstone, dark grey, abundant mussels and ostracods and Estheria	0	4	1598	4
	Mudstone, grey-green	3	8	1602	0
	Mudstone, grey and chocolate	6	9	1608	9
	Mudstone, grey, calcareous towards base	6	11	1615	8
RED SHAGG	Ironstone, blackband, calcareous	1	11	1617	7
RED SHAGG	Coal	2	5	1620	0
	Seatearth and mudstone, grey	18	8	1638	8
	Mudstone, mottled grey and chocolate	4	4	1643	0
	Mudstone, grey	15	3	1658	3
	Coal	0	7	1658	10
	Seatearth and mudstone, grey	5	8	1664	6
	Sandstone, medium to coarse coal pellets near base	5	10	1670	4
	Mudstone, grey	5	9	1676	1
	Sandstone, coaly laminae	4	2	1680	3
	Siltstone and mudstone, grey	3	4	1683	7
	Mudstone, becoming dark and canneloid downwards with Estheria ostracods and mussels	1	11	1685	6
	Ironstone, grey with shell fragments	0	3	1685	9
	Mudstone, black	0	3	1686	0

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
RED MINE	Ironstone, blackband, abundant mussels	2	2	1688	2
	Coal	2	3	1690	5
	Seatearth and mudstone, grey	3	1	1693	6
	Measures, mainly grey mudstones, mottled red-brown below 1703 ft.	56	6	1750	0
	Siltstone/Sandstone, grey	3	6	1753	6
	Seatearth/Mudstone, grey	6	2	1759	8
CLOD	Coal	0	7	1760	3
	Mudstone, black	0	6	1760	9
	Coal	1	7	1762	4
	Seatearth, mudstone and thin coals	19	11	1782	3
	Seatearth and mudstone, grey-brown, sphaerosideritic in part	17	9	1800	0
	Measures (mainly grey mudstones)	39	6	1839	6
	Mudstone, dark and light finely interlaminated with ostracods and mussels	3	9	1843	3
	Grit, grey-brown with pink and grey patches	0	6	1843	9
	Coal	0	8	1844	5
	Mudstone and seatearth	1	8	1846	1
	Coal	0	8	1846	9
	Mudstone, grey	15	1	1861	10
	Mudstone, dark grey with fish fragments, <u>Estheria</u> and ostracods	1	1	1862	11
	Ironstone	0	2	1863	1
	Mudstone, dark, fish fragments	0	11	1864	0
HOO CANNEL	Coal	4	0	1868	0
	Seatearth and mudstone, grey, <u>Estheria</u> below 1882 ft. <u>Spirorbis</u> and mussels at 1891 ft., calcareous nodules for 1ft.10in. at 1898 ft.	34	1	1902	1
	Grit, c.f. Espley	7	0	1909	1
	Mudstone, grey mussels and ostracods at 1915 ft. Mudstone interlaminated dark and light grey, faulted base	3	1	1928	7
BASSEY MINE	Coal	1	8	1930	3
	Ironstone	0	2	1930	5
	Coal	0	6	1930	11

Borehole continues.

N.C.B. Highway Borehole (1972)

Location:- National Grid Reference E.380172 m, N.345113 m.

Starting level:- 568 ft. Above Ordnance Datum.

Seam	Strata	Thickness ft.	Thickness in.	Depth ft.	Depth in.
BLACKBAND	Ironstone, interbanded with carbonaceous mudstone	2	0	1574	11
BLACKBAND	Coal	4	0	1578	11
	Seatearth and mudstone, grey	2	10	1581	9
	Sandstone, fine, coaly laminae	6	3	1588	0
	Siltstone, medium, muddy in part	6	0	1594	0
	Mudstone, grey	17	7	1611	7
RED SHAGG	Ironstone	1	5	1613	0
RED SHAGG	Coal	1	5	1614	5
	Seatearth, grey-brown and grey	3	3	1617	8
	Mudstone, grey, red colouration from 1636 ft. - 1647 ft.	35	2	1652	10
	Coal	0	2	1653	0
	Seatearth and mudstone, grey, dip 21°	3	6	1656	6
RED MINE	Coal	0	11	1657	5
RED MINE	Mudstone	2	3	1659	8
RED MINE	Coal	3	4	1663	0
	Seatearth, grey	2	8	1665	8
	Measures, mainly grey, mudstone with red mottling below 1684 ft. to 1693 ft. and below 1698 ft.	48	7	1714	3
	Mudstone, grey	3	4	1717	7
CLOD	Coal	2	6	1720	1
	Seatearth, grey	3	4	1723	5
	Measures, mainly grey mudstones with occasional thin coals and seatearth horizons, ostracods at 1767 ft.	81	6	1804	11
HOO CANNEL	Coal	1	0	1805	11
HOO CANNEL	Mudstone, dark grey	0	3	1806	2
HOO CANNEL	Coal	0	1	1806	3
HOO CANNEL	Ironstone	0	5	1806	8
HOO CANNEL	Coal	0	2	1806	10
	Mudstone and seatearth	11	0	1817	10
	Sandstone, gritty in part	5	2	1823	0
	Mudstone, grey	16	0	1839	0
	Sandstone, coarse, conglomeratic in places	1	3	1840	3
	Mudstone, red colouration in part, 3" Limestone at 1847 ft.	19	4	1859	7

		Thickness ft.	Thickness ins.	Depth ft.	Depth ins.
	Mudstone, grey	2	3	1861	10
BASSEY MINE	Ironstone	0	6	1862	4
BASSEY MINE	Mudstone, black, carbonaceous	0	5	1862	9
BASSEY MINE	Coal	1	6	1864	3

Borehole continues.

N.C.B. Groundslow Borehole (1973)

Location:- National Grid Reference E.386662 m, N.337712 m.

Starting level:- 391 ft. Above Ordnance Datum.

		Thickness ft.	Thickness ins.	Depth ft.	Depth ins.
	Mudstone and siltstone, grey-green, some red tinges, occasional thin seatearth horizons, dip 11°	11	0+	2584	0
	Mudstone, grey	13	4	2597	4
	Mudstone, seatearth and thin coals	2	1	2599	5
	Mudstone and seatearth, grey, mottled red-brown and purple below 2612 ft., rare thin grey plant horizons	108	7	2708	0
	Siltstone and fine sandstones, grey-green, some carbonaceous debris	16	10	2724	10
	Seatearth and mudstone, red-brown and grey-green, some sphaerosiderite, rare thin siltstone horizons	66	2	2791	0
	Mudstone, grey	6	9	2797	9
	Coal, inferior, carbonated	0	6	2798	3
	Seatearth/Mudstone	4	11	2803	2
	Siltstone, grey, calcareous	1	8	2804	10
	Mudstone, grey, calcareous at 2814 ft., mussels and *Spirorbis* below 2816 ft.	12	9	2817	7
	Siltstone, grey, calcareous, *Spirorbis* and ostracods	0	9	2818	4
	Mudstone, grey, ostracods at top, red mottled below 2820 ft.	7	9	2826	1
	Limestone, grey-brown	0	9	2826	10
	Mudstone and calcareous siltstone, grey	8	6	2835	4
	Mudstone, grey, red mottling at 2842 ft.	12	5	2847	9
	Mudstone, pale and dark grey, interlaminated	0	1½	2747	10½
	Ironstone, siltstone matrix	0	10½	2848	9
BASSEY MINE	Coal	0	7	2849	4
BASSEY MINE	Mudstone, black, carbonaceous	0	1	2849	5
BASSEY MINE	Coal	0	5	2849	10

Borehole continues.

N.C.B. Peacock's Lane Borehole (1974)

Location:- National Grid Reference E.384447 m, N.341126 m.

Starting level:- 498 ft. Above Ordnance Datum.

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
	Coring commenced at 902 ft.				
	Measures, mainly grey mudstones	14	0	916	0
	Coal, canneloid in basal 2 ins.	0	8	916	8
	Seatearth and mudstone, grey	1	1	917	9
	Coal	0	3	918	0
	Mudstone	0	2	918	2
	Coal	0	9	918	11
	Seatearth and mudstone, grey	4	9	923	8
	Coal	0	9	924	5
	Seatearth/mudstone, grey-brown	1	10	926	3
	Seatearth/mudstone, mottled purple and grey with some ochreous colouration	0	4	926	7
	Sandstone, grey-green, coarse	1	7	928	2
	Measures, mainly red-brown mudstones with some grey mottling and seatearth horizons	51	10	980	0
	Mudstone, grey, some plants	6	2½	986	2½
	Coal, inferior	0	2½	986	5
	Seatearth/mudstone, coaly wisps	2	7	989	0
RED MINE	Coal	2	0	991	0
	Seatearth/mudstone, grey-brown	0	1	991	1
	Coal	0	1	991	2
	Seatearth/mudstone, sphaerosideritic	5	10	997	0
	Measures, mainly green mudstones with occasional thin dark grey layers and seatearth horizons	81	0	1078	0
	Mudstone, grey, some plants	4	2	1082	2
CLOD	Coal, dip 5°	0	3½	1082	5½
	Seatearth/mudstone, coaly in part	6	2½	1088	8
	Mudstone, grey, occasional thin fine calcareous sandstone layers, rare red mottling	49	3	1137	11
	Mudstone, grey, green tinge plants below 1144 ft., becoming darker downwards	11	1	1149	0
HOO CANNEL	Coal, inferior, dip 10°	0	8	1149	8
	Seatearth and mudstone, dips 60° at 1156 ft. for 1 ft. ? fault	12	8	1162	4
	Mudstone, light grey, abundant Estheria and occasional mussels	0	1	1162	5

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
	Limestone, grey with pyritised plant fragments, siltstone matrix, numerous ostracods and poorly preserved mussels, numerous small calcareous nodules at base	1	0	1163	5
	Mudstone, grey pyrite aggregates mottled red-brown below 1177 ft. to 1184 ft., red patches below 1187 ft.	25	8	1189	1
	Limestone, grey, calcite veining, mussels, fish debris, Spirorbis, pyritised plants	1	5	1190	6
	Mudstone, grey, red-brown patches below 1192 ft.	16	0	1206	6
	Seatearth and mudstone, grey	7	0	1213	6
	Ironstone, grey-brown, numerous dark grey carbonaceous muddy streaks and patches, irregular base	1	3	1214	9
BASSEY MINE	Coal	1	6	1216	3
	Mudstone, dark grey, coaly in part	4	9	1221	0
	Coal	0	2	1221	2
	Seatearth				

Borehole continues.

N.C.B. Swallowcroft Borehole (1974)

Location:- National Grid Reference E.382285 m, N.343416 m.

Starting level:- 504 ft. Above Ordnance Datum.

Rock bit drilling.
Driller reported Coal at 885 ft., 933 ft. and 995 ft.
(? RED MINE)

Coring commenced at 995 ft.

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
	Mudstone, grey, red mottling below 1004 ft.	44	6	1039	6
	Mudstone, grey	1	9	1041	3
	Seatearth/mudstone, grey, listic	3	9	1045	0
	Coal	0	7½	1045	7½
	Mudstone, dark, coalified plants	0	10	1046	5½
CLOD	Coal	1	1½	1047	7
	Measures, mainly seatearths and mudstones, grey with thin coals, dip 10°	42	11	1090	6
	Mudstone, some sphaerosiderite, coaly in part	13	5	1103	11
	Seatearth/mudstone, grey	5	1	1109	0
	Measures, mainly mudstones, silty in part, rare seatearth horizons, poorly preserved mussel fragments at 1130 ft. and 1135 ft. to 1137 ft.	28	3	1137	3
	Mudstone, dark, carbonaceous mussels, ostracods and megaspores?	0	9	1138	0

		Thickness ft.	Thickness in.	Depth ft.	Depth ins.
	Seatearth/mudstone, grey	7	0	1145	0
	Mudstone, grey, some plants	23	5	1168	5
	Mudstone, dark grey, mussels and fish scales and spines	0	10	1169	3
	Seatearth mudstone with some thin coals	3	10	1173	1
HOO CANNEL	Coal	1	8	1174	9
	Mudstone and seatearth, coaly in part	4	3	1179	0
	Mudstone, grey, some thin off-white, pink and green speckled sandstone layers	7	0	1186	0
	Mudstone, grey, *Estheria*, mussels, ostracods calcareous in part	6	1	1192	1
	Mudstone, grey, some red-mottling from 1200 ft. to 1204 ft., mussel fragment at base	12	5	1204	6
	Limestone and mudstone, interlayered, mussels, ostracods, *Spirorbis* and *Estheria*, some red mottling	10	0	1214	6
	Mudstone, grey, mottled red and yellow	8	6	1223	0
	Mudstone, grey and dark grey	5	0	1228	0
	Coal	0	5	1228	5
	Ironstone, nodular in black mudstone	0	7	1229	0
	Mudstone, dark grey, canneloid below 1229 ft.	0	5	1229	5
BASSEY MINE	Coal	2	7	1232	0
	Mudstone and seatearth				

Borehole continues.

N.C.B. Quarry Bank Borehole (1975)

Location:- National Grid Reference E.381061m, N.345646 m.

Starting level:- 602 ft. Above Ordnance Datum.

	Thickness ft.	Thickness in.	Depth ft.	Depth ins.
Coring commenced at 1500 ft.				
Mudstone, grey, fish debris at 1502 ft.	4	0	1504	0
Core missing	1	0	1505	0
Seatearth/mudstone, pale grey, sphaerosideritic	4	8	1509	8
Mudstone, grey, some plant horizons, dip 22°, mussels from 1521 ft. to 1523 ft.	22	0	1531	8
Mudstone, dark grey, numerous mussels, ostracods, canneloid in part	1	0	1532	8
Coal	0	8	1533	4

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
	Mudstone and seatearth, grey, occasional thin siltstone horizons, dip 13° at 1550 ft.	26	10	1560	2
HOO CANNEL	Coal and thin carbonaceous mudstone, interlayered	2	9	1562	11
HOO CANNEL	Coal, appears inferior	1	5	1564	4
HOO CANNEL	Mudstone, carbonaceous	0	2	1564	6
HOO CANNEL	Coal	0	9	1565	3
	Seatearth and mudstone, grey	5	0	1570	3
	Mudstone, grey, <u>Estheria</u> and ostracods at 1580 ft.	10	5	1580	8
	Limestone, grey, siltstone matrix, ostracods and <u>Spirorbis</u>, mussels and <u>Estheria</u> dark and muddy with rare coalified plant fragments below 1581 ft.	0	8	1581	4
	Mudstone, grey, occasional thin siltstone horizons, mussels below 1605 ft.	24	2	1605	6
	Limestone, grey, siltstone matrix	0	6	1606	0
	Mudstone, grey, dip 12° at 1607 ft.	13	8	1619	8
	Sandstone, pale grey, medium grained, felspathic, some green and pink speckling	0	9	1620	5
	Mudstone and fine siltstone, grey	5	6	1625	11
	Mudstone, dark, canneloid	0	4	1626	3
	Seatearth/mudstone	0	2	1626	5
	Mudstone, dark	0	2	1626	7
	Ironstone, irregularly interlayered with black mudstone, some calcite veining, large ironstone nodules, thin coal layers towards base	1	4	1627	11
BASSEY MINE	Coal	2	1	1630	0

Borehole continues.

<u>N.C.B. Whitmore Borehole (1957)</u>

Location:- National Grid Reference E.380783 m, N.342183 m.

Starting level:- 128 m Above Ordnance Datum

		Thickness m	Depth m
	Coring commenced at 690 m		
	Seatearth and mudstone, grey	0.42	690.42
RED MINE	Coal, dip less than 5°	0.75	691.17
	Mudstone, some seatearth and siltstone horizons, red mottling below 695 m, occasional thin grey horizons	26.52	717.69

		Thickness m	Depth m
	Breccio-Conglomerate, grey-green, speckled dark grey-green, white and red-brown, 'Espley'	0.66	718.35
	Mudstone, some ochreous colouration, dark grey in basal 0.03	1.43	719.78
CLOD	Coal, appears inferior	0.15	719.93
	Seatearth and mudstone, mottled red-brown below 722 m to 742 m, calcareous nodules at 729 m, some thin grey horizons, dark below 742 m	24.30	744.23
HOO CANNEL	Coal and thin mudstones	0.98	745.21
	Mudstone, grey, occasional siltstone horizons, mussel fragments and abundant ostracods in basal 0.04	6.65	751.86
	Siltstone, calcareous, grey, <u>Spirorbis</u> and ostracods	0.35	752.21
	Mudstone, grey, mottled red-brown from 752.80 to 754.60	2.96	755.17
	Seatearth/mudstone, grey	1.71	756.88
BASSEY MINE HORIZON	Mudstone, dark, 0.01 Coal at base	0.10	756.98

Borehole continues.

<u>N.C.B. Werburgh Borehole (1976)</u>

Location:- National Grid Reference E.379790m, N.343915m.

Starting level:- 155 m Above Ordnance Datum.

Cores commenced at 619.64 m

	Mudstone, silty in part, some sphaerosiderite	2.56	622.20
	Mudstone, grey, red-brown mottling	1.80	624.00
	Mudstone, grey becoming darker downwards	1.61	625.61
RED MINE	Coal	0.22	625.83
	Mudstone and seatearth, grey	1.81	627.64
	Mudstone, grey, red-brown mottling, poorly bedded sphaerosideritic	2.81	630.45
	Mudstone, grey, dip 20°, red-brown mottling below 631 m	1.55	632.00
	Mudstone, dark grey, listric	0.76	632.76
	Coal	0.08	632.84
	Mudstone, grey, sphaerosideritic red-brown mottling below 635 m to 637 m and from 639 m to 641 m, dark and carbonaceous below	11.72	644.56
	Coal	0.07	644.63
	Seatearth and mudstone	2.54	647.17

MITCHELL'S WOOD OPENCAST SITE

Approximate Location:- National Grid Reference E.383200m, N.350800 m.

Seam		Thickness ft.	Thickness in.	Depth ft.	Depth in.
BLACKBAND	(Ironstone				
	(Coal	1	4		
	Seatearth/mudstone, grey	7	5	7	5
	Coal	0	7	8	0
	Mudstone, brownish	8	7	16	7
	Coal	0	5	17	0
	Measures, mainly grey mudstones	10	8	27	8
	Mudstone with *Anthraconauta phillipsi*, ostracods and *Spirorbis*	0	7	28	3
	Mudstone, grey	7	2	35	5
	Not exposed	10	1	45	6
	Seatearth/mudstone, grey	0	6	46	0
RED SHAGG	(Ironstone	4	10½	50	10½
	(Coal	2	4½	53	3
	Seatearth/mudstone, sphaerosideritic	23	3	76	6
	Coal	0	2½	76	8½
	Seatearth and mudstone, grey	12	1	88	9½
	Measures, mainly mudstones, mussels in basal 4"	10	6	99	3½
	Mudstone, black, canneloid, mussels in basal 1"	0	4	99	7½
	Seatearth and mudstone, some coaly horizons to 105'0", generally mudstone below, mussels common in basal 5 ft.	18	8½	118	4
	Mudstone, dark, thinly bedded, abundant mussels	1	0	119	4
RED MINE	(Ironstone (heavily worked)	approx. 4	0	123	4
	(Coal	2	8	126	0
	Seatearth and mudstone	23	0	149	0
	Mudstone, dark, carbonaceous	0	2	149	2
CLOD	Coal and mudstone interlayered. Dip 16°	approx. 9	0	158	2
	Seatearth	10	6	168	8
	Coal	0	4	169	0
	Seatearth and mudstone	32	10	201	10
	Mudstone, dark, abundant mussels, ostracods and *Spirorbis*	0	8	202	6
HOO CANNEL	Coal and mudstone interlayered	4	6	207	0
	Not exposed	approx. 75	0	282	0
BASSEY MINE	(Ironstone with mussels and *Spirorbis*				
	(Coal				

(Thicknesses corrected for dip)

MITCHELL'S WOOD OPENCAST SITE (continued)
(Hoo Cannel to Bassey Mine interval exposed later)

		Thickness ft.	Thickness in.	Depth ft.	Depth in.
HOO CANNEL	Coal and mudstone interlayered	4	7	211	7
	Mudstone, seatearth and thin ironstone bands	9	0	220	7
	Mudstone, light and dark grey, finely interlayered, occasional thin ironstone bands	1	6	222	1
	Mudstone, dark, some fish debris and ostracods, occasional mussels		8	222	9
	Mudstone, grey, ironstained, some thin ironstone bands, Estheria and ostracods		7	223	4
	Mudstone, dark, abundant crushed mussels and ostracods		4	223	8
	COAL		9	224	5
	Seatearth/mudstone, dark		3	224	8
	Mudstone, dark, carbonaceous		9	225	5
HOO CANNEL	Ironstone		7	226	0
	Mudstone, dark, some sideritic patches	1	3	227	3
	Ironstone, carbonaceous		4	227	7
	COAL		4	228	1
	Seatearth and mudstone	9	1	237	2
	Sandstone, pale, fine grained, calcareous	1	1	238	3
	Mudstone, plants common, Estheria, mussels and ostracods towards base	9	7	247	10
	Limestone, pale, sideritic, Estheria common		3	248	1
	Mudstone, interlaminated light and dark, mussels and ostracods		4	248	5
	Limestone,		11	249	4
	Measures, mainly mudstones, Estheria common towards base with mussels and ostracods	15	8	265	0
	Limestone,	3	5	268	5
	Measures, mainly mudstones	14	4	282	9
BASSEY MINE	Ironstone				

APPENDIX III

AA Data

BLACKBAND I/S, Mitchell's Wood, N Staffs

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
6.6	36.6	0.42	1.28	1.06	BH 002-2
3.6	39.6	0.70	1.88	2.16	BH 002-1
COAL (18 cm)					
6.4	36.2	0.42	0.81	0.77	BH 004-3
4.9	39.4	0.54	0.87	0.70	BH 004-2
6.5	33.0	0.44	0.76	0.61	BH 004-1
4.8	33.4	0.42	0.87	0.88	BH 005-2
4.1	23.6	0.34	0.40	0.68	BH 005-1
5.1	34.4	0.38	0.57	0.90	BH 006
3.8	34.8	0.38	0.53	0.91	BH 007
2.9	35.0	0.36	0.56	0.78	BH 008-2
3.4	39.0	0.54	0.65	0.97	BH 008-1
4.0	33.6	0.46	0.71	0.86	BH 009
2.4	36.2	0.50	0.84	0.86	BH 010-2
2.4	35.6	0.42	0.76	0.74	BH 010-1
2.6	30.0	0.40	0.59	0.79	BH 011-2
2.5	35.8	0.44	0.72	0.82	BH 011-1
5.1	38.8	0.68	0.92	0.85	BH 012
5.7	36.6	0.66	1.10	0.97	BH 013-2
4.5	37.2	0.86	1.12	0.92	BH 013-1
1.9	39.8	0.70	1.05	0.72	BH 014
73.0					

RED SHAGG I/S, Mitchell's Wood, N Staffs

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
10.6	27.5	0.9	2.3	0.9	BH 021-2
8.4	20.0	0.4	1.2	0.8	BH 021-1
18.4	20.0	0.7	1.0	1.1	BH 022
7.6	-	-	-	-	BH 023a
7.6	32.5	2.0	2.9	2.3	BH 023b-3
7.6	25.0	0.7	2.4	1.9	BH 023b-2
7.6	27.5	0.8	2.6	0.8	BH 023b-1
4.8	12.5	0.2	1.0	0.3	BH 024
15.2	22.5	0.5	1.2	0.7	BH 025
2.5	20.0	0.4	1.3	0.6	BH 026
2.5	22.5	0.5	1.5	0.8	BH 027
4.1	27.5	0.6	1.7	1.1	BH 028
2.2	25.0	0.6	1.3	0.7	BH 029
4.4	17.5	1.1	1.4	1.6	BH 030
4.0	25.0	0.6	1.7	1.0	BH 031-2
4.3	32.5	1.3	2.1	1.3	BH 031-1
2.4	27.5	0.5	1.6	0.9	BH 032
5.7	27.5	0.7	1.4	0.9	BH 033
5.4	32.5	1.1	2.2	1.0	BH 034-3
5.2	32.5	1.1	2.1	1.0	BH 034-2
5.2	32.5	1.0	1.8	0.9	BH 034-1
3.5	32.5	1.3	1.8	0.9	BH 035-2
4.1	-	-	-	-	BH 035-1
4.0	20.0	0.3	1.3	0.6	BH 036
2.0	27.5	0.4	1.0	4.5	BH 037
149.3					

RED MINE I/S, Mitchell's Wood, N Staffs

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
3.8	21.1	0.29	1.30	0.39	BH 073
3.8	25.1	0.39	1.54	0.55	BH 072
2.5	18.1	0.22	1.02	0.21	BH 071
6.3	28.3	0.46	2.41	0.37	BH 070
5.7	35.6	1.19	3.13	0.59	BH 069b
5.7	41.6	0.82	3.51	0.49	BH 069a
2.5	34.6	0.75	3.42	0.37	BH 068
30.3					

BASSEY MINE I/S, Mitchell's Wood, N Staffs

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
13.3	19.5	0.09	0.60	0.03	BH 082
3.8	18.5	0.19	0.84	0.09	BH 081
3.8	23.5	0.17	0.89	0.08	BH 080
5.7	32.4	0.22	1.04	0.05	BH 079
6.3	36.0	0.51	2.19	0.28	BH 078
COAL (1)					
7.6	36.2	0.65	1.09	0.96	BH 077
40.5					

BASSEY MINE I/S. Quarry Bank BH, N Staffs

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
8.5	25.1	3.11	0.92	0.98	QB 002b
3.5	13.6	1.74	0.94	0.89	QB 002a
6.0	-	-	-	-	-
7.5	5.7	0.62	0.54	0.96	QB 001c
3.5	21.6	1.46	1.69	0.36	QB 001b
6.0	12.6	1.90	1.52	1.04	QB 001a
35.0					

BASSEY MINE I/S, Hem Heath (NCB) Colliery, N Staffs

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
20.3	-				
20.3	-				
35.6	35.3	2.46	0.67	1.17	HH 007
22.8	36.5	2.06	0.69	1.02	HH 006
3.8	44.3	1.70	0.89	0.93	HH 005
3.8	39.6	1.86	0.84	0.86	HH 004
6.3	37.2	2.01	0.76	0.91	HH 003
5.1	40.4	1.81	1.00	0.40	HH 002
3.8	37.1	1.42	1.53	0.50	HH 001
121.8					

BASSEY MINE I/S, Apedale Licensed Mine, N Staffs

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
7.6	11.7	0.3	0.6	2.1	AP 016
8.9	25.1	1.8	1.1	19.5	AP 015
5.1	23.7	1.5	1.0	9.2	AP 014
3.8	-	-	-	-	m/s
5.1	-	-	-	-	m/s
6.3	-	-	-	-	m/s
5.1	25.8	2.3	1.8	17.5	AP 010
17.8	31.5	3.0	1.2	9.7	AP 009
10.2	-	-	-	-	m/s
5.1	-	-	-	-	m/s
6.3	26.2	0.8	1.3	16.0	AP 005
7.6	24.0	1.8	2.4	8.3	AP 004

MAIN BRIGHT I/S, Sunrise BH, Nottinghamshire

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
6.5	40.2	1.12	0.5	0.06	SR 004
5.5	25.9	1.03	0.62	0.56	SR 005
9	40.3	2.0	0.84	0.8	SR 006
3	33.8	1.9	1.04	0.1	SR 007
6	33.3	1.0	0.65	0.72	SR 008
6	15.4	1.8	0.63	1.27	SR 009
4	13.1	1.7	0.66	1.46	SR 010
40.0					

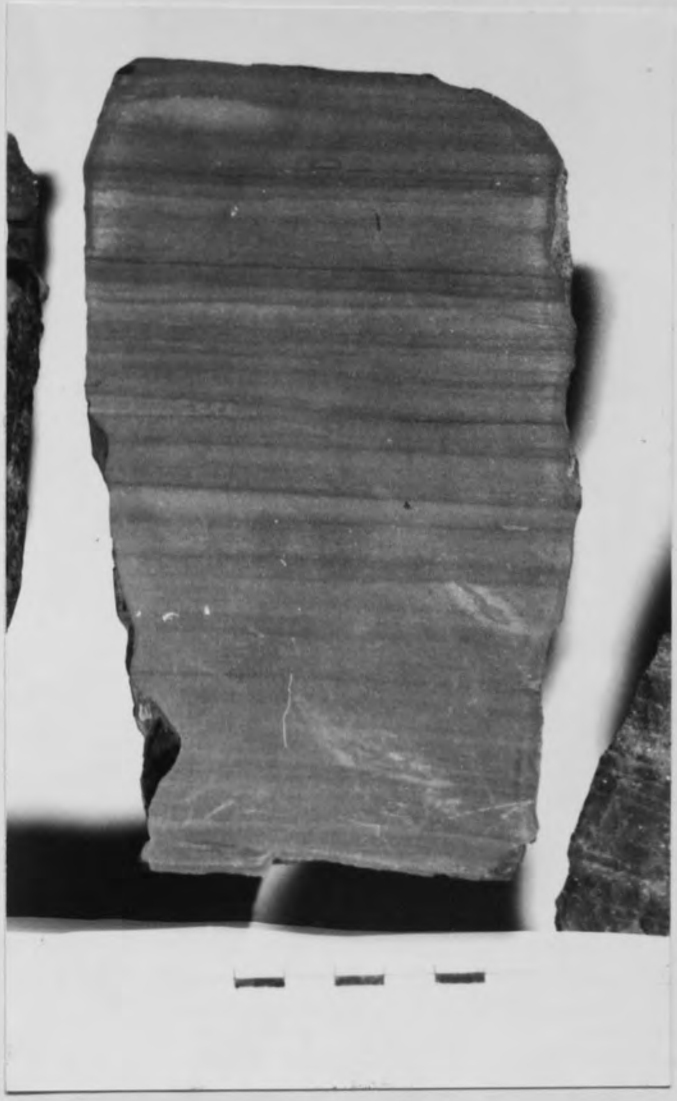
CALPATIE I/S, Monktonhall Colliery, U/G BH 7/78

Sample thickness (cm)	Fe%	Mg%	Mn%	Ca%	Sample Ref No
5	13.05	3.1	0.35	0.51	CAL 004
4	11.8	2.4	0.30	0.38	CAL 003
5	17.4	2.9	0.35	0.51	CAL 002
28	-	-	-	-	Mz
6	10.8	2.2	0.29	0.29	CAL 001
10	-	-	-	-	

COAL

PLATES

Plate 1 Typical layered blackband ironstone. Red Shagg Ironstone, Mitchell's Wood, north Staffordshire (scale bar in cm)



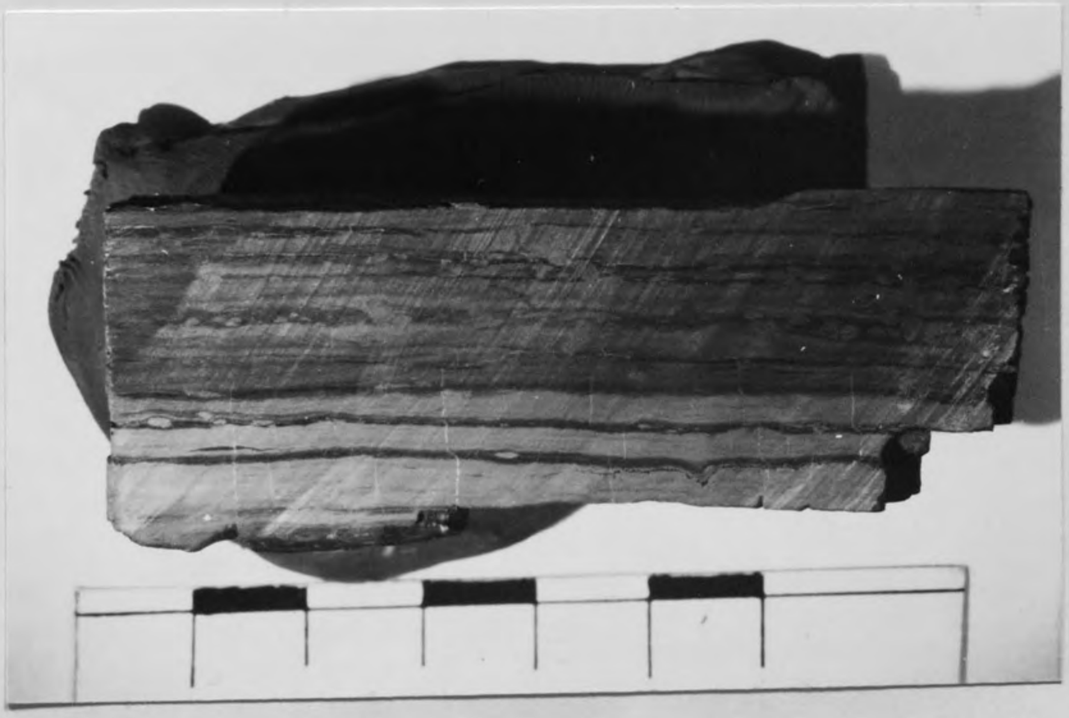


Plate 2 Finely laminated 'varved' mudstone from above the Red Mine Ironstone. Mitchell's Wood, north Staffordshire (scale bar in cm)

Plate 3 Blackband 'seatearth' Ironstone, Mitchell's Wood, north Staffordshire. Sample from immediate floor of thin top leaf of coal exhibiting well developed seatearth texture (scale bar in cm)

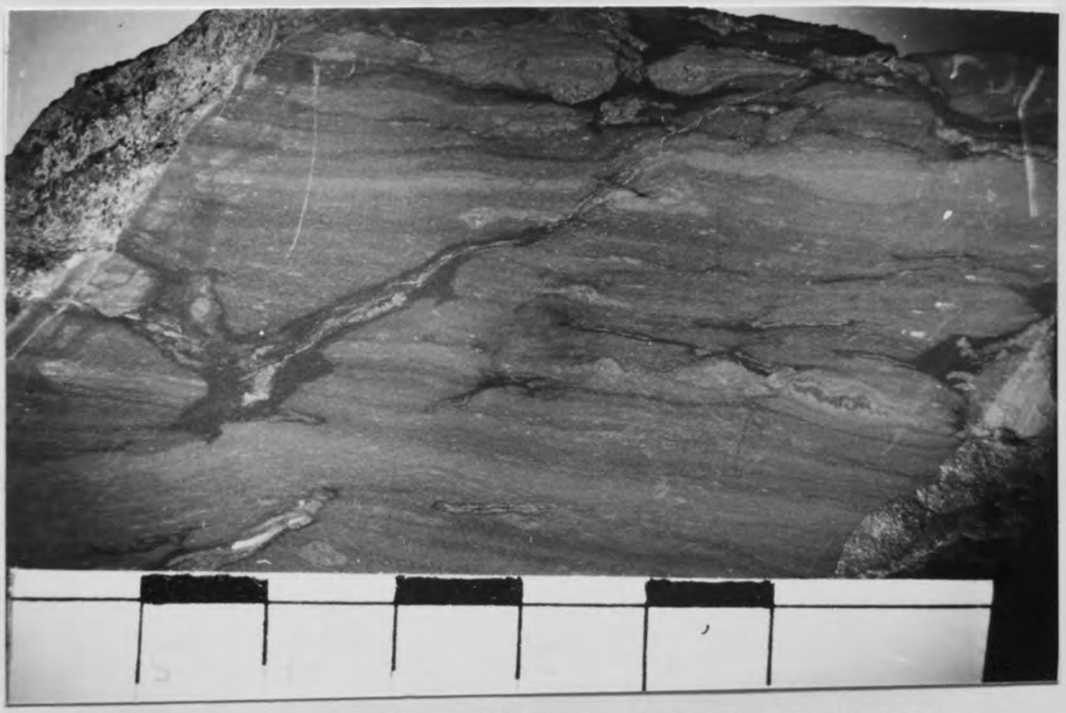


Plate 4 Blackband Ironstone, Mitchell's Wood, north Staffordshire. Sample from 36 cm below floor of the thin top leaf of coal exhibiting root disturbed laminae (scale bar in cm)

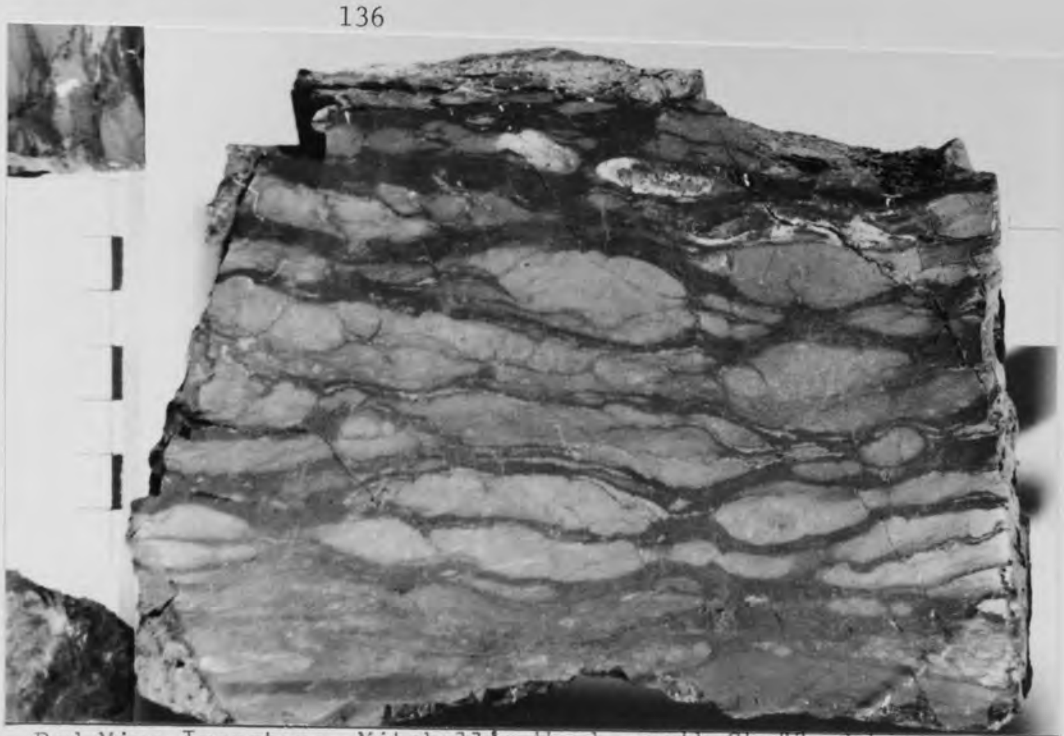


Plate 5 Red Mine Ironstone, Mitchell's Wood, north Staffordshire. Nodular siderite layer, 'brazils', from within the Red Mine Coal Seam (scale bar in cm)

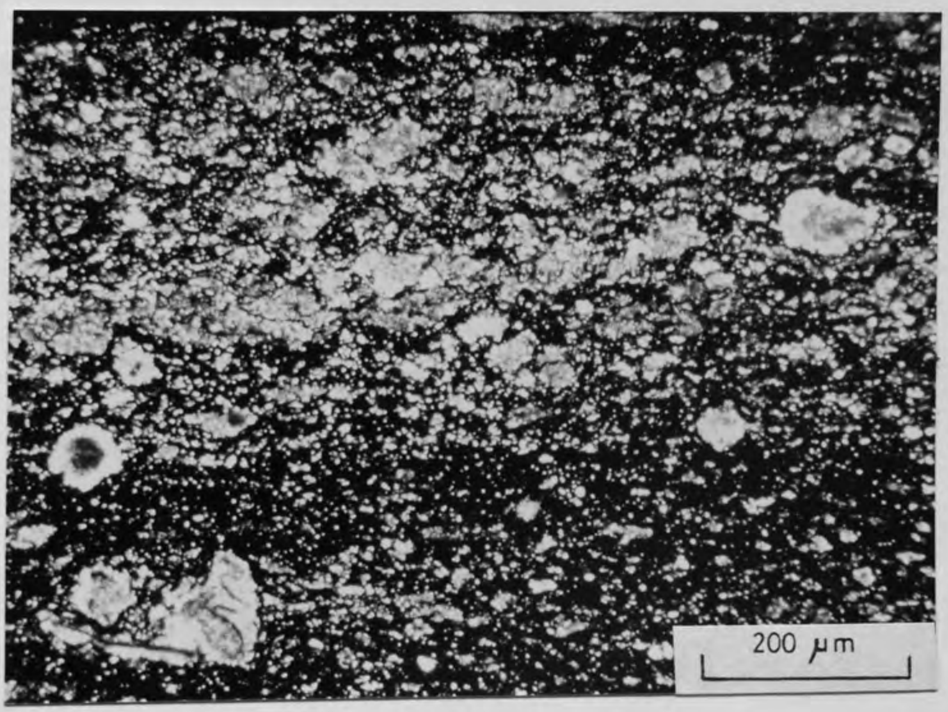


Plate 6 Photomicrograph of a subsection of the Red Mine Ironstone, Mitchell's Wood, north Staffordshire showing overgrowths on some of the peloids of siderite.

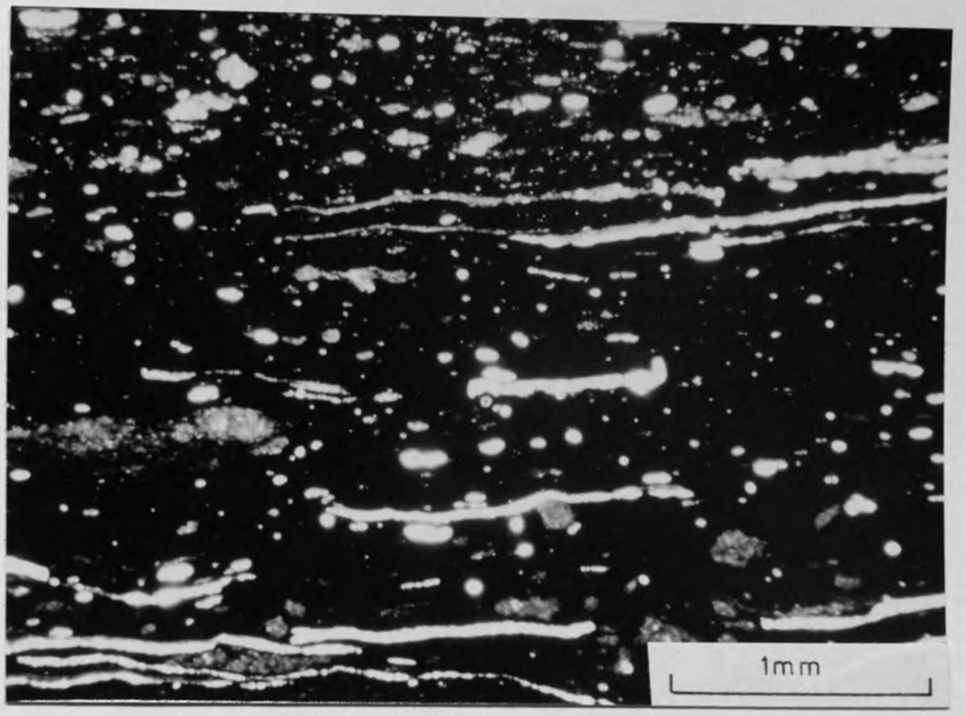


Plate 7 Photomicrograph of a subsection from the upper part of the Red Mine Ironstone, Mitchell's Wood, showing many orange coloured oil algae in a carbonaceous spore bearing matrix.

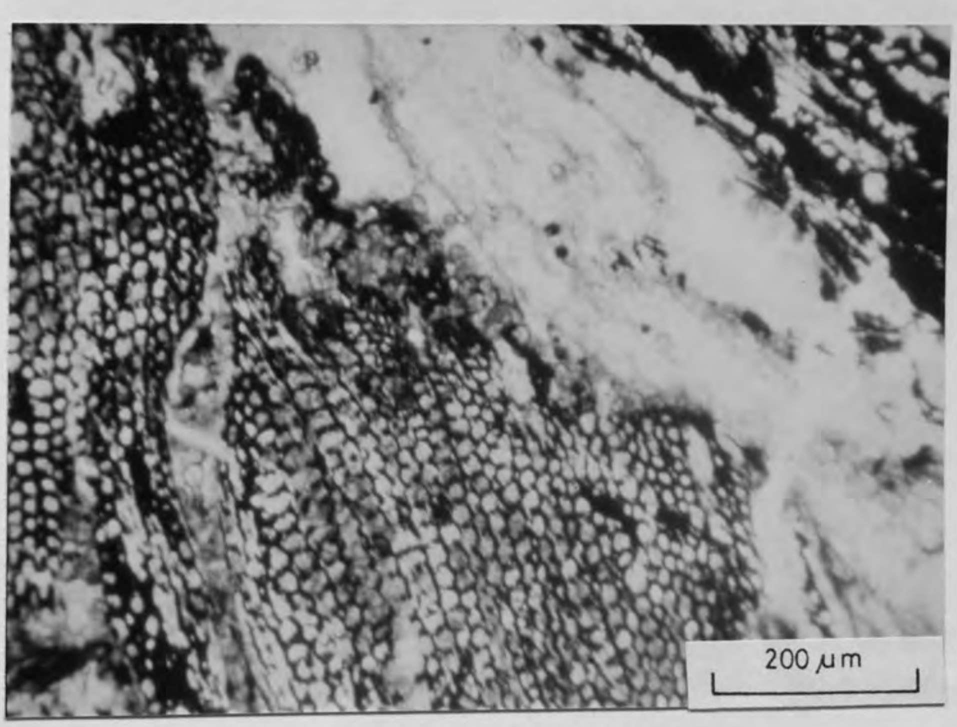


Plate 8 Bassey Mine Ironstone, Seabridge Borehole, north Staffordshire. Well preserved planty cellular tissue. (photomicrograph)

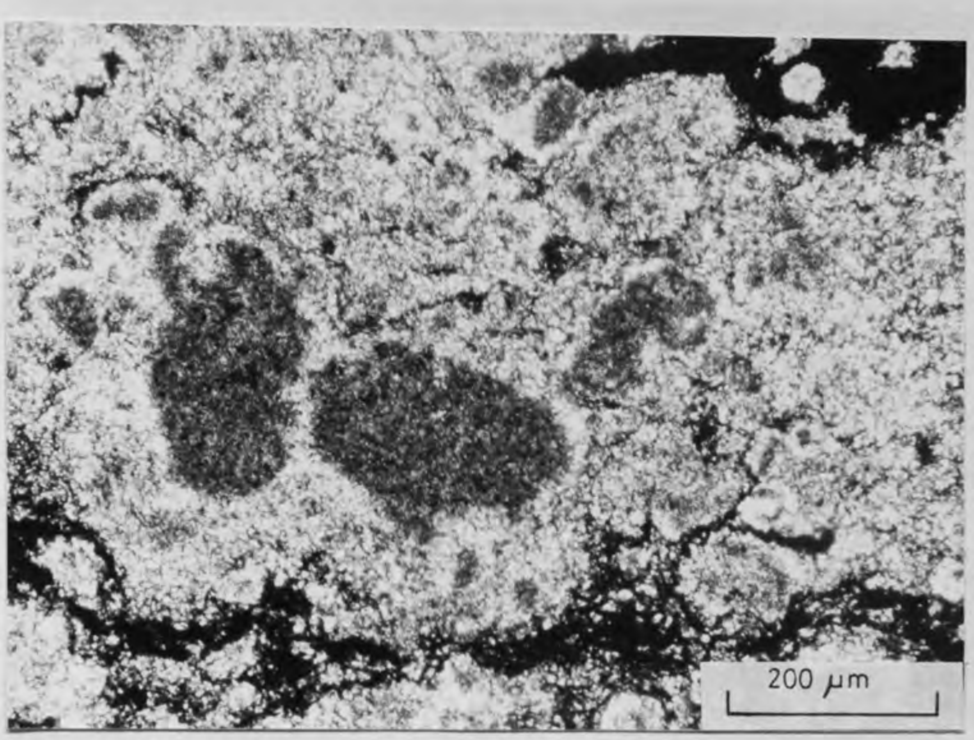


Plate 9 Composite siderite peloid with 'ghosts'. Blackband Ironstone, Mitchell's Wood, north Staffordshire. (photomicrograph)

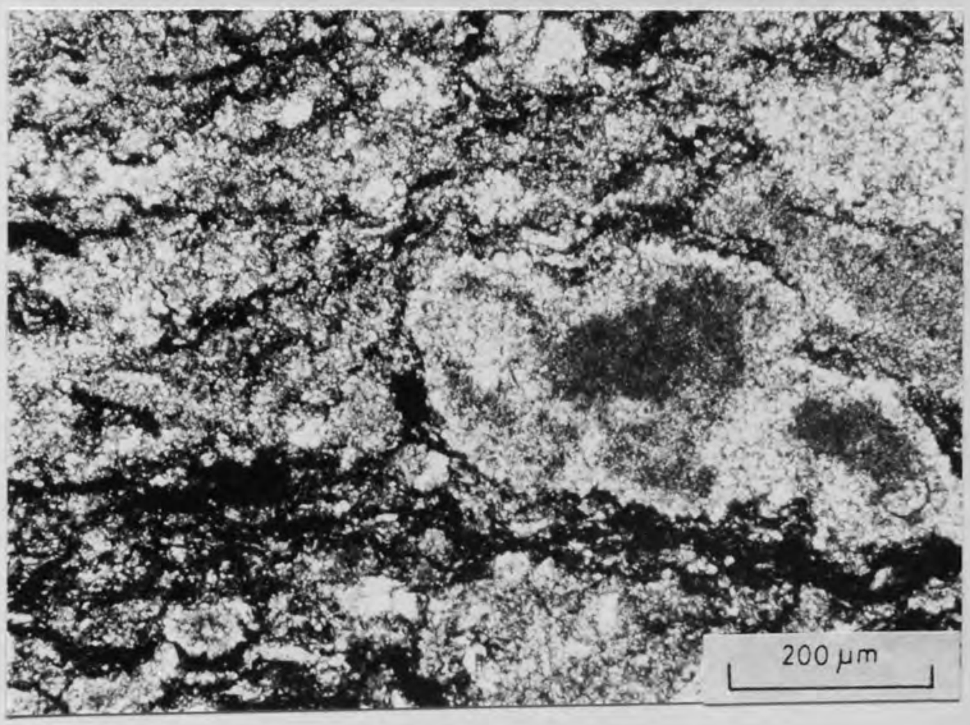


Plate 10 Composite peloid with 'ghosts'. Red Mine Ironstone, Mitchell's Wood, north Staffordshire. (photomicrograph)

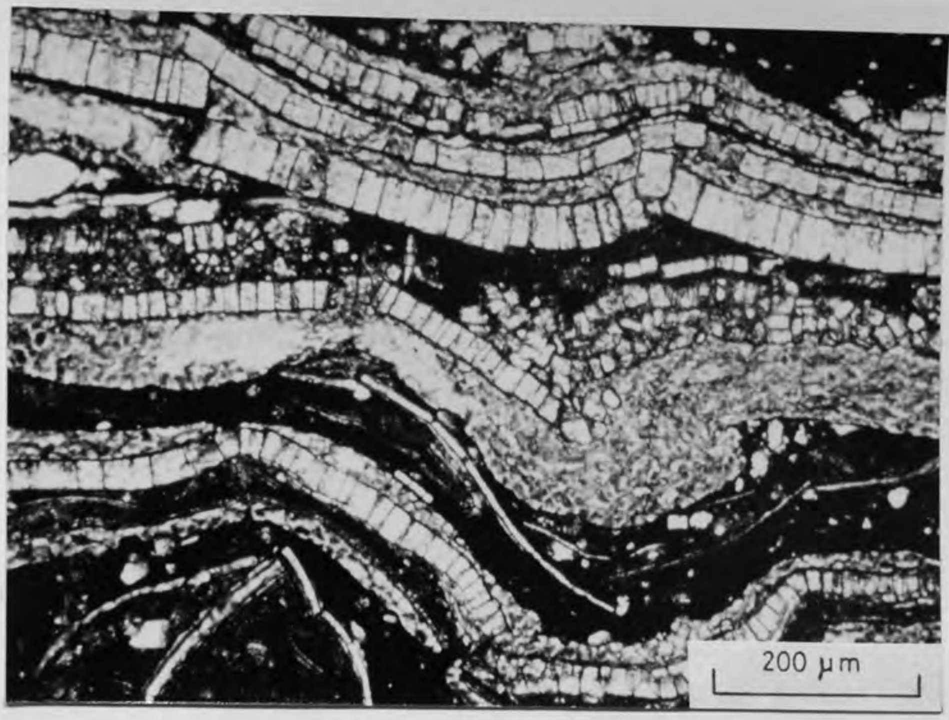


Plate 11 Bassey Mine Ironstone, Apedale, north Staffordshire. Calcareous prismatic mollusc shells with ferroan calcite nacreous layer. (Alzarin Red S stained section)

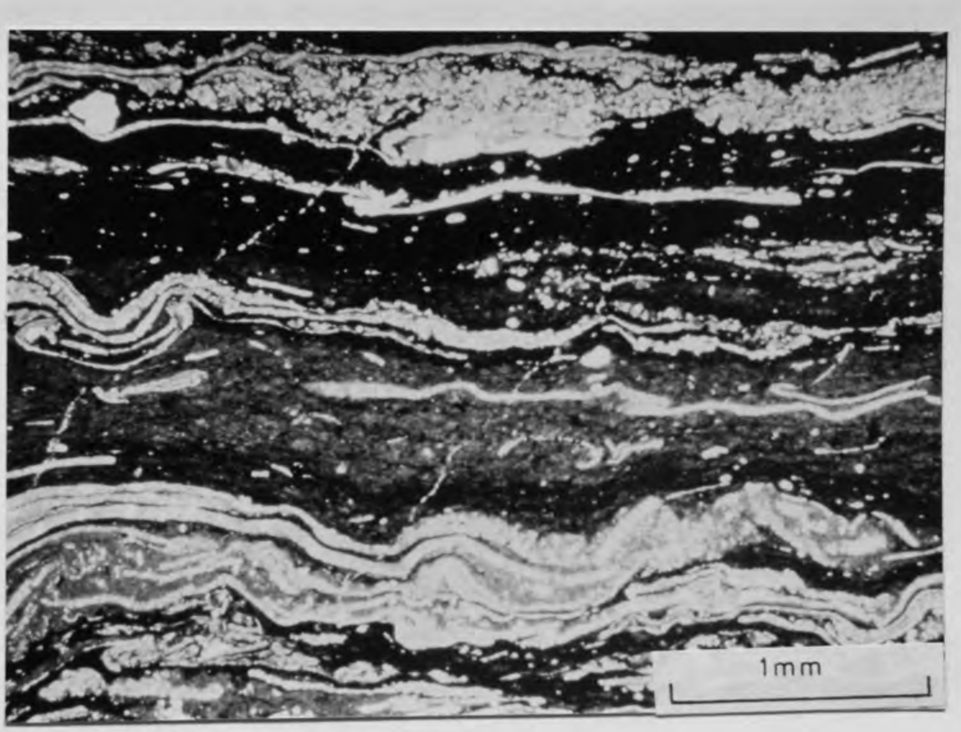


Plate 12 Laminated calcite (non-marine lamellibranch shells), siderite and organic material. Bassey Mine Ironstone, Apedale, north Staffordshire (Alzarin Red S stained section)

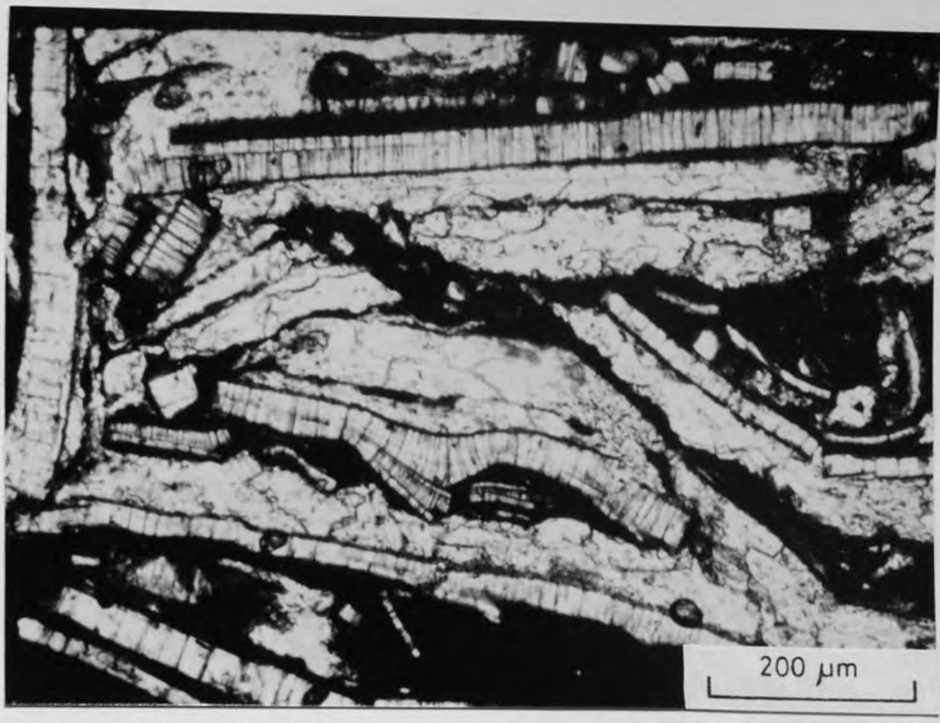


Plate 13 Bassey Mine Ironstone, Apedale showing growth lines in shell prismatics. (stained section)

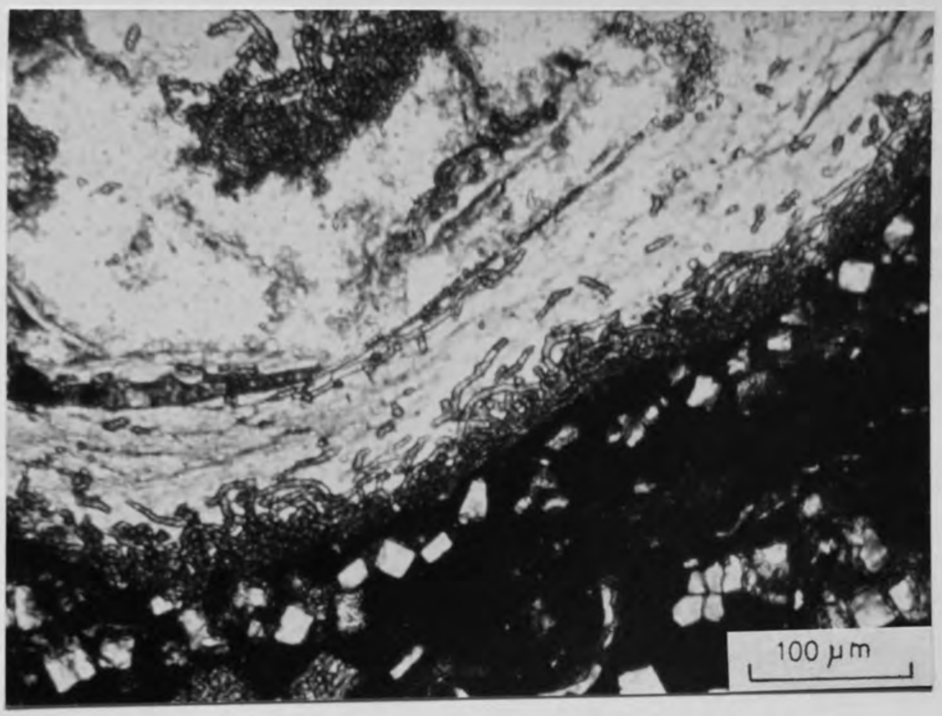


Plate 14 Bassey Mine Ironstone, Apedale. Algal borings in replaced nacreous shell layer. (stained section)

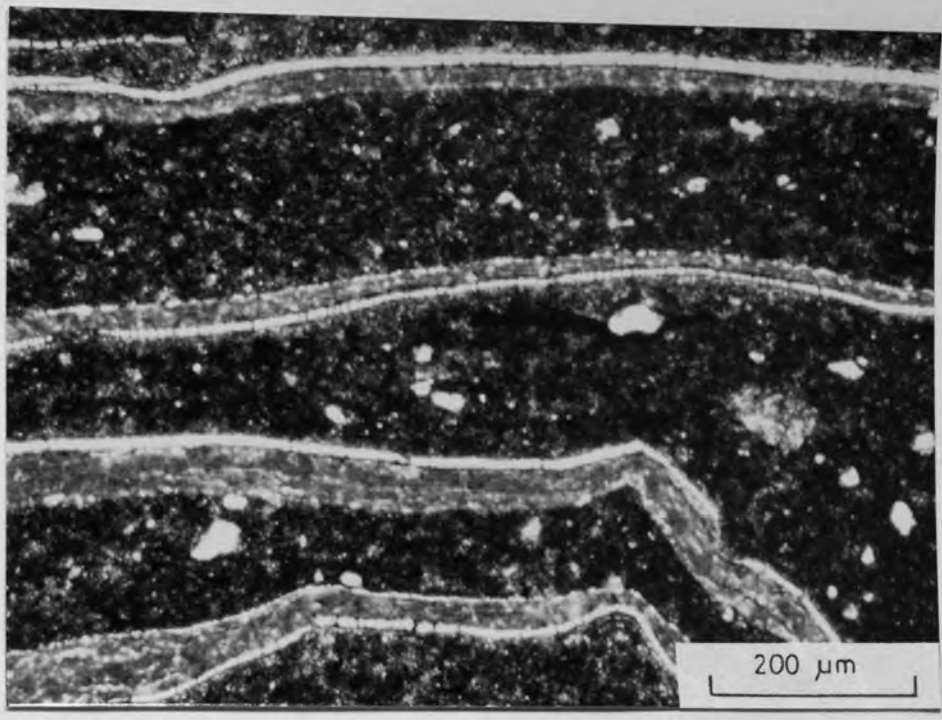


Plate 15 Two articulated non-marine lamellibranch shells in fine grained sideritic matrix showing two layers of shell - outer prismatic preserved in calcite and inner nacreous layer replaced by ferroan calcite (blue). Bassey Mine Ironstone, Apedale. (stained section)

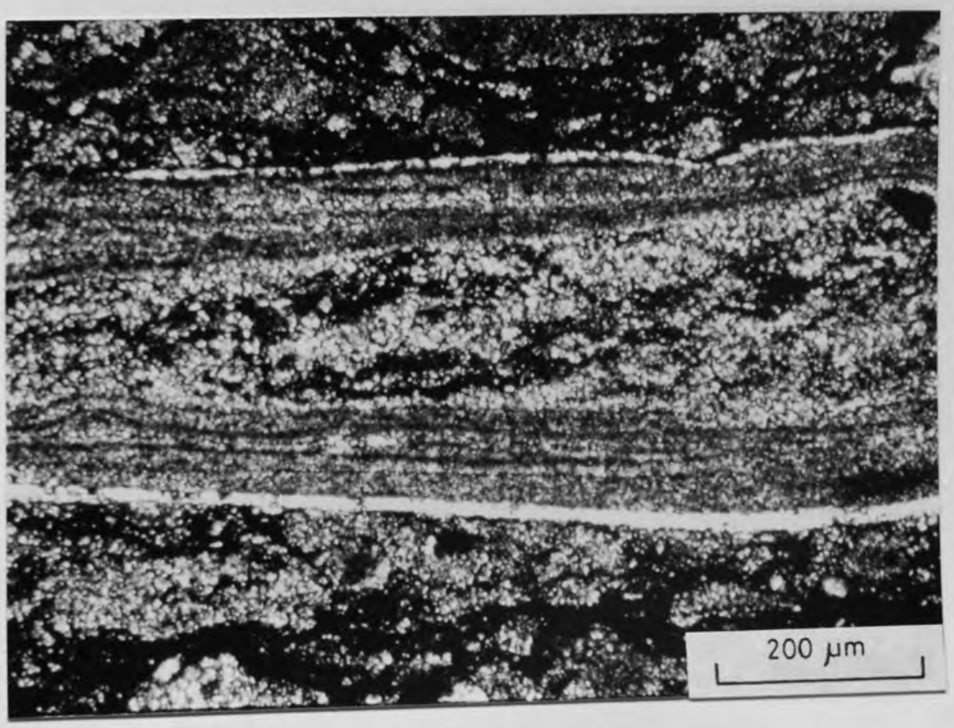


Plate 16 Sideritised non-marine lamellibranch shell showing remnant two layer structure. Red Mine Ironstone, Mitchell's Wood. (photomicrograph)

Plate 17 Bassey Mine Ironstone (core) Quarry Bank BH, Keele, north Staffordshire (scale bar in cm) (X joins with X)

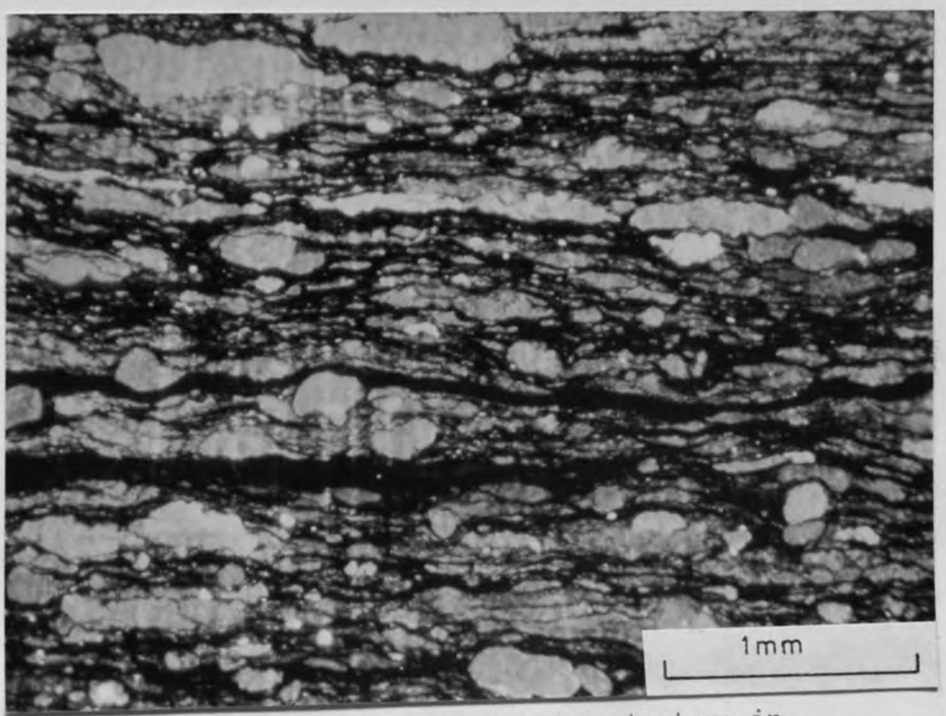


Plate 18 Well developed siderite peloidal micro-texture in carbonaceous matrix. Bassey Mine Ironstone, Hem Heath Colliery, north Staffordshire. (photomicrograph)

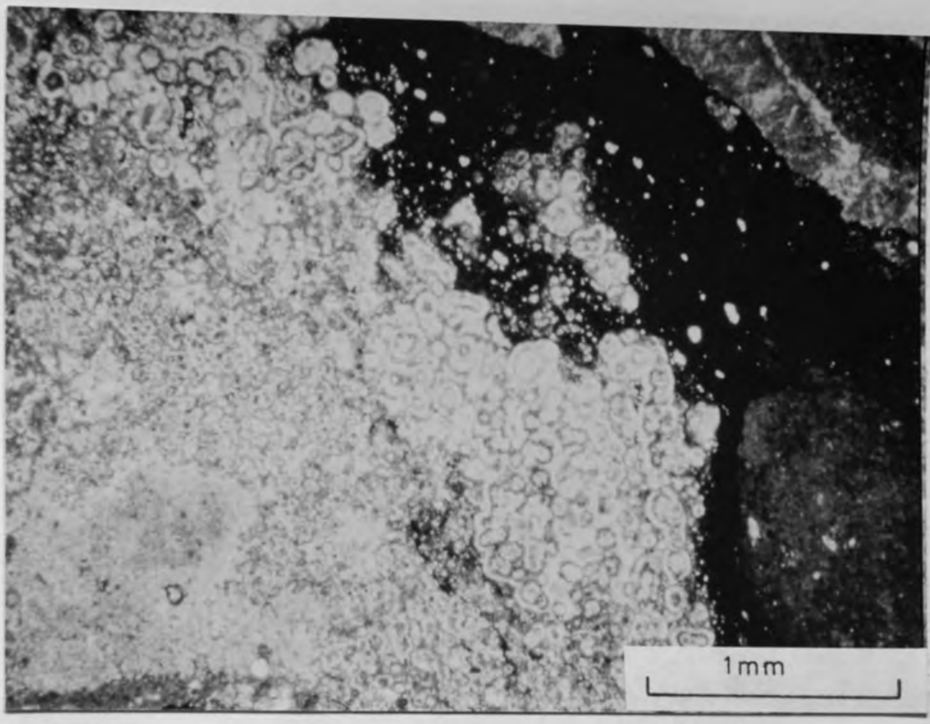


Plate 19 Bassey Mine Ironstone, Seabridge Borehole (NCB), north Staffordshire. Colloform texture in siderite. (stained section)

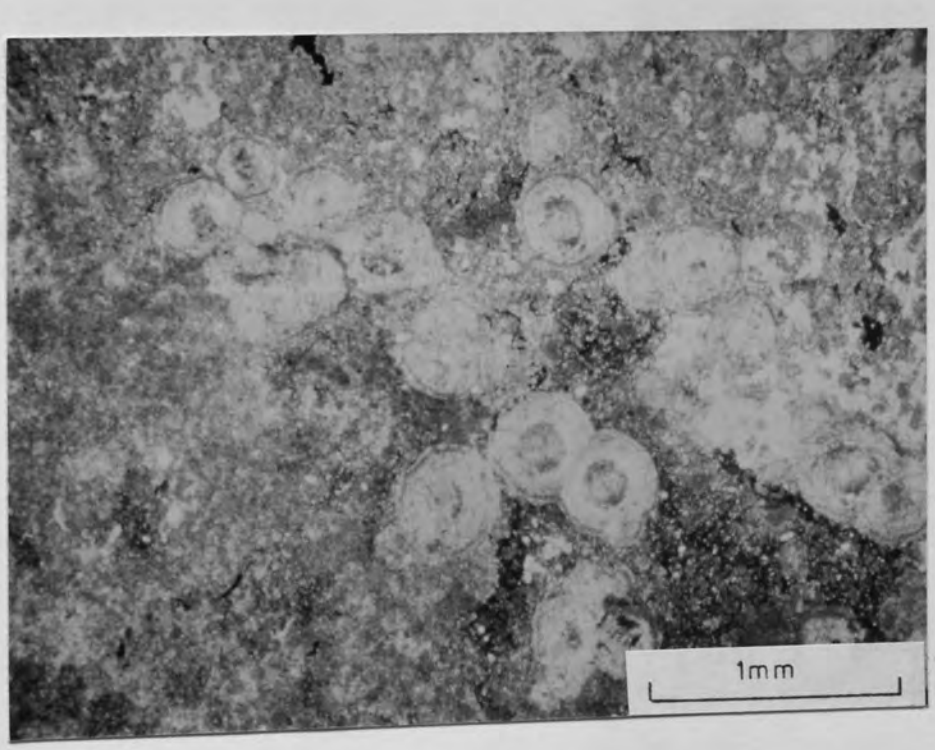


Plate 20 Bassey Mine Ironstone, Seabridge Borehole (CB), north Staffordshire. Ooliths in fine grained siderite. (stained section)

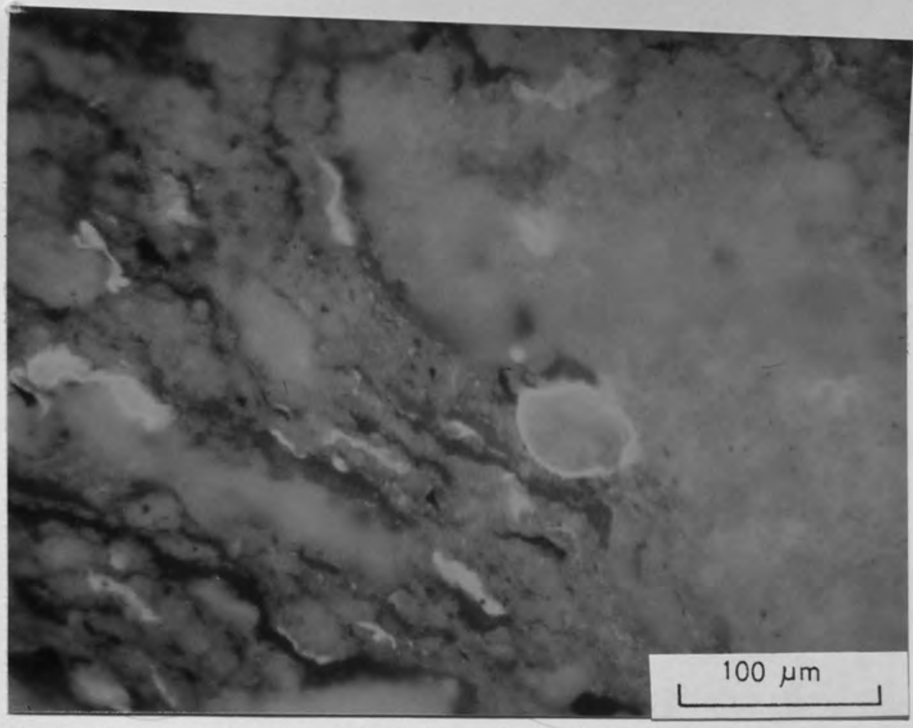


Plate 21 Photomicrograph of polished section (oil immersed objective) of immediate roof of Bassey Mine Coal Mitchell's Wood, north Staffordshire showing round spore preserved in siderite.

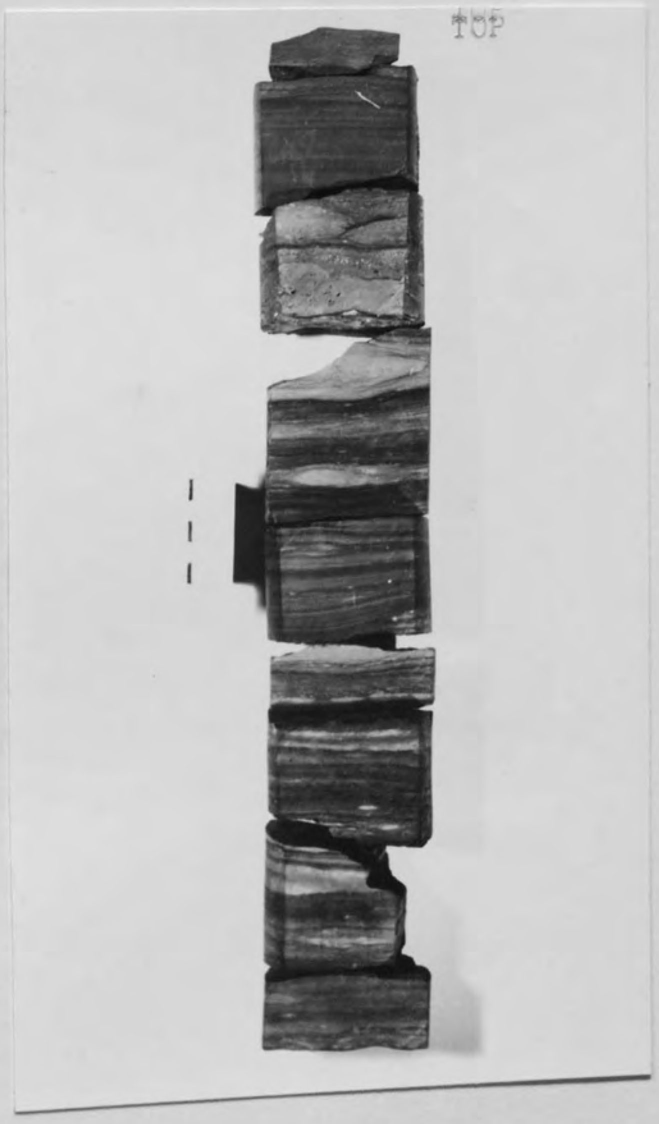


Plate 22 Core of blackband ironstone from Sunrise BH (NCB), Notts (scale bar in cm)

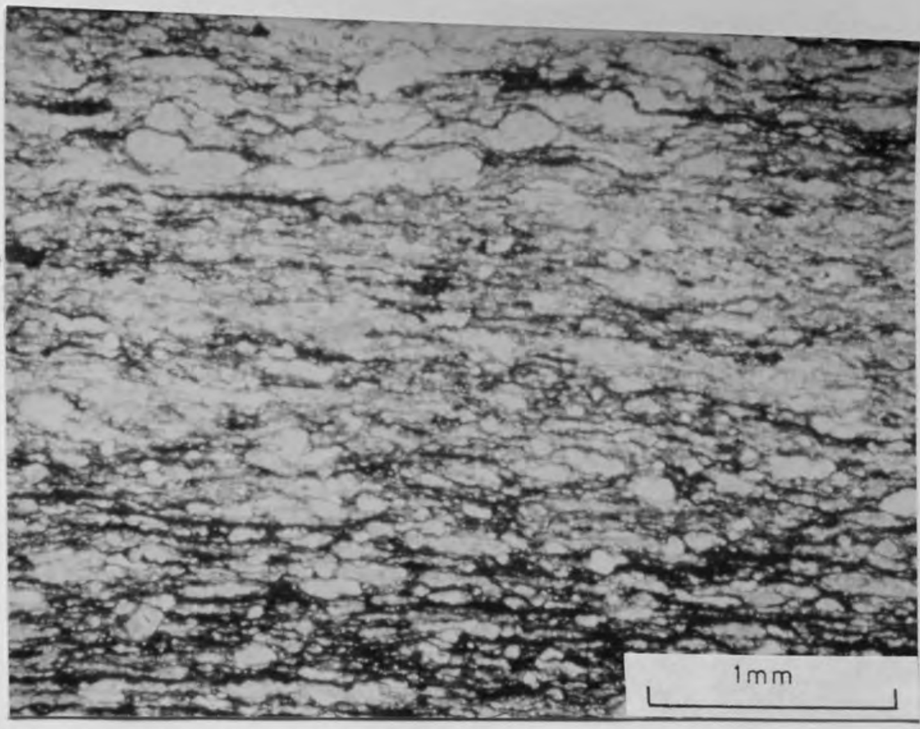


Plate 23 Blackband Ironstone from the Main Bright Horizon, Sunrise Borehole (NCB), Blidworth, Nottinghamshire. Well developed peloidal siderite. (photomicrograph)

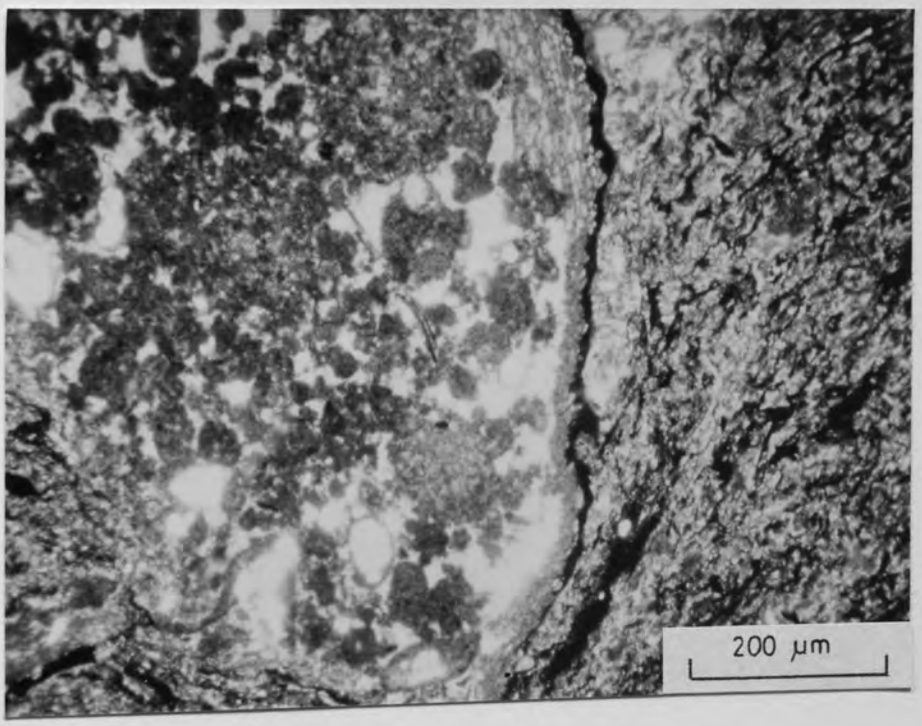


Plate 24 Blackband ironstone, Main Bright horizon, Sunrise Borehole, Blidworth, Nottinghamshire. 'Ghosts' enclosed by cellular planty tissue. (photomicrograph)

Plate 25 Core (part) of blackband ironstone, Radcliffe By-Pass borehole, Nottinghamshire (depths in metres below surface)

Plate 26 Core of the Calpatie Ironstone (blackband), Monktonhall Colliery (NCB), Midlothian (scale bar in cm)

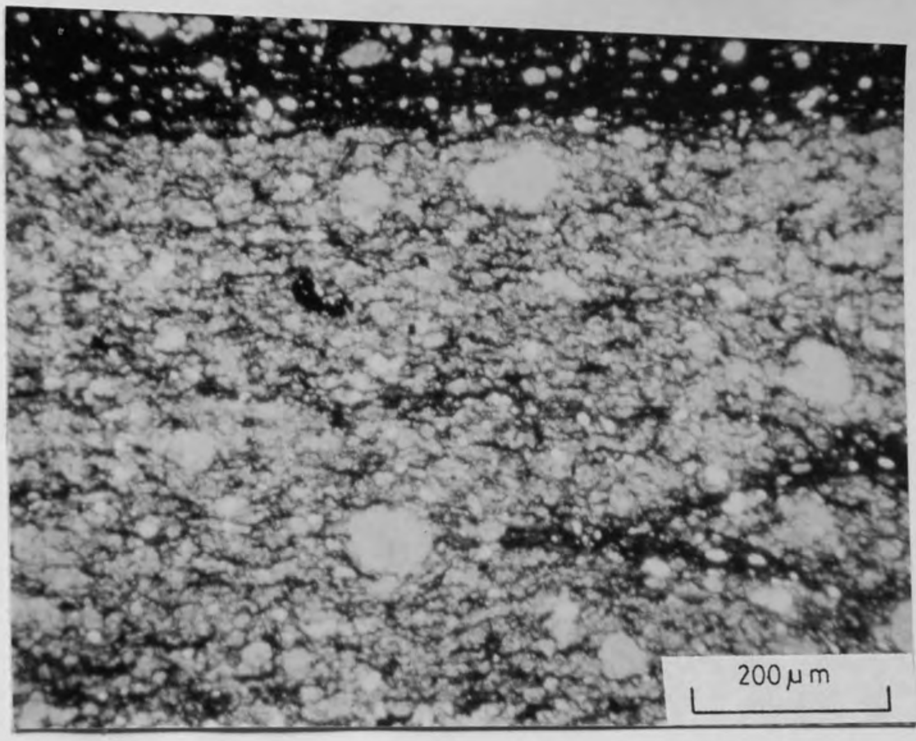


Plate 27 Calpatie Ironstone, Monktonhall Colliery (NCB), Midlothian. Peloidal siderite and quartz grains. Sharp junction with carbonaceous layer containing many oil algae in upper part of photomicrograph.

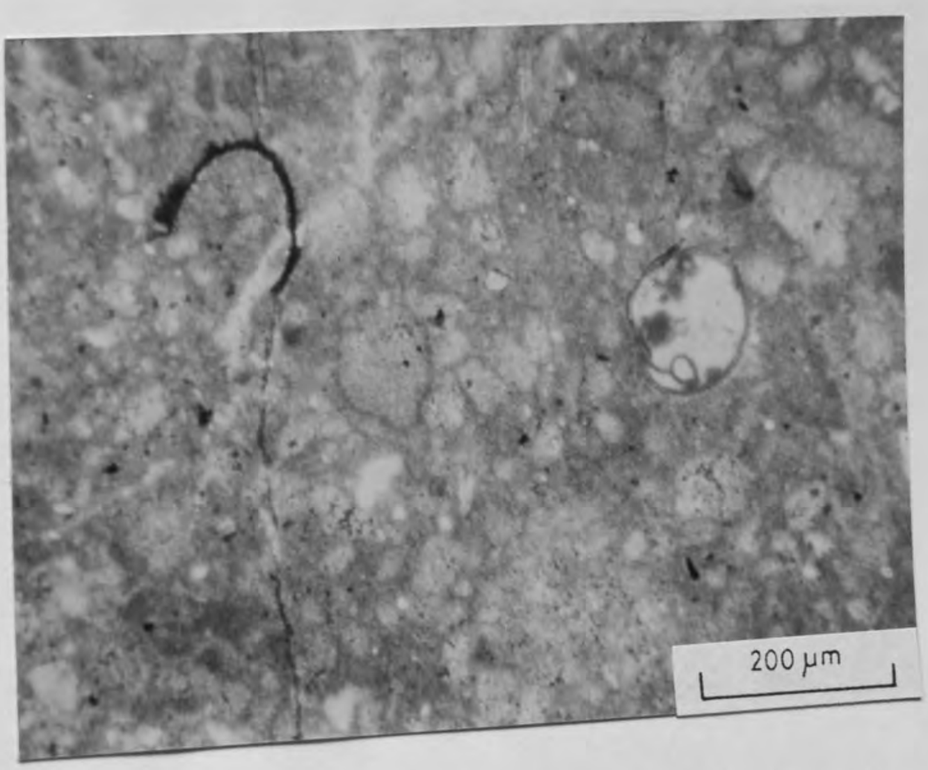


Plate 28 Calpatie Ironstone, Monktonhall Colliery (NCB), Midlothian. Photomicrograph of fine grained siderite with ostracods and siderite 'ghosts'.

Plate 29 Blackband Ironstone, Silverdale Colliery (NCB), north Staffordshire (scale bar in cm)

Plate 30 Red Mine Ironstone, Silverdale Colliery (NCB), north Staffordshire (scale bar in cm)