The faunal phases and palaeoecology of ostracod-mussel bands in the coal measures of the north and England

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THE FAUNAL PHASES AND PALAEOECOLOGY OF OSTRACOD-MUSSEL BANDS IN THE COAL MEASURES OF THE NORTH OF ENGLAND.

by

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ABSTRACT.

The stratigraphy of three ostracod-mussel bands occurring respectively in the Lower Modiolaris, Upper Communis and Upper Similis-Pulchra Zones of the Northumberland and Durham Coal Measures is described. The Hopkins' Band in the Lower Modiolaris Zone is compared with similar bands at an equivalent stratigraphical horizon in the Midgeholme and Cumberland coalfields. The dominant non-marine lamellibranchs in this band resemble, or are related to, Anthracosia regularis and Carbonicola oslancis. The Three Quarter ostracod-mussel band from the Communis Zone contains Curvirimula and Carbonicola declevis, while the Claxheugh Shell Bed from the Upper Similis-Pulchra Zone contains Naiadites and forms resembling Anthraconauta phillipsi. The ostracod, annelid, plant and fish remains in these bands are also described.

The validity and distinction of the ostracod genera Jonesina and Geisina are established and the species J. fastigiata, G. arcuata and G. subarcuata are described in detail. The ostracod species Carbonita cf. evelinae, C. cf. rankiniana, C. humilis, C. pungens, C. inflata, C. secans and C. concava sp. nov. are described from the Hopkins' Band and the presence of moults and dimorphic forms of these species is shown in the ostracod populations of the bands. The synonomy, morphology and stratigraphical ranges of the above species of ostracods from the British Coal Measures are reviewed and discussed. The true generic assignment and growth forms of the worm Microconchus (Spirorbis) pusillus are discussed. Vertical sequences of six "faunal phases" for the Hopkins' Band and three for the Three Quarter Band are deduced from a study of the respective faunas at several localities. These faunal phases are subsequently related to changing ecological conditions.

The conditions under which the sediments of the Hopkins' Band were laid down are deduced from a study of the petrology of the sediments and their chemical composition. The orientation and associations of fossils in the sediments are recorded and the published information on palaeoecology and comparative ecology of living mussels and ostracods is reviewed.

It is concluded that the Hopkins' Band was deposited in a brackish lagoonal environment at the beginning of a typical Coal Measures cyclothem. At first the richly carbonaceous bottom sediment of this lagoon prohibited the establishment of a benthonic fauna, but a change in the source and type of sediment and increase in turbulence enabled a mussel fauna to thrive with a reduction of the previously abundant pseudo-planktonic ostracod fauna. Increased sedimentation eliminated this fauna and the conditions became more deltaic. Similar environmental conditions are deduced for the Three Quarter Band, but the Claxheugh Shell Bed is believed to have formed in a small isolated brackish or fresh water lake within the main delta or swamp.

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INTRODUCTION

The argillaceous rocks of the Coal Measures frequently contain an association of non-marine lamellibranchs and non-marine ostracods in distinct shell beds, which are often referred to as "Ostracod-mussel Bands". A particularly good example of an ostracod-mussel band is the "Hopkins' Band" or Hopkins' Shell Bed" of the Northumberland and Durham Coalfield. The chief aim of this present research is to study the detailed palaeontology of this Band and to attempt to reconstruct the conditions of ecology at the time of its formation.

The Hopkins' Band has been intensively studied throughout the wide area of its occurrence, and compared with two other ostracod bands, which are of respectively lower and higher stratigraphical horizons but of more restricted geographical distribution. The emphasis in this study has been on the detailed palaeontology and taxonomy of the ostracods and the non-marine lamellibranchs have only been examined in terms of their association with the Ostracods and their ecological significance. The taxonomy of the non-marine lamellibranchs has already been done by other workers (Trueman and Weir 1946 ff. and Eagar 1961). The evidence as to the palaeoecology of this band is derived from the study of the fossils, their associations and relationship to the enclosing sediment, and a detailed study of the petrology and sedimentary geochemistry of the associated shales.

While most of this study has been confined to the Northumberland and Durham Coalfield, strata equivalent to the Hopkins' Band preserved in the Midgeholme Outlier and the Cumberland Coalfield have also been examined, largely from borehole material in the possession of the Geological Survey.

A study of this nature borders on so many branches of Geological science that it is not possible at this stage to give an account of previous relevant work, but a full discussion of such research is included as appropriate in the chapters that follow.

SECTION A

"THE STRATIGRAPHY, PALAEONTOLOGY AND FAUNAL PHASES

OF THE OSTRACOD-MUSSEL BANDS"

CHAPTER I

STRATIGRAPHY

In the past forty years there have been several major advances in Coal Measures stratigraphy. The sequence of faunal zones based on non-marine lamellibranchs established by Davies and Trueman (1927), has been further refined by recognition of the importance of marine bands (Trueman 1953). This refined sequence of marine bands and intervening non-marine, lamellibranch faunas, as applied to the Pennine Coalfields by Calver (1956), now permits a satisfactory correlation between most British Coalfields. The widespread nature of the Amman-Clay Cross- Katharina and the Cefyn Coed- Mansfield- Aegir Marine Bands has enabled correlation between "paralic" coalfields of Great Britain and Western Europe, Trueman (1946). The Marine Bands have also been used to divide the Coal Measures into, Lower, Middle and Upper divisions. (Stubblefield and Trotter 1957),

PREVIOUS WORK.

The stratigraphy of the Coal Measures of the extreme North of England, comprising the coalfields of Northumberland and Durham, Cumberland, Midgeholme and smaller outliers (shown on Fig. 1.1) is not so well known as that of the Pennine or Midland Coalfields.

Most of the work in the Northumberland and Durham Coalfield was carried out by W. Hopkins (1927, 1928, 1929, 1930, 1934, 1947, 1953). In his earlier papers, Dr. Hopkins showed that Davies and Trueman's zonal scheme of non-marine lamellibranchs can be applied directly to this coalfield. Many of the <u>Lingula</u> bands first recorded by Hopkins (1934), have since been correlated with important Marine Bands of other coalfields. The <u>Lingula</u> band recorded by Hopkins (1934, p. 186-187) from Bates Pit, Blyth, and Harton has since been found occurring widely and named the Harvey Marine Band (Armstrong and Price, 1953, p.986), and is equivalent to the Clay Cross Marine Band or Mid-modiolaris Marine Band of other coalfields. The Ashington-Ryhope Marine Band recorded by Burnett (1947) and

Armstrong and Price (1953) is equivalent to the Mansfield Marine Band of the Pennine area.

In the past ten years a very extensive boring programme by the National Coal Board, has greatly increased the knowledge of the detailed stratigraphy of this coalfield. Some of this information as concerned with N.E.Durham has been given by Armstrong and Price (1953) but much remains unpublished. The series of off-shore borings carried out by the National Coal Board in the North Sea and a resurvey by the Geological Survey, of the north east part of County Durham has greatly increased our knowledge of the highest Coal Measures in this coalfield. A Lingula horizon equivalent to the Edmondia Marine Band of the Yorks-Derby coalfield has been found (Calver 1959), and several new "Estheria" horizons are recorded. These horizons are near that of the "Main Estheria Band" of Nottinghamshire, but the equivalent of the important Top Marine Band, at the base of the Phillipsii zone, has not yet been found. The full stratigraphical succession of this coalfield, as far as it is now known, is shown in Fig. 1.2., but this may be further completed when the details of the off-shore boring programme are published.

The Midgeholme Coalfield is the largest and most westerly of a series of small outliers of the Coal Measures which extend westward up the Tyne Valley from the Northumberland and Durham Coalfield (Fig. 1.1.). These outliers owe their preservation to their being on the north or downthrown side of the Stublick Fault System. This coalfield has been studied in detail by Trotter and Hollingworth (1928) and an important faunal link with Northumberland and Durham has since been recorded by Hopkins and Bennison (1957). A series of recent boreholes by the National Coal Board near Lambley Colliery (Geol.Survey Summ.Prog. 1955), have shown the presence of the Mid-Modiolaris Marine Band and a lower Lingula Band. The succession at Midgeholme can be correlated directly with both the Northumberland and Durham and the Cumberland Coalfields as on Fig. 1.3., and indicates that the Lower and perhaps basal part of the Middle Coal Measures are preserved in this outlier.

The Cumberland, or West Cumberland Coalfield, occupies, the narrow coastal strip between the Lake District 'Massif' and the Irish Sea. (Fig. 1.1.) It has been described in great local detail in the Maryport (1930) and Whitehaven and Workington (1931) memoirs of the Geological Survey. A more general description has been given by Eastwood (1935, 1953) and Trotter (in Trueman, 1953). The results of a detailed series of boreholes made in the past thirty years, have recently been published by the Geological Survey, (Taylor and Calver, 1961). The Bolton Marine Band is the local equivalent of the Mansfield-Ryhope Marine Band, and is overlain by a thick series of Upper Coal Measures. The Solway Marine Band is the Cumberland equivalent of the Harvey Marine Band of Northumberland and Durham (Fig. 1.3.).

Although no precise correlation of coal seams has been established between the Northumberland and Durham, and the Cumberland Coalfields, it is possible to recognise equivalent marine bands and other faunal horizons such as the Hopkins Band as on Fig. 1.3.

1. The Hopkins Band.

a) Northumberland and Durham.

This faunal horizon was first recorded by Hopkins (1927) as "The Ostracod Band" in the Modiolaris zone of the Northumberland and Durham Coal Measures above the Harvey or Beaumont Seam. It soon became recognised as a horizon of importance for seam correlation and Carruthers (1929, p.62) and Eastwood (1935) termed it the "Hopkins Shell Bed". A full definition of the shell bed has been given by Hopkins (1960) in "The Lexicon of Upper Carboniferous stratigraphy". The names "Hopkins Shell Bed" and "Hopkins Band", (Armstrong and Price, 1953, p.986) have both been used by different authors, but the latter is preferred here because by the nature of the fauna it is essentially an "ostracod-mussel" band.

i) Description. The Hopkins' Band occurs in the roof shales of the Beaumont-Townley-Harvey Seam of Northumberland and Durham, and is about 40 feet below the Harvey Marine Band. For definition it is best to quote Hopkins (1928, p. 6): "This Band is unique in the Coalfield as wherever it is found, it shows a constant three-fold division:

(3) An upper division composed of Carbonicola and Naiadites.

(2) A middle division composed of Spirorbis and a few Carbonicolae and

(1) A basal division composed entirely of ostracods.

It is not the presence of the ostracod "Beyrichia" (Geisina) arcuata Bean, which makes it distinctive but the assemblage and order of deposition of the ostracods, annelids and mussels".

This present research confirms the general nature of the Band as originally described, but the more detailed examination naturally shows certain differences. For instance, there is a distinct lithological change between divisions (1) and (2), while divisions (2) and (3), although of similar lithology, faunally grade into one another. The genera Naiadites and Spirorbis occur in all three divisions and in fact are more adundant in division (1) than in divisions (2) and (3). Further minor differences will be mentioned in later chapters.

The ostracod Geisina arcuata is now known to occur in adundance in association with mussels of the Modiolaris Zone, in other coalfields. For example, Wright (1931) records such an association from the Manchester area, Wood (1937) from North Wales, and Edwards and Stubblefield (1947) and Eagar (1961) from the Yorkshire-Nottinghamshire-Derbyshire Coalfield. The work of Eagar (1961) is particularly relevant to a study of Hopkins' Band, as he has worked on the shales above the Flockton Coals of Yorkshire, which are approximately at the same stratigraphical horizon. He records (ibid, p.146) a series of five faunal phases in these shales which are very similar to those which this present investigation has shown to be present in the Hopkins' Band. Indeed the restricted vertical thickness of this Band in Northumberland and Durham and its wide lateral persistence have made it particularly suitable for a study of its fauna and faunal phases in Chapters II - V, and its palaeoecology in Chapters VI - VIII.

ii) Geographical Distribution. The geographical distribution of this Band has also been recorded by Hopkins (1929, 1930), to quote (1930, p.4) "I have traced it southwards from Choppington in Northumberland to Tudhoe in Durham, and westwards from Sunderland to Pelton. I have, however, not seen it in the western districts of Blaydon and Crawcrook, or in south eastern districts such as Thornley, Wheatley Hill and Fishburn".

The localities, where this band, or equivalent strata, have been sampled in this present research, are shown on Fig. 1.4. and the vertical profiles of about five feet of strata above the Harvey-Beaumont Seam, at most of these localities, are shown in Figs. 1.5 - 1.7. With the exception of Locality (7), which is the former Whitworth Park Opencast site, the localities are underground sites from colliery workings at or near names mentioned in the text. The Hopkins' Band has not been traced north of Choppington. At locality (1), near Longhurst (Fig. 1.5) about four miles north of Choppington, there are three seams in 30 ft. of strata named the Lower, Middle and Upper Beaumont Seams respectively. The Hopkins' Band is not present above any of these seams. The Lower Beaumont Seam is believed to be the equivalent of the true Beaumont Seam to the south, but it has a roof of thin cannel shale overlain by a thick siltstone and sandstone. Locality (2) is under the North Sea, three and a half miles north-east of Blyth, and indicates the persistence of the Band in this direction, The Band can then be traced southwards across the coalfield, as shown on Fig. 1.5., to locality (8) at Ferryhill, County Durham. Borehole information of the National Coal Board indicates, however, that the Band, or shales with ostracods, occurs in the Shildon area, six miles south-west of Ferryhill.

The most westerly occurrence of the Band in its full development is at Pelton, County Durham, Fig. 1.5 and 1.6., locality (5), but ostracod-rich shales extend to the north-west as far as Burnopfield, north-east of Consett. At locality (9), near Hedley on the Hill, in the extreme north-west corner of County Durham, there is a pocket of ostracods and mussels, preserved in cannel shale and blackband ironstone.

The Hopkins' Band does not appear to extend much to the east of Sunderland or Ryhope (locality (15)), as it is not recorded from the series of recent National Coal Board Off-shore Borings about three miles east of the coast. Ostracod bearing shales do occur in these boreholes but not in the density characteristic of the Hopkins' Band.

The absence of the Band from areas in the Tyne valley west of Newcastle, has been confirmed by sampling near Prestwich, (26), Heddon on the Wall and Barlow near Winlaton (25), and borehole evidence. In the south-east of the coalfield towards west Hartlepool, boring information again confirms the absence of the Band, especially in the Fishburn area (22).

iii) Detailed stratigraphy and thickness variation. Locality (6) on Fig. 1.5 and 1.7. at Bearpark near Durham City, has been chosen as the "type locality" and "type section" of the Hopkins' Band, for this investigation. Here the Hopkins' Band is about one foot in thickness.

Between the top of the Harvey Seam and the basal division of the Band, the "Geisina Band" - there are two inches of ankeritic mudstone conglomerate and two inches of black shale with scattered ostracods Naiadites. Division (1), - the "Geisina Band", is half an inch thick, and this is overlain by a faintly laminated shaley mudstone, containing the mussels of division (2). This shaley mudstone passes vertically into a pale grey mudstone with scattered mussels - Hopkins' division (3).

Division (3) of the Band extends to about 1 ft 2 inches above the seam when the mussels die out and the mudstone becomes siliceous. Some two feet above the Harvey Seam this siliceous mudstone becomes silty, and persists as a siltstone for the next three feet or so. The siltstone is disconformably overlain by a plant-rich sandstone. The lateral changes in thickness of the various lithological types throughout the coalfield, can be traced on Figs. 1.5, 1.6 and 1.7.

It will be seen on Fig. 1.5 that north of Bearpark the mudstone conglomerate is variable in thickness with a general thinning towards Northumberland, while the Black shale and Geisina Band remain fairly constant in thickness in this direction. To the south of Bearpark, however, both the mudstone conglomerate and the black shale show a distinct thickening, while the Geisina Band thins in this direction, Fig. 1.5 , amd also to the west Fig. 1.7. Eastwards from Bearpark the mudstone conglomerate persists but with variable thickness to locality (14) Silksworth, but it is replaced at Ryhope (15), and Harton (24) by 1 ft. of seat earth siltstone (Fig. 1.6). The "Geisina Band", however, shows its maximum thickness just west of Sunderland, at Washington (12), Hylton (13) and Silksworth (14) (Fig. 1.6).

To the west and north-west of Pelton, the mudstone conglomerate, the black shale and the Hopkins' Band are replaced by a grey plant-rich siltstone with fine sandstone bands as for example at - Tanfield Lea (11) (Fig. 1.6). Cannel coal and cannel shale develop above the seam and below these banded siltstones in the area north-west of Consett. This cannel thickens to the west as seen on Fig. 1.6. Ostracods and mussels have been found in cannel shale and blackband ironstone, at Hedley (9), and borehole information suggests other isolated occurrences, but these fossils are not concentrated into the typical phases of the Hopkins' Band.

The Hopkins' Band and immediately overlying strata, are replaced laterally both in south-west Northumberland, Prestwich (26) and in south-east Durham, Thornley to Fishburn (22), by thick white sheet sandstones.

The upper divisions of the Hopkins' Band and the overlying strata of mudstones and siltstones do not show any distinct thickness changes, largely because they grade into one another without any sudden change of lithology. A restricted and thin ostracod-mussel band about half an inch thick, and about two feet above the seam does occur in north-east Durham (Fig. 1.6) at Washington (12), Hylton (13) and Harton (24). This thin band together with that reported by Armstrong and Price (1953, p.987), ten feet above the Harvey Seam at Boldon Colliery, appear to extend eastwards to give the repetition of the ostracod bands, recorded in some of the National Coal Board Off-shore borings, between the mouths of the Wear and the Tyne (Fig. 1.4).

There is a slight but visible increase in the macroscopic silt content of these rocks towards Morpeth and Blyth in Northumberland and this is most pronounced at locality (2) - north-east of Blyth, where there is also a faunal change within the Hopkins' Band, (Chapter II),

A lithofacies map of the roof strata of the Harvey-Beaumont Seam, Fig. 1.8. has been constructed from information obtained from sampling localities and about 130 borehole records. This map confirms the general pattern of the distribution of the lithologies, shown in the series of vertical sections, (Fig. 1.5 - 1.7) and discussed above. The map clearly shows the restriction of the Hopkins' Band to the central area of the coalfield, with a peripheral replacement by sandstone to the north and south-east, and by siltstone and cannel coal to the north-west and west. The further significance of this map as indicating distribution of sedimentary environments, is discussed in Section C. Chapter IX.

b) Cumberland.

Although the Hopkins' Band does not appear to extend to the western extremity of the Northumberland and Durham Coalfield, very similar ostracod-mussel bands have been found at a similar stratigraphical horizon in both the Cumberland Coalfield and the Midgeholme Outlier (Fig. 1.1 and Fig. 1.3).

In Cumberland a profusion of ostracods in association with lower Modiolaris Zone lamellibranchs, occurs in the roof shales of the Eighteen Inch and Little Main Seams (Taylor and Calver, 1961). The densest fauna is above the

Eighteen Inch Seam, at a level about eighty feet below the Solway Marine Band, the equivalent of the Harvey Marine Band of Durham. The Little Main Seam is about twenty feet above the Eighteen Inch Seam and although of wider persistence, only locally possesses roof shales rich in mussels and ostracods.

The Eighteen Inch Seam, as its name implies, is a thin coal seam and is impersistent laterally. The Seam is best developed in the northern part of the coalfield around Dovenby and Flimby but to the south the Potash and Upper Birkby Seams are its lateral equivalencs. Figure 1.9. shows the position of boreholes and sample sites at which ostracod rich shales have been found above the Eighteen Inch Seam. Specimens have been examined in this study from the lettered localities. The numbered boreholes are recorded by Taylor and Calver (1961).

Locality A, Nelson Park Pit (disused), Broughton Moor, has been chosen as the "type locality" for this band as a fairly large amount of material has been presented for study from this locality by Mr. Gatenby of the National Coal Board Opencast Executive.

The succession here may be summarised as follows:

Grey siliceous mudstone with scattered mussels and ironstone

Mussel Band with Anthracosia c.f. regularis

2" Geisina Band

6" Black shale with fish scales

1' 4" COAL.

The thickness of the upper members of this succession is not known as the sampling is rather poor, but the general succession of lithologies is similar to the Hopkins' Band of Durham. The basal black shale is slightly thicker than the equivalent member of the Hopkins' Band and it is poorer in ostracods and Naiadites but richer in fish remains. The two inch ostracod, or "Geisina" Band, is a dark grey shale, rich in well preserved ostracods which occur throughout the full two inches of shale and are not assembled into distinct laminae as they are in division)1) of the Hopkins' Band. Unfortunately not enough specimens of the mussel band

and overlying mudstone were available from this locality to compare with the full Hopkins' Band succession, but the mussels present are of an Anthracosia regularis fauna. The succession at locality B, Hennow Hall Opencast Site, is very similar to that at Broughton Moor.

The most complete succession of these ostracod rich shales has been seen in two boreholes near Crosby, Crosby Nos. 6 and 7 (Taylor and Calver, 1961, p.26-27), localities E and F on Fig. 1.9. Succession of borehole Crosby No. 7, locality F.

16' Mudstone

2' Grey shaley mudstone with mussels and scattered ostracods

2" Ostracod Band with abundant Geisina

11" Black shales with crushed Naiadites and ostracods.

3" Black shales with fish scales

1' 6" COAL.

The individual lithological units are thicker here than at Broughton Moor, and in the Hopkins' Band, but the general succession of lithologies and fauna is similar. The black shale, rich in ostracods and Naiadites, is more like that of the Hopkins' Band than is the shale at Broughton Moor. The succession at locality F, is compared with that of Midgeholme and the Hopkins' Band at Bearpark in Durham, in Fig. 1.10., to show the general similarities and differences. All of the lithological units are thicker in both Cumberland and Midgeholme than in the Hopkins' Band, but the similarity of lithologies and the lithological and faunal succession, suggest the existence of similar environments that were geologically contemporaneous.

The strata between the Eighteen Inch and Little Main Seams are well knwon in the coastal area around Maryport. At locality D, (borehole No. 9 of Taylor abd Calver), near Risehow Colliery the two seams are separated by 53 feet of mudstone, sandy mudstone and sandstone. This is more than twice the thickness of intervening strata at Broughton Moor and Crosby to east. The succession of ostracod rich shale is similar.

6" Ostracod band

3' 6" Grey shale with mussels

1' 0" Black shale with abundant ostracods

1' 0" Black Shale

1' 6" COAL.

The appearance of this upper Ostracod band may indicate the approach to more unsettled conditions that appear to have existed to the north west, as in borehole No. 6. the ostracod-mussel rich shales are replaced by a thick series of shales, siltstones, and flaggy sandstones. In fact in this borehole 95 feet 6 inches of strata separate the Eighteen Inch and Little Main Seams.

South of Maryport towards Workington there is a thinning of the strata between the two Seams, 37 ft. being recorded from borehole (15), 17 ft. 5 in. from borehole (22) and about 10 ft. from boreholes (38, 40 and 41). The ostracod bearing strata also thins in this direction, 16 ft. 6 in. of mudstone in borehole (15), 13 ft. 8 in. in borehole (22) and only 1 - 2 ft. in boreholes (38, 40 and 41). This southerly thinning is due to a reduction of sandstone in the strata and the development of black carbonaceous or cannel shale, suggesting an area of quieter lagoonal deposition. The change in facies continues southwards as at locality C, near Branthwaite, ostracods, fish and plants occur in a cannel shale and in borehole (48) a black mudstone with fish and mussels is recorded. East of Whitehaven ostracod-fish bands are recorded from boreholes (58 and 59) but to the south and west the ostracods are replaced by a fish-mussel fauna or by plant bearing siltstones.

The general change in the facies of the rocks above the Eighteen Inch Seam south of Workington is very similar to that occurring in the Hopkins' Band in north-west Durham, as previously described.

The ostracod-mussel fauna above the Little Main Seam was first recorded from locality G, near Bullgill Station, in the Maryport Memoir but it has since been recorded in many of the later boreholes. Taylor and Calver (p. 9) record

d

a typical lower Modiolaris mussel fauna and the original Bullgill specimens that have been examined in the Geological Survey collections at Leeds show a lithological succession very similar to that of the Eighteen Inch Band and the Hopkins Band. At the base there are between 6 - 16 in. of cannel shale overlain by grey shales and mudstones with ostracods and mussels. Although this faunal horizon is not so widespread as the Eighteen Inch Band there does seem to be a similar replacement of ostracods by plant rich siltstones to the south.

Thus, while there are two horizons in the Cumberland Coalfield either of which may be approximately equivalent to the Hopkins' Band, only the better developed Eighteen Inch Band has been studied in detail here.

c) Midgeholme.

In the Brampton Memoir of the Geological Survey, (Trotter and Hollingworth, 1930), the only faunal horizon recorded from the Midgeholme Coalfield is above the Upper Craignook Seam. This horizon, only found at one locality, consisted of a mussel band with ostracods and Spirorbis, which was correlated with the Hopkins' Band of Northumberland and Durham (op, cit., p.100), (Hopkins and Bennison 1957, p.215). The actual specimens from this locality have been seen at the Geological Survey, and although the ostracods are now lost, the associated mussels indicate a Modiolaris Zone horizon and perhaps an Anthracosia regularis fauna. Thus, on the rather limited evidence of the mussels and the association of ostracods and Spirorbis, this horizon does seem to be equivalent to the Hopkins' Band.

Ten years ago, however, several boreholes were drilled at Lambley Colliery in the Midgeholme Coalfield and three of these, Lambley 10, 13, and 14, revealed other faunal horizons in this coalfield. Borehole Lambley No. 10 started in measures below the Craignook Seam and black earthy shales rich in mussels and ostracods were found. The mussel fauna is of Carbonicola cristigalli and Carbonicola pseudorobusta Groups indicating a horizon high in the Communis Zone, correlated with the strata between the Busty and Brockwell Seams of Northumderland

and Durham, by Mr. M. A. Calver of the Geological Survey. The ostracods at this horizon, Geisina arcuata and Carbonita humilis in association with Upper Communis Zone mussels, make up a fauna very similar to that of the Three Quarter Horizon of Northumberland and Durham, but such a correlation is not certain.

In Borehole No. 13 the measures believed to be just below the Craignook Seam yielded black micaceous shales with ostracods and a Carbonicola c.f. oslancis fauna. This horizon would seem to be near the base of the Lower Modiolaris Zone and thus below the level of the Hopkins' Band.

The most interesting succession was seen in Borehole No. 14 where many faunal horizons were encountered. The highest measures contained a scattered mussel fauna of Anthracosia c.f. regularis while just forty feet below the surface a band of dark grey micaceous shale with Lingulae, fucoid markings and the ostracod Parpachites indicated the presence of a Marine or Lingula Band. The association of this marine band with an Anthracosia regularis fauna suggests that it is the mid-modiolaris Marine Band, correlating with the Harvey Marine Band of Northumberland and Durham, and the Solway Marine Band of Cumberland (Fig. 1.3). At a level about 65 feet below the marine band there was a two foot succession of shales with mussels and ostracods, in precisely the equivalent position of the Hopkins' Band in relationship to the Harvey Marine Band in the Northumberland and Durham Coalfield. Several other mussel bands occurring twenty to thirty feet below the Ostracod Band, proved a Carbonicola oslancis fauna and thus Lower Modiolaris Zone horizon.

The detailed succession of the equivalent of the Hopkins' Band is given below:-

1' Grey mudstone with ironstone bands and mussels Carbonicola oslancis-bipennis.

8" Black shale mussels and ostracods. Carbonicola bipennis.

3" Dense ostracod-Naiadites-Spirorbis Band.

4" Black shale with bands of ostracods and Naiadites.

The upper three divisions of this band correspond very closely with the three divisions of the Hopkins' Band of Durham, and the four inches or more of black shale with scattered ostracods and Naiadites, is exactly similar to the shales below the Hopkins Band in the type locality (Fig. 1.5, locality (6)). Naturally the thicknesses of the various divisions of this band are different from the Hopkins' Band in its type section, and division (2), the association of ostracods and Carbonicola is here in a black shale rather than a dark grey shale as in Durham, but the general succession and fauna can leave no doubt that this horizon is the lateral equilvalent of the Hopkins' Band of Northumberland and Durham. The relationship of this faunal horizon to the Craignook Seam could not be determined from Borehole No. 14 as the Seam appears to be faulted out close below this band.

d) Conclusion.

Thus the presence of the Hopkins' Band or a distinct ostracod-mussel band, close below the Mid-Modiolaris Marine Band has been shown for all three of these Northern England Coalfields. The comparison of these Bands in Fig. 1.10. reveals their general similarity in type and succession of lithology and fauna, and their local difference in thickness and degree of development of these various phases. The major part of this research is to study in great detail the exact nature of these lithological and faunal similarities, and differences, and to interpret these in terms of local and regional palaeoecology.

2. The Three Quarter Seam Ostracod-Mussel Band.

In the south-eastern part of the Northumberland and Durham Coalfield, an ostracod-mussel band is present in the shales of the Upper Communis Zone about 200 feet below the Hopkins' Band. This band shows its maximum development in the East Hetton area but has been recorded from Bowburn, Ferryhill, Mainsforth and Fishburn areas (Fig. 1.4).

The ostracods and mussels are contained in shales at several levels within a series of this coals, seat earths and siltstones, approximately midway between the Busty and Brockwell Seams. The stratigraphical horizon of this Band or bands, about 70 to 80 feet below the Bottom Busty Seam and about 40 to 50 feet aobve the Brockwell Seam, is equivalent to the Three Quarter Seam Horizon shown on Fig. 1.2. The Three Quarter Seam is, however, best developed in north and north-west Durham (Hopkins, 1928), and this series of three or more thin seams would seem to be the lateral equivalent in the south-east part of the coalfield.

The presence of this ostracod-mussel band has not been previously recorded in print, but records of a non-marine lamellibranch fauna above the Three Quarter Seam are given by Hind (1894-96), Ford (1927) Hopkins (1928 and in Trotter 1960). This mussel fauna is said to indicate the Carbonicola pseudorobusta sub-zone of the Upper Communis Zone (Hopkins and Bennison (1957, p.219). The fauna of mussels found in this ostracod-mussel Band is described in detail in Chapter II but the presence of Carbonicola c.f. communis and Carbonicola declevis indicate that it is in the Upper Communis Zone and thus probably equivalent to the Three Quarter Seam Shell Bed, Hopkins (in Trotter, 1960).

This Band has been examined from core samples of three bore-holes put down by the National Coal Board in south-east Durham. Two of these boreholes were south-east of Fishburn Colliery and the third at Bowburn Colliery, Fig. 1.4. Although there may be several thin ostracod bands near the Three Quarter Horizon, only the major one, usually up to two feet in thickness, has been studied. In borehole Fishburn (6) the Band is about 75 feet below the Bottom Busty Seam, while in Fishburn (7), half a mile to the west, it is 81 feet and in the Bowburn Borehole 74 feet, below the seam. The lithological sections of these three boreholes is shown in Fig. 1.11.

The Band is distinctly thinner at Bowburn than in the two Fishburn bores, and the lithologies slightly different. The general succession however of the band can be summarized as:-

Grey mudstone with ironstone bands and scattered Carbonicolae.

Pale grey shaley mudstone with ostracods and Curvirimula fragments.

Grey or black shale with ostracods and Cürvirimula.

Black shale with ostracods, fish and Curvirimula fragments.

Black mudstone conglomerate or shale on 3" Coal or seat earth.

A succession of thin coals, 3 to 5" in thickness, seat earths, and shales, below.

The detailed faunal phases of this Band are discussed in Chapter V, but in broad Ourline there appears a general similarity with the Hopkins' Band. The ostracods and fish fragments occur in the darker shales below those bearing Carbonicola, and Curvirimula seems to be associated with the ostracods in the darker shales as is Naiadites in the Hopkins' Band.

The black mudstone conglomerate seen in Fishburn bores (6) and (7) is very similar to that at the base of the Hopkins' Band immediately above the Harvey Seam, at the type locality Fig. 1.5., locality (6). The fact that this mudstone conglomerate is on top of a seat earth in Fishburn bores (6) and (7), while the shale immediately overlies a thin coal at Bowburn, may indicate a period of local erosion in the Fishburn area before the deposition of the ostracod-bearing shales.

3. The Claxheugh Shell Band.

An exposure of fossiliferous Coal Measure shale in the north bank of the River Wear at Claxheugh near Sunderland, has been known for a long time to be the only permanent exposure of the highest Coal Measures in the Northumberland and Durham Coalfield. The fauna from this exposure was described and recorded by Kirby (1864), Stobbs (1905), Trechman and Woolacott (1919), Hopkins (1929) and Calver (in Armstrong and Price, 1953). The exact horizon however of this exposure has been controversial for a long time, due to this isolated locality and the restricted fauna.

The exposure at Claxheugh has been very thoroughly described and drawn by Trechman and Woolacott (1919, p.203-205, Figs. 1 and 2). However in the past forty years the condition of the exposure has deteriorated due to landslipping, but the importent fossiliferous shale at locality XY can still be recognised clearly as on Plate VIII, Fig. 2. The section of this shale that has been sampled is shown in Fig. 1.12.

This two foot succession of dark grey shale with bands of ironstone nodules, has an abrupt base on a fine plant-rich sandstone and is overlain by a 1" band of brecciated shale and pale grey micaceous siltstone above. This brecciated band would seem to be due to a large compaction effect, or perhaps very local movement of a very thin bed of shale over a hard and persistent bed of ironstone which is present at the top of the two foot shale successions.

Most of the identifiable fossils are contained in the ironstones, especially the 1" and 3" nodular layers near the base of the shale, as in the shale itself most of the fossils are crushed.

The fauna of this Shell Bed consists mostly of lamellibranchs of the genera Naiadites, and Anthraconauta, the crustacean Euestheria, and ostracods of the genus Geisina. The exact nature of this fauna is described in the later chapters. By a consideration of the fauna this horizon was placed in the Anthraconauta phillipsi Zone of the Upper Coal Measures by Stobbs (1905), Trechmann and Woolacott (1919), and Hopkins (1929) but more recently in the uppermost strata of the Upper Similis pulchra Zone by Calver (1953). This problem of the true stratigraphical horizon is considered later in terms of all the faunal evidence,

There has been difficulty in the past as regards the exact height of this fossiliferous horizon above the chief workable seam of the area, the Bensham and Maudlin Seam (see Fig. 1.2). Trechmann and Woolacott (1919, p.205) suggest that it is about 1,300 feet while Armstrong and Price (1953, p.89) are more precise suggesting that it is 1,248 feet about the Maudlin Seam.

In recent years there have been several new records of lamellibranch plant faunas, dominated by Euestheria and sometimes ostracods, from measures slightly lower or higher than the Claxheugh Horizon. Among lower strata Hopkins (1930) records faunas similar to "*Anthraconauta phillipsi*" at Offerton while Price (1954) and Smith (1955) record *Euestheria* and ostracod faunas west of North Hylton and at Offerton Gill, respectively. The only undoubted surface exposure of a horizon higher than the Claxheugh Shell Bed, was at Town End Farm, a mile or so north of Claxheugh, Smith (1959). At this locality a meagre fauna included undoubted specimens of *Anthraconauta phillipsi*, proving the presence of the *phillipsi* zone in the Durham Coalfield but at a horizon slightly higher than that of Claxheugh. (Fig. 1.2).

CHAPTER II

THE PALAEONTOLOGY OF THE NON-MARINE LAMELLIBRANCHS

Although the non-marine lamellibranch faunas of the Northumberland and Durham coalfield have been well described by Hopkins (1929 and 1930), previously no variation study of the fauna at one horizon has been attempted in this coalfield. This method of studying a large fauna of lamellibranchs from one horizon pioneered by Davies and Trueman, Wright, Leitch and latterly Eagar, has greatly helped the understanding of the wide morphological variation of the non-marine lamellibranchs and consequently their classification and nomenclature. This chapter describes the pattern of variation of the lamellibranch faunas of the three "ostracod-mussel bands" that have been studied.

1. THE HOPKINS' BAND.

Hopkins (1929, 1930 and in Trotter, 1960) has recorded the mussel fauna of the Hopkins' Band. He records (ibid, 1930, p.425) a total of twenty one species of lamellibranch from fourteen localities throughout the coalfield (Table 2.1). The fauna is dominated by the species Carbonicola cf. "subconstricta", Carbonicola venusta and Carbonicola oslancis, in association with the zonal form Anthraconaia modiolaris and Naiadites productus and cf. carinatus. Since 1930 similar mussel faunas from the same stratigraphical horizon in other coalfields have been recorded by many workers. These include; Wray and Trueman (1931) from Yorkshire, Wright (1931) from the Manchester area, Wood (1937) from North Wales, Leitch, Absalom and Henderson (1937) from Scotland, Melville (1946) from North Staffordshire and Eagar (1961) from Yorkshire and Nottinghamshire. In all these records the mussels have been associated with ostracods as in the Hopkins Band.

In this present study mussel faunas have been collected from fifteen localities in Northumberland and Durham and seen and identified from boreholes in the Midgeholme Outlier and Cumberland (Table 2.2). The actual number of species and variants found, twenty three, is very close to that of Hopkins (Table 2.1.)

Key ot the localities recorded by Hopkins

shown here on Table 2.1.

No.		Locality and date of record.
1.	-	Washington. (1930)
2.	-	Washington J sinking (1947)
3.	-	Usworth (1930)
4.	-	Silksworth (1930)
5.	-	Hylton, Follonsby and Bowburn. (1930)
6.	-	Pelton. (1930)
7.	-	Bearpark. (1930)
8.	-	Tudhoe. (1930)
9.	-	East Holywell (1930)
10.	-	Choppington. (1930)
11.	-	Norwood. (1930)
12.	-	Bates sinking ,Blyth. (1935)

Carbonicola oslancis opposite includes the species *C.cf. oslancis*, *C.cf. bipennis* (*binneyi*) and *C. cf. pectorata*.

TABLE 2.1.

MUSSELS RECORDED BY HOPKINS (1929, 1930 and 1935) FROM THE HOPKINS' BAND

Localities	1	2	3	4	5	6	7	8	9	10	11	12	Total
Species													
<u>Carbonicola</u>													
subconstricta	x	x	x		x	x				x		x	7
venusta		x							x			x	3
oslancis	x	x					x	x				x	5
cf. communis	x	x		x								x	4
cf. obtusa			x	x									2
cf. matrini				x									1
<u>Anthracosia</u>													
regularis							x	x					2
aquilina												x	1
<u>Anthracosphaerium</u>													
tugidum		x				x						x	3
<u>Naiadites</u>													
cf. carinatus		x	x										2
cf. triangularis			x										1
cf. quadratus			x										1
cf. productus								x			x		2
cf. modiolaris		x	x									x	3
<u>Anthraconaia</u>													
modiolaris		x		x		x			x			x	5
williamsoni												x	1
robertsoni		x										x	2
cf. curtata												x	1

but changes in nomenclature and a study of the detailed variation reveal certain differences.

The dominant species of Carbonicola recorded by Hopkins is, Carbonicola cf. subconstricta Wright, but most of these specimens are now considered to be variants of Carbonicola cf. oslancis. Those with a rounded posterior ventral corner approach Carbonicola cf. bipennis (Plate II, Figs. 5 and 6). The Carbonicola fauna appears to be dominated by C.oslancis and its variants C.cf.bipennis, C.pectorata and C.embletoni, but the small orbicular form C.venusta is fairly common.

The form Anthracosphaerium [Carbonicola] turgidum recorded by Hopkins has not been identified conclusively in this study. Certain specimens approaching this form are here considered as slightly timid variants of Anthracosia regularis. Undoubted forms of Anthracosia regularis and its variants dominate the mussel fauna. The larger relatively high variants are homeomorphic with A.cf.aquilina, while the more elongated forms resemble A.cf.ovum. The fact that Anthracosia regularis (sensu stricto) was so rarely found by Hopkins may be due to a more detailed sampling in this study of the higher shales and mudstones of Division (3) of the Hopkins' Band, where Anthracosia seems to replace Carbonicola. But variants of A.regularis (sensu lato) were recorded by Hopkins as C.elliptica Wright.

The genera Anthraconaia and Naiadites show a general agreement in both these studies. The zonal species Anthraconaia modiolaris is dominant and A.cf.fugax Eagar are found occasionally. Naiadites of the productus-triangularis group and the strongly carinate, carinatus-flexuous group, are the commonest members of this genus.

The overall nature of this fauna, dominated by Carbonicola oslancis and Anthracosia regularis, agrees well with the "Anthracosia regularis fauna", described by Calver (1956) from the rocks just below the mid-modiolaris Marine Band in the Pennine Coalfields.

A detailed study of the four hundred specimens collected from various

TABLE 2.2

DETAILS OF MUSSELS COLLECTED FROM HOPKINS' BAND IN THIS STUDY

Species	Number of localities recorded			Number of specimens collected	
	Durham	Cumberland	Midgeholme	Bearpark Whitworth East Holywell	Total numbers all localities
<u>Carbonicola</u>					
oslancis	6			5	10
cf. oslancis	12	x	x	49	68
cf. venusta	9		x	20	31
cf. bipennis	10	x	x	8	16
cf. pectorata	8			4	10
cf. embletoni	5		5	7	9
cf. rhomboidalis	4			0	5
cf. communis	1		x	1	1
<u>Anthracosia</u>					
regularis	4			2	4
cf. regularis	13	x	x	45	67
cf. ovum	6			13	17
cf. retrotracta	4		x	6	7
cf. aquilina	6			14	16
regularis-retrotracta	2			2	2
regularis-ovum	2			0	1
<u>Naiadites</u>					
cf. triangularis	7		x	13	21
cf. productus	7	x	x	36	51
cf. quadratus	3	x		4	6
cf. flexuous	8	x		13	22
cf. subtruncatus	2			4	4
<u>Anthraconaia</u>					
modiolaris	8	x		4	14
williamsoni	3			3	4
robertsoni	1		x	0	1
cf. curtata	1			0	1
cf. fallax	1			0	1

localities in the coalfield (Table 2.2) Columns 4 and 5) confirm the nature of the "oslancis-regularis fauna" as indicated in terms of the frequency of occurence (Table 2.2, Column 1). Only three localities, Bearpark Colliery and Whitworth Park Opencast Site, in County Durham and Fenwick Colliery in Northumberland (Fig. 1.4, localities 6, 7, and 3 respectively) have yielded mussels in any abundance. But even here the faunas were not dense enough for a detailed variation study to be carried out at one locality. From table 2.2 however it is possible to see the nature of the "typical populations" of each genus, and these are illustrated in Figs. 2.1. - 2.5.

These variation pictograms are made up of variants from many localities and thus do not represent thue "fossil communities or populations". They do however give an idea of the range of variation of the various genera that has been found in the upper two divisions of the Hopkins'Band. The following section describes the pattern of this variation within the various gehera and further consideration of the fauna as a whole is continued later.

a) The variation of the non-marine lamellibranchs.

No new species of non-marine lamellibranch has been found in the study so that all the named specimens approach the specific descriptions given by Trueman and Weir (1946 and following) in monograph "The Carboniferous non-marine lamellibranchia".

i) Carbonicola. The species *Carbonicola oslancis* Wright was described by Wright (1929) from the basal beds of the Modiolaris Zone near Manchester and later (Wright 1939) he defined these beds as the *oslancis* subzone. Within this subzone Wright (1931, p.138-139) records the variants *C.oslancis var pectorata*, *C.cf.rhomboidalis*, *C.cf.similis*, *C.cf.communis*, *C.cf.subconstricta* and even *C.cf.martini*. Trueman and Weir (1946, p.60) further commented on the frequency of forms indistinguishable from *C.bipennis* in faunas of *C.oslancis*. The fauna of the Hopkins Band shown in Fig. 2.1. and Plates I and II does indeed show a range of variants similar to that recorded by these workers.

Thus on Fig. 2.1. the form "l" is Carbonicola oslancis (sensu stricto) form "a" is Carbonicola venusta, s.s., while forms "g, h, i" are Carbonicola embletoni and form "u" is Carbonicola pectorata. The central form "f" is a large elongated specimen with a distinct dorsal ridge, and is thus identified as Carbonicola aff. oslancis. This central form can be related directly in C.pectorata via the variant "t", with the development of the chatacteristic re-entrant angle just in front of the posterior ventral corner.

The line of horizontal variation on Fig. 2.1 from "f- p, q, r" shows the retention of this dorsal ridge and an increase in the relative height thus giving forms similar in shape to C.cf.communis "q", and C.cf.rhomboidalis "r". This dorsal ridge does, however, decrease in prominance from "f - p - q" and is lost in "r", but the fairly sharp angle of the posterior ventral corner indicates the relationship of these variants to the C.oslancis fauna.

The variation from "f - n, o" indicates an increasing prominance of the umbo and elevation of the posterio-dorsal edge to give the form "o" very similar to Carbonicola bipennis. This form C.cf.bipennis is a common variant in this fauna (see table 2.2) as mentioned by Trueman and Weir. The species Carbonicola venusta can tenuously be derived from the central form "f" by a decrease in size and increase in the relative height, via the variants "a, d, c, b, a". The form "b" is C.aff.venusta and "a", C.venusta (sensu structo).

The species C.embletoni Brown, according to Trueman and Weir is a rare variant of C.oslancis but in the Hopkins Band faunas it is of fairly common occurrence (Table 2.2). It seems to have related to C.oslancis by the variant "k". A further decrease in size of C.embletoni "j, h or g", increase in the relative height, and loss of the posterior angulation, ight lead to, C.venusta, "a".

The dominant form recorded and figured by Hopkins (1929, Plate II, Fig. "e"), as C.cf.subconstricta, seems similar in shape to forms "m, p, q, and s" of Fig. 2.1. but it has a more pronounced umbo. The graphic plot of the dimension ratios of these forms and of the holotypes of the various species, Fig. 2.2., confirms their general affinity with Carbonicola oslancis and variants rather than C.subconstricta s.s. Hopkins form (Fig. "e") falls closest to C.subconstricta s.s., but even this is not far removed from the area of C.cf.oslancis. The form "r" considered here as a variant toward C.cf.rhomboidalis, has a height to length (H/L) ratio typical of the latter species but a longer anterior A/L 37% rather than the usual 25-30%. Trueman and Weir indicate (op.cit., p.35), howdver, that forms of C.cf.rhomboidalis can have an A/L ratio up to 42%. Thus the form commonly described by Hopkins a C.cf.subconstricta is here generally referred to as C.cf.oslancis.

Carbonicola venusta is undoubtedly a species in its own right at this horizon and of fairly common occurence (Table 2.2). Certain specimens however may closely approach poorly preserved or juvenile forms of Anthracosia cf. regularis, such as Fig. 2.3. forms "Q and R", when the characteristic growth lines are not seen.

The pattern of variation of this genus in the Hopkins' Band very closely approaches that described by Eagar (1961, p.143, Fig. 5) from 3 inches of shale above the Flockton Thin Coal at Barnsley in Yorkshire. As these two faunas are at similar stratigraphical horizons their close similarity tends to confirm the true nature of the variation of Carbonicola from the Hopkins' Band as represented on Fig. 2.1.

ii) Anthracosia. The species Anthracosia regularis, that shares the dominance of the Hopkins' Band faunas with Carbonicola oslancis, is according to Trueman and Weir (op.cit., p.106) "of critical importance, stratigraphically because of its short range, at its acme, across the mid-modiolaris Marine Band, and taxonomically because it is in some respects intermediate between Carbonicola and the derivative genus Anthracosia".

The stratigraphical level of the Hopkins' Band is about that of the first appearance of the genus Anthracosia, and so the generic characters of the umbonal tilt of the growth lines and the parallel sided dorsal outline, are frequently not well developed. The fauna however recorded in Table 2.2. and represented in the pictogram Fig. 2.3 is an early "Anthracosia regularis fauna" as described by Calver(1956).

The forms G, N and P, on Fig. 2.3 are specimens of Anthracosia regularis (sensu stricto) while forms O and M and Q and R , may be refered to as A.aff and A.cf.regularis respectively. The form Q, apart from the slightly tilted growth lines, is homeomorphic with C.aff venusta, as already mentioned and described by Trueman and Weir (op.cit., p.163) and Eagar (1961, p.144, Fig. 6).

An increase in size and relative height, produces a variant from A.regularis towards A.retrotracta, "C" as is seen from G, F, E, D to C on Fig. 2.3. However relative elongation of form G, from G to M, L to K, produces a variant A.cf.ovum "K" . Further elongation of both the anterior and posterior ends of the form A.cf.ovum, can produce the form I which resembles A.cf.aquilina. A tenuous link between the form A.cf.retrotracta and A.cf.aquilina "I" is suggested via the variants. D to C, B, A, H to I . The forms A and H are similar in shape to Anthracosia retrotracta but as they lack the pronounced umbonal tilt of the growth lines and the very reduced anterior of this species, they would seem to be variants nearer "A.cf.aquilina", although with some homeomorphic tendency towards A.retrotracta.

The forms Anthracosia cf.retrotracta, A.cf.ovum, and A.cf.aquilina are fairly common in this fauna (Table 2.2) especially from the best sampled localities. These three forms become dominant in the higher strata above the mid-Modiolaris Marine Band, and characterise the "Anthracosia ovum fauna" described by Calver (1956). At the level of the Hopkins Band however they are perhaps only early forms of their respective species and may indicate either, the derivation of later species of Anthracosia from variants of A.regularis sensu lato, or else a polyphyletic origin of this genus.

In the siliceous mudstone about 2 ft. above the Harvey Seam at Whitworth Part Opencast Site (Fig. 1.4, locality (7)), and rarely at other localities, a very small form of mussel occurs that resembles "Carbonicola "carissima" Wright. This form was described by Wright (1931, p.42, Plate I, Fig. 9) but has not been recorded subsequently. Wright suggested that this could be a juvenile specimen of Anthracosia cf.concinna or cf. aquilina, but due to its common occurrence and restricted vertical range, he named it as a new species. He later erected the "carissima" subzone in the upper part of the Modiolaris Zone.

Specimens of "Carbonicola carissima" are figured on Plate V, Fig. 8. It occurs usually as isolated groups of small individuals in varying orientations and therefore seems to be an arrested juvenile, stunted, or dwarf form of Anthracosia, perhaps A.cf.ovum or aquilina or even Carbonicola cf. oslancis. The presence of this dwarf form is perhaps due to changing ecological conditions, as suggested by Broadhurst (1959, p.530-31, 542 and 544) for dwarf forms of Anthraconaia pulchella. Eagar (1952, p.186) further suggests that stunting of a Carbonicola exporrecta fauna from the Namurian of Yorkshire, may be caused by an increase in sedimentation.

iii) Naiadites. Naiadites is well presented in the Hopkins' Band, the commonest species being N.cf.productus with N.cf.triangularis and N.flexuosus showing a secondary place and the forms N.quadratus and N.subtruncatus occurring only rarely (Table 2.2). The variation diagram Fig. 2.4 suggests the presence of two distinct groups of Naiadites, the group N.triangularis-productus-subtruncatus (i - viii) and the group N.quadratus-carinatus-flexuosus (ix-xii).

The dominant form N.cf.productus (iii-vi) appears to show a complete gradation to forms similar to N.cf.triangularis (i and ii) - by increase in the relative height and decrease in the prominance of the carina, and a displacement of this towards the ventral edge. A further increase in the relative height and straightening of the ventral border could give a quadrate form similar to N.cf.quadratus, but no variants obviously intermediate between N.cf.triangularis and N.quadratus have been found. The elongation of the dorsal margin and reduction of the height of N.cf.productus (vi-vii) produces a mytiliform variant N.cf.subtruncatus (viii). The variant "vii" seems to be intermediate between N.productus and N.subtruncatus and is very similar to that figured by Trueman and Weir (Plate XVIII, Figs. 23 and 24).

Although the species N.cf.quadratus (ix) is fairly rare as complete specimens, it is probably that many of the Naiadites fragments abundant in the shale below the "Geisina Band" are of this species. The thinner shell and large quadrate shape of this species means that it is easily broken. The form "xi" possesses the quadrate shape of N.quadratus but also has a strong carina with a sigmoid flexure and so it seems to approach the variant between N.quadratus and carinatus figured by Trueman and Weir (Plate XXX, Fig. 40). Naiadites carinatus sensu stricto (xi) has a strong sinuous carina and a great relative height or depth but is a rarer variant than the shallower form N.cf.flexuosus (xii). No specimens of this latter species have been found with the distinct posterior "wing" characteristic of Naiadites flexuosus sensu stricto.

The overall nature of the Naiadites fauna dominated by N.cf.productus and N.flexuosus is similar to that described by Calver for associates of an "Anthracosia regularis"fauna, but the intermediate between N.productus-quadratus that he mentions, is not common in the Hopkins' Band.

iv) Anthraconaia. This genus is not so well represented as the other genera of non-marine lamellibranchs. Most localities yielded one or two specimens of the zonal species but only at locality (2), off shore of Bates Pit, at Blyth, were sufficient numbers found to be called a population. Thus any discussion of the variation of this genus is rather speculative.

The forms Y, X and W of Fig. 2.5 are typical members of the species Anthraconaia modiolaris, with the characteristic wing and umbonal ridge both in the juvenile forms X and W and the adult Y. Specimen Z has a greatly raised dorsal margin and thus an expanded posterior wing and resembles Anthraconaia cf. curtata.

The elongation of A.modiolaris from Y-V, produces form U resembling A. Williamsoni and in the extreme case form V . This latter variant V is very elongate and possesses almost parallel dorsal and ventral margins, resembling A.cf.fugax Eagar, although this species has not been recorded previously from this horizon.

Eagar (1961, p.142, Fig. 4) describes a community of Anthraconaia sp.nov., as yet unnamed, some variants of which closely approach forms U and V from the Hopkins' Band. The specimen figured as Fig. 4.e. by Eagar is very close to that of Wright (1931, Fig. 50 E) from above the Oldham Great Mine Seam of the Lower Modiolaris zone in the Manchester region. This form he calls Carbonicola martini [ovalis] and it is later figured as such by Trueman and Weir (Plate V, Fig. 9). Its appearance however is extremely like an Anthraconaia or anthraconaid Carbonicola such as that figured by Hopkins (1929, Plate II, Fig. "n").

v) Curvirimula. No complete or specifically identifiable specimens of this genus have been found in the sediments of the Hopkins' Band. In the upper part of the mudstone conglomerate and basal black shale, however, very thin irridescent shell fragments occur, that resemble the undoubted shells of Curvirimula seen in the Three Quarter Band. Further reference to Curvirimula refer to these scattered fragments.

b) Vertical and lateral changes in the non-marine lamellibranch fauna of the Hopkins' Band.

In almost all localities the densest mussel fauna of the Hopkins' Band lies in the three inches of shale immediately above the "Geisina Band". This shale comprises, division (2) and the lower part of division (3) of the Hopkins' Band, as previously described (Chapter I), but mussels may persist as scattered individuals up to a foot or more above the Geisina Band. (Chapter I, Fig. 1.5.-1.7.) Table 2.3 indicates the vertical distribution of mussels collected from all localities for which detailed vertical position was recorded. The actual division of the mussel bearing shales and mudstones into three inch units is purely arbitrary and is not necessarily reflected by lithological or other changes.

TABLE 2.3

Vertical distribution of mussels in the Hopkins' Band

Height above the Geisina Band. (all localities)

Species	0 – 3 inches	3 – 6 inches	6 – 9 inches	9 – 12 inches	Above 12 inches
Carbonicola					
oslancis	6	2			
cf. oslancis	16	7	5	4	5
venusta	15	7			
bipennis	6	1	2		
pectorata	5				
embletoni	2		1	1	
cf. rhomboidalis	3				
cf. communis		1			
NO. SPECIES	7	5	3	2	1
Anthracosia					
regularis	1	3			
cf. regularis	28	18	2	5	20+ "carissima"
cf. ovum	1	4		3	
cf. retrotracta	2	2			
cf. aquilina	4	1			
regularis-retrotracta	1	1		2	
regularis-ovum	3	2	2	1	
NO. SPECIES	7	6	2	4	1 ?
Naiadites					
triangularis	12	4	2	2	1
productus	13	4	2	6	4
quadratus	1			1	
flexuosus	12	1	3	2	1
subtruncatus	1			1	4
NO. SPECIES	5	3	3	5	4
Anthraconaia					
modiolaris	6	1			
williamsoni	7				
curtata	1				
cf. fallax	1				
NO. SPECIES	4	1			
TOTAL NO. OF SPECIES	23	15	8	8	6

The great variations in numbers of mussels collected from the different localities make any quantitative predictions doubtful, but certain general trends do emerge. The oslancis-regularis fauna from 0 - 3 inches above the Geisina Band is confirmed from all localities, and consist of Anthracosia regularis, Carbonicola oslancis, Carbonicola venusta, with Naiadites cf. productus, N.cf.triangularis and N.cf.flexuosus. The species and variants of Anthraconaia appear to be virtually re tricted to this basal three inches of shale, but all the other genera occur above. In the unit 3 - 6 inches A.regularis and its variants seems to dominate over the Carbonicolas and there is a more restricted variation in the Naiadites. The fauna from 6 - 9 inches above the Geisina Band is rather sparse and is dominated by Naiadites with Anthracosia and Carbonicola equally subordinate. From 9 - 12 inches the fauna is dominated by Naiadites with subordinate Anthracosia and rare Carbonicola sp. Above 12 inches mussels are extremely scattered and groups or individuals of Anthracosia occur, the stunted form "A.carissima" being common at Whitworth Park Opencast Site.

The vertical pattern of variation of the different genera can be seen from the number of species and variants recorded at each level (Table 2.3). Anthracosia and Carbonicola both show up the seven distinct variants in the lowest three inches, but while the number of species of Carbonicola is reduced by 5, 3, 2, to 1 , from 3 to 12 inches+, Anthracosia does not show such a consistent reduction and four distinct variants are recorded from the level 9 - 12 inches. Naiadites shows a wide variation in the lowest 3 inches, then a reduction from 3 - 9 inches and finally above 9 inches its variation appears to increase as it survives the other genera. It has not been possible to determine the pattern of variation of Naiadites where it occurs in the shales below the Geisina Band but the main variants would appear to be N.cf.triangularis-productus and N.cf.quadratus. The actual variation however at this level may be wide as above 12 inches as Naiadites has no competition from other genera of lamellibranchs.

In the shales and mudstones more than 6 inches above the Geisina Band, there is a tendency for the mussels to be concentrated into groups and this fact is probably of ecological significance (Chapter VIII).

Eagar (1961, p.142-144) records a marked vertical distinction of faunas in the shale above the Flockton Thin coal of Yorkshire. Variants of the genus Anthraconaia occur between 2' 5" and 2' 8½" above the coal, a community of Carbonicola oslancis-bipennis between 2' 8½" to 2' 11" and a community of Anthracosia cf. regularis above 2' 11". Compared with this clear cut vertical distinction, the genera of the Hopkins' Band show a distinct overlap, but something of the same general pattern can be seen in the restriction of Anthraconaia to the basal 3" of shale, and the vertical survival of Anthracosia above Carbonicola, but these so called "phases" will be discussed in Chapter V.

Due to the scattered nature of the sampling it is not possible to draw any general conclusions as to the lateral variations in the mussel fauna of the Hopkins' Band within the Northumberland and Durham Coalfield. The only major lateral change in fauna that has been found, occurs north-east of Blyth in Northumberland (Chapter I[illegible]). At locality (2), 3½ miles north-east of Blyth, the fauna of the basal 3 inches of shale above the Geisina Band, consists of Anthraconaia modiolaris and A.williamsoni together with Naiadites, but no specimens of Anthracosia or Carbonicola. About four inches above the Geisina Band however a few scattered Anthracosia cf. regularis do occur with the Anthraconaia but no Carbonicolae. Scattered specimens of A.cf.regularis also occur higher up in the more silty mudstones. This faunal change therefore suggests a lateral replacement of Carbonicola by Anthraconaia in the basal three inches of mussel bearing shales.

There is some suggestion of this faunal change to be seen in the area of Blyth itself from the fauna collected and recorded by Hopkins (1935, p.9) from the Bates sinking at Blyth (Table 2.1, locality (12)). This fauna, when compared with that of another sinking, at Washington, County Durham, (Hopkins and Philipson, 1947, p.4), Table 2.1, locality (2)), shows the presence of a larger number of variants of Anthraconaia than is usually recorded from this horizon. Anthraconaia modiolaris, A.williamsoni, A.robertsoni, A.cf.curtata, are all recorded at Blyth compared with the usual record of just the zonal species at Washington. Five species of Carbonicola and one of Anthracosia however are recorded from Bates sinking so that the main change in the dominance of the fauna must occur north-east of Blyth.

The non-marine lamellibranchs that have been examined in the geological survey collection from the boreholes in the Midgeholme outlier and Cumberland coalfield at the equivalent horizon to the Hopkins' Band are included in Table 2.2. From both these areas the fauna is typically one of Anthracosia regularis with, C.oslancis+bipennis and Naiadites cf. productus. Other species of the Hopkins' Band such as Carbonicola venusta, Anthracosia cf. ovum, Naiadites cf. triangularis and Anthraconaia robertsoni are recorded from Midgeholme, while N.cf.flexuosus and Anthraconaia modiolaris are recorded for Cumberland. Trotter and Hollingworth (1931 and p.109) record the species Anthracosia cf. nitida ? and Anthracospherium cf.affine ? from the original fossiliferous locality above the Craignook Seam at Midgeholme but these would seem to be a typical variants more truly characteristic of a higher Modiolaris Zone horizon. Generally there seems to be a close similarity between the mussel faunas of these three coalfields at the level of the Hopkins' Band.

2. The Three Quarter Seam Ostracod-mussel Band.

The presence of an ostracod-mussel band in the south east part of the Durham coalfield, in strata of the Upper Communis Zone, has been recorded and its stratigraphy described in Chapter I. The stratigraphical horizon of this Band would seem to indicate its equivalence to the Three Quarter Seam of N.W.Durham, so the faunal evidence of the non-marine lamellibranchs has been studied to elucidate this problem.

The Three Quarter Shell Bed has been defined by Hopkins' in Trotter 1960 although previously recorded by Hind (1894-96), Ford (1927) and Hopkins (1929). The mussels from this horizon from the Washington sinking are recorded by Ford (op. cit.)) as Carbonicola cf. martini (= C. ovalis Davies and Trueman 1927), Curvirimula belgica [formerly Anthraconauta minima], and Naiadites cf. triangularis.

Specimens have been collected from the roof shales of the Three Quarter Seam at Medomsley Colliery, near Consett, and these consist of a fauna of Carbonicola cf. cristi-galli (Plate VI, Fig. 2), Carbonicola cf. pseudorobusta (Plate VI, Fig. 1.), Carbonicola cf. communis, Naiadites cf. quadratus and "Spirorbis" but no ostracods. This fauna confirms that this horizon is in the pseudorobusta subzone of the Upper Communis Zone (Hopkins and Benison 1957, p.219).

Whilst fragments of Carbonicola sp. occur quite frequently in the boreholes through the ostracod mussel band in south-east Durham, specific identification of these mussels was only possible from two of the 3 in. cores. In borehole Fishburn (6), well preserved specimens of Carbonicola declevis and Curvirimula belgica were found while in the Bowburn Borehole, fragments of Carbonicola cf. communis, C. cf. cristi-galli and C. cf. acuta have been recognized.

The specimen of C. declevis (Plate VI, Fig. 4) from borehole Fishburn (6) is very close to the holotype described by Trueman and Weir (1946, p.12-19) Plate II, Figs. 15, 17, 18), which also came from a borehole near Fishburn Colliery, but at a slightly lower stratigraphical horizon. The shape is identical with the holotype possessing the characteristic carina, and obliquely truncate posterior and the dimensions are very similar, H/L 37.7% as against 41.5% and A/L 23.8% as against 20% both well within the specific range given, H/L c.40%, A/L 20-25% . The speciman of Curvirimula belgica [formerly "Anthraconauta minima" and A. subovata var. candela Dewar] (Plate VI, Fig. 3.), also is a typical specimen as described by Weir (1960, p.304-305). Although the stratigraphical range of Curvirimula belgica, as now understood, is very wide, Lower Carboniferous to Westphalian A, the form here is typical of the species, previously called "Anthraconauta subovata var candela Dewar" which characterises the Upper Communis zone.

Thus the faunal evidence from the lamellibranchs of these boreholes does confirm that the Three Quarter Seam Ostracod-Mussel Band is in the pseudorobusta Subzone of the Upper Communis Zone, on account of the mussels C.cristigalli, C.acuta and C.declevis and is the lateral equivalent of the Three Quarter Shell Bed of N.W.Durham.

3. The Claxheugh Shell Bed.

The main interest in the mussel fauna of this horizon lies in the true relationship of the forms recorded as "Ancylus vinti" (Kirby 1864) and "Anthraconauta phillipsi"(Stobbs, 1905). However this fauna has recently been studied in detail by Mr. Calver of the Geological Survey (in Armstrong and Price, 1953, p.989 and Weir, 1960, p.286), and his general conclusions are confirmed here. The emphasis of this present research however has been on the ostracod fauna of this horizon so that the mussel fauna has not been examined in very great detail.

The form described as "Ancylus vinti"by Kirby (1864), later as Carbonicola vinti by Stobbs (1905), then as "a young stage of Anthraconauta phillipsi" by Bolton (in Trechmann and Woolacott, 1919), has finally been recognised as a species of Euestheria by Calver (op.cit., p.989).

The specimens of "Anthraconauta phillipsi" of previous authors are considered by Calver, from a study of the large amount of material in the Geological Survey collection, to be variants of Naiadites davesi-elongata group, often homeomorphic with Anthraconauta cf. phillipsi. He writes (op.cit., p.989) "Certain of these shells resemble A.phillipsi and as single occurances might well be termed A.cf.phillipsi. However by far the larger proportion of these shells show Naiadites characteristics. It is considered that the stock as a whole should be considered as Naiadites, with some shells as homeomorphs of A.cf.phillipsi, although typical examples of the latter species have not been seen". These conclusions of Calver are endorsed by Weir (1960, p.285-286) who mentions similar homeomorphy of A.phillipsi by N.davesi in the lower Similis-Pulchra Zone at Maltby in Yorkshire, and in the Knowles Ironstone of the Upper Similis Pulchra zone of North Staffordshire.

By kindness of the Geological Survey it has been possible to examine the faunas in their collections both from Claxheugh and North Staffordshire and compare these with the specimens collected personally from Claxheugh. The North Staffordshire material, from below the Wingley and above the Billy Coals, is very similar in both lithology and fauna to that from Claxheugh. The ostracods are compared in Chapter III, and Euestheria cf. vinti ? and the "Anthraconauta phillipsi" like forms of Naiadites are both present. The Naiadites are largely of the N. davesi-hindi group but some forms more typical of N. cf. productus or N. triangularis are present.

The specimens of "A. phillipsi" like forms that have been collected personally from Claxheugh when compared with Trueman and Weir, plate XXVII, Fig. 45, and plate XXXIII, Fig. 76 and 77, show their true nature as crushed forms of Naiadites cf. daviesi. In the smaller specimens, there is a faint trace of the ventral byssel notch that according to Weir (1960, p.285 Footnote 1) is characteristic of N. daviesi in its early stages. There are frequent elongate crushed "Anthraconauta" like specimens which would seem to be Naiadites cf. hindi Trueman and Weir [N. elongata hindi]. There are however certain shells, both juvenile and adult, that show no Naiadites characters and must thus be identified as cf. Anthraconauta phillipsi sensu lato.

The stratigraphical horizon of the North Staffordshire fauna is well established (Melville 1946, p.303 and 324), as high in the Upper Similis Pulchra Zone and below the Lady or Bay Marine Band, (equivalent to the Top Marine Band of Yorkshire and Nottinghamshire), that is the true dividing line between the Upper Similis Pulchra and the Phillipsi Zones.

The close faunal similarity and the evidence of other workers thus suggest that this is also the true stratigraphical horizon of the Claxheugh Shell Bed of north-east Durham.

CHAPTER III

THE PALAEONTOLOGY OF THE OSTRACODS

The ostracods are the dominant fossils of the Coal Measure micro-fauna but when compared with their macrofaunal associates they have not been studied to the same extent. The microfossils in the marine bands of the Coal Measures consist of foraminifera, conodonts, and a few ostracods but in non-marine beds ostracods and serpulid worms predominate. Little work has been done on these British faunas when compared with that done on similar faunas in the American Pennsylvanian and little is known of their detailed taxonomy.

In the latter half of the nineteenth century many species of ostracods from the Upper and Lower Carboniferous of Great Britain were described and named by Professor R. T. Jones and Mr. J. Kirkby (1867, 1870, 1879, 1886 and 1890). The Carboniferous ostracod faunas of Scotland were revised and further described by Latham (1932), in the light of the then current American work, but since then little has been published on British Coal Measure forms except for occasional lists and brief records in the publications of the Geological Survey.

The Coal Measures of Europe, however, especially the Rhur Coalfield, have yielded ostracod faunas which have been described by Kummerow (1949, 1953), Krempe and Grebe (1955) and Vangerow (1957). In the last five years this German work has shown an awareness of the vast amount of work done on Pennsylvanian ostracods in the United States since the turn of the century.

The earliest American records are probably those of specimens sent to Jones and Kirkby in the 1860's, but since 1900 the work of Ulrich and Bassler (1906 and 1908) has stimulated many workers to study these fossils. Thus many of the early volumes of the Journal of Palaeontology contain papers by such authors as Harlton (1927), Knight (1928), and Kellett (1933), all describing Pennsylvanian ostracods from various parts of the United States. Other workers like Bradfield (1935), Holland (1934) and Johnson (1936), published their work in journals of a more restricted circulation and local interest, as for example Johnson's description of Geisina in the Bulletin of the Nebraska Geological Survey. So great was the spate of ostracod description from the Pennsylvanian and lower Systems in the United States, that "The Bibliographic Index of Palaeozoic Ostracods" was written by Bassler and Kellett (1934).

In the next decade work on these forms was continued by Kellett (1943), Cooper (1941 and 1946), Scott (1944) and Scott and Summerson (1943) and more recently by Scott and Sohn (1961) in "Treatise of Invertibrate Palaeontology Part Q: Ostracoda". Echolls and Creath (1959) are prominent among the many Pennsylvanian ostracod workers of the 1950's. Work on ostracods is now known to be going on in Russia (Polenova 1960) but the results are not yet available for study in this country. Thus there is a vast amount of German and American literature, to say nothing of untranslated Russian work, which must be taken into account by anyone attempting to study in detail the ostracod faunas of the British Coal Measures.

In the Coal Measures there is a fairly sharp distinction into marine and non-marine types among the ostracods. *Hollinella bassleri* and related species are the commonest forms in the Marine and *Lingula* Bands, while species of *Parapachites* are not uncommon. A unique fauna from the Cefyn Coed Marine Band of South Wales Coalfield, containing in addition the genera *Amphissites*, *Cornigella*, *Cypridina*, *Kirkbya*? *Knightina*, and *Roundyella*, has been recorded by Ramsbottom (1952). The non-marine assemblages are of commoner occurrence than the marine ones and occur in greater profusion, but the number of genera pepresented is smaller. *Geisina* and *Carbonita* are the dominent genera but some variants of these have been included in such doubtful genera as *Jonesina* and *Whipplella*. The rest of this Chapter is concerned with the genera *Geisina* and *Carbonita*.

Many species of Coal Measure ostracods were first described in the latter half of the last century but type material was neither designated nor deposited in a museum for subsequent reference. The ostracods that have been found in this present study in the Coal Measures of Northumberland and Durham are therefore described in detail and compared with original descriptions and other specimens of the appropriate species where these are known.

No type material is known for Geisina arcuata and so a lectotype and paratypes have been chosen from specimens from Bean's Collection now in the British museum. The genus Carbonita however has been revised recently by Dr. F. W. Anderson of the Geological Survey, and is not in manuscript, (Anderson MS), and so reference is made to the lectotypes he has chosen from the British Museum Collections. The descriptions of the species from the Hopkins' Band are extended by studying populations and brief reviews of stratigraphical range, distribution, and faunal associates of the species are included.

The refinement of taxonomic description of ostracods has naturally led to a multitude of special terms to describe the shell characters, but in this chapter these are reduced to a minimum. These terms are explained in Figs. 3. 1 and 2, in accordance with those of the American Treatise (Moore 1961, p.47-56). The classification herein adopted is again that of the American Treatise, the characters of the various taxa are briefly defined where necessary and sharp differences from previous classifications briefly discussed.

The latter half of this chapter is a detailed study of the ostracod populations of the ostracod-mussel bands in the Northumberland and Durham Coalfield. While many of the species here described are fairly well known as isolated specimens from the Coal Measures in general for most species of Carbonita this is the first record from this Coalfield. Little has previously been known about specific associations and vertical and lateral population changes within an ostracod-mussel band.

The specimens of ostracods here described from the Hopkins'Band have been extracted by the techniques, explained in Appendix I and studied both under the binocular microscope and in thin sections of the Geisina Band.

1. SYSTEMATIC DESCRIPTION.

a) The Geisina group.

Classification.

Phylum : ARTHROPODA

Class : CRUSTACEA

Sub-class : OSTRACODA Latrielle

Order: : PALAEOCOPIDA Hemmingsmoen 1953

Sub-order : KLOEDENELLOEOPINA Scott 1961

Superfamily : KLOEDENELLACEAE Ulrich and Bassler 1908

Family : GEISINIDAE Sohn 1961

Diagnosis : Straight; smooth, punctate, or pitted, subquadrate to subelliptical small; anterodorsal half sulcate; overlap slight; probably ridge and groove hinge; inner lamella narrow, of even width along free margins, feathering towards cardinal angles, dimorphic in width of posterior part.

(Sohn suggests that this family belongs to the PODOCOPIDA because of a duplicature in Geisina.) M.Devonian - M.Permian.

Genus : GEISINA Johnson 1936.

Genotype : Geisina (Jonesina) gregaria Ulrich and Bassler.

Diagnosis : Carapace sub-ovate to subrectangular in lateral view; dorsal margin straight; ventral margin straight to convex; ends rounded; maximum thickness in posterior half; hinge depressed posterior to sulcus; right valve larger than left, and overlapping it along the ventral and end margins; well defined sulcus is located slightly anterior to the middle along the dorsal half, and there may be a second less prominent sulcus in the anterior (Johnson posterior) half.

Hinge formed by overlap of the left valve along the anterior half of the dorsal margin and a flange in the posterior half of the dorsal margin of the left valve which fits into a corresponding groove in the right valve; surface finely reticulate.

Species : Geisina arcuata Bean 1836.

Geisina subarcuata Jones 1867.

The diagnosis of the family and genus are given in detail as the family is of recent establishment and the validity of the genus Geisina must be examined before Geisina arcuata Bean is considered in detail.

The Generic Assignment of "Geisina" arcuata Bean.

i) Historical. Since that first description of this species by Bean in 1836, it has been placed in not less than six different genera. This long taxonomic history is partly due to the development and refinement of ostracod classification and partly due to a confusion resulting from a holotype neither having been designated nor properly described.

The original description of Bean (1836) is brief and in general terms, while the original figure is vague though artistic. The features mentioned however, "smooth, brown, glossy and distinctly reniform with a slight depression in the middle of the front margin", are typical of this species. The type locality and horizon, given as, "the coal formation near Newcastle", are also vague. It is probably that the original specimens of this species came from the Hopkins' Band in the Newcastle area. The Beaumont Seam was certainly being worked at this time along the north bank of the Tyne at Benwell, just west of Newcastle (History of Northumberland, 1930, 8, 25). The roof shales of this seam observed personally, at East Holywell 5 miles north-east and at heworth 2 miles south-east of Benwell, contain abundant ostracods. Probably the shale specimen collected from the roof shales of this Seam was sent to the well known Yorkshire naturalist William Bean.

Further evidence in support of the type horizon being the Hopkins' Band is derived from the shale enclosing these ostracods from Bean's Collection now in the British Museum. (B.M. - In 43596) This specimen bears a label "Cypris arcuata mihi" and therefore may include his first examples of this species. The shale is lithologically and faunally identical with material collected personally in the Newcastle area. An ostracod from this shale specimen of Bean's collection is here designated 'the Lectotype' and is described later.

The first detailed description of "Beyrichia" [Cypris] arcuata was given by Jones and Kirkby (1886), although the species had been previously recorded by Geinitz (1846) and Jones and Kirkby (1867), from Germany and Scotland respectively. Jones and Kirkby (1886) record specimens from the Midlands, Manchester and Lanark and from Ryhope and Claxheugh in County Durham. They figured specimens from Claxheugh, Carluke in Lanark and Longton, Staffordshire. These figured specimens are all from the Coal Measures, but those from Claxheugh and Longton are probably from the Upper Similis-Pulchra Zone, and more correctly Geisina subarcuata Jones, while those from Carluke may be nearer the type horizon of G.arcuata in the Modiolaris Zone.

The genus Jonesina was erected by Ulrich and Bassler (1908) on the genotype J.fastigiata Jones and Kirkby, but without description or reference to a type specimen. This genus was broadly defined and included six species besides the genotype one of which was "Jonesina" arcuata. The genus Jonesina has since proved to be multigeneric and is finally rejected in the American Treatise (moore et.al. 1961, p.413). However "Cypris" arcuata Bean has freqeutnly been referred to this genus by many ostracod workers in the past fifty years as is recorded later in the detailed synonomy of this species.

The actual genus Geisina was erected by Johnson (1936) on the genotype J.gregaria, a form that is frequently associated with "Geisina" arcuata in the American Pennsylvanian and differs only in the possession of a posterior spine (Co oper, 1946). Johnson examined the only known material of Jonesina fastigiata from the British Muesum Collections and distinguished Geisina from Jonesina in terms of hinge structure and sulcation. Part of this present study has been the re-examination of the British Museum material of "Jonesina" fastigiata, and other species of "Jonesina", to elucidate this doubtful genus and to ascertain the true generic relationship of "Geisina" arcuata.

The remaining genera to which this species has been assigned are Sansabella Roundy, by Latham (1932), and Limnoprimitia Kummerow (1949). The designation of Latham (1932) was a wrong one as she was not acquainted with the type material of Sansabella. Limnoprimitia is really a synonym of Geisina. Kummerow not being aware of the American genus, and because of the poor state of preservation of his material he felt that the species "arcuata" was more closely allied to the Primitidae rather than to the Kloedenellidae (Krempe and Grebe, 1955, p.161.)

ii) Evidence from the present study. The main confusion which has arisen seems to be whether the species "Cypris" arcuata Bean, should be called Jonesina arcuata or Geisina arcuata. In order to sort out this problem, the validity of the genus Jonesina has been assessed by examination of all the specimens of this genus in the British Museum, originally identified by Jones and Kirkby. This material includes specimens of "Jonesina" fastigiata, "Jonesina" cratigera, and "Jonesina" bradyana. The specimens of "Jonesina" fastigiata described here are the only ones known to have been identified by Jones and Kirkby (Johnson, 1936) and are therefore designated the genotype and lectotype material.

SYSTEMATIC DESCRIPTION OF Jonesina Fastigiata. Jones and Kirkby, 1886.

Synonomy : Beyrichia fastigiata Jones and Kirkby, 1865
Geol.Soc.Glasgow. Tr.2., p.219.
" " Jones and Kirkby, 1886.
Geol.Mag.Dec.3.3., p.438, pl.12, Fig.8-10.
Jonesina fastigiata Ulrich and Bassler, 1908. U.S.Nat.Mus. Pr.35, p.324, pl. 44, Fig. 10-12.
" " Johnson, 1936. Nebraska Geol.Survey. Paper No. 11, p.19-20, pl.11, Figs. 1-4.

Type specimens.		Lectotypes	Paratypes
	Female	B.M. I 1774	In 32494
	Male	B.M. In 32496	In 32495

Figure 3.3

Description of Lectotype (Personal)

Carapace sub-rectangular in lateral view; greatest height anterior of mid line; dorsal margin straight; ventral margin straight, flatly convex, sloping slightly anterior to posterior; ends rounded; anterior broadly and evenly rounded, posterior more obtusely rounded in dorsal area.

Dorsal outline - Male: Subovate, widest medially or just posterior to the middle.

Female: Sub-cuneiform, posterior broadly inflated, maximum thickness in posterior quarter, anterior pointed.

S_2. Median sulcus deeply incised in dorsal view.

S_1. Anterior sulcus distinct, narrow and shallow; gives an indistinct node anterior to it, and a very swollen and distinct node posterior and giving a deeply incis ed S_2.

S_2. Median sulcus, anterior of mid-line, narrow and deep, sloping slightly antero-dorsally. It narrows and deepens from the dorsal margin to just dorsal of the antero-median area, where it terminates in a deep pit.

Posterior to the sulcus the surface is raised into a broad node which slopes away posteriorly, in the male, to the posterior margin, while in the female it is delineated posteriorly by a short, shallow S_3 posterior sulcus.

In the female in the posterior ventral area below the S_3 where is a furrow or short ventral sulcus, posterior to which the posterior end of the carapace is greatly inflated and tumid. Dorsum sloping at the sides.

Hinge line straight, highest part of the dorsum.

Cardinal angles obtuse with a distinct but narrow advance of the right valve over the left at both cardinal angles.

Both valves are equally raised along the hinge line and there may be a very narrow slit-like channel between them.

The actual hinge appears to be formed by the close contacts of the unthickened adges of the dorsal contact margins of both valves and the advance of the R. valve over the L. at the cardinal angles. Sometimes the R. valve may be raised very slightly above the L. along the hinge, but does not overlap it. (The internal hinge contact is not visible on specimen.)

Right valve larger, overlaps the Left around the ventral and end margins but narrowly, perhaps more an over-reach than true overlap. There is a slight thickening around the free edge of both valves to accommodate the overlap, thus both valves are rimmed.

Muscle scab pattern is not seen, probably muscle in inner base of the sulcus, swelling internally.

The shell substance is thin and the external surface is finely punctate.

Dimensions.	I 1774.	In 32496.
Length	0.89 mm.	0.91 mm.
Height	0.48 mm.	0.54 mm.
Posterior Thickness	0.40 mm.	0.38 mm.
Height of S_2	0.13 mm.	0.16 mm.
Median Thickness	0.35 mm.	0.32 mm.
Anterior to posterior Thickness	0.20 mm.	0.40 mm.

Dimorphic features.

Female : More elongate-oblong in lateral view than male due to inflated posterior.

Dorsal outline subcuneiform, maximum thickness in the posterior quarter. Faint S_3 and ventral sulcus present.

Male : Shorter, subrectangular in lateral view.

Dorsal outline subovate, maximum thickness just posterior to the middle.

S_3 and ventral sulcus absent.

Comments on the British Museum Types.

The lectotype I 1774 was figured by Johnson (1936, Plate II, Fig. 1.) and is here believed to be an adult female. The actual specimen is an internal mould of the carapace in calcite with the shell attached to the L. valve but lost from the R. valve. The posterior sulcus S_3 and the ventral furrow are well seen. The male lectotype In 32496 was also figured by Johnson (1936, Plate II, Fig. 2) but likened to "Jonesina" bradyana. It is however a typical specimen of the male form and although both valves are preserved medially, the anterior and posterior ends of the R. valve are missing.

The paratype In 32494 was also figured by Johnson (1936, Plate II, Fig. 3). The specimen appears to be an internal mould of the adult female. All the shell is missing, the dorsal anterior end is broken off and the mould is slightly eroded so that the overlap and hinge features cannot be seen. The characteristic inflated posterior however, indicates the female form. The other paratype In 32495 is a complete carapace of the adult male. Both valves are preserved and there is a tubercle posterior to S_3 sulcus. The hinge is well seen with prominent overlap at the cardinal angles. The node L2 is eroded on the L. valve and the ventral posterior end of the R. valve is missing.

Dimensions of the Paratypes.	In 32494 female	In 32495 male
Length	0.85 mm.	0.83 mm.
Height	0.44 mm.	0.49 mm.
Posterior Thickness	0.39 mm.	0.34 mm.
Thickness at S2	0.13 mm.	0.15 mm.

The paratype specimens confirm both the features and dimensions of the lectotypes described previously and also indicate that a posterior tubercle may sometimes be present on the male form.

Type Locality.

Chalkieside, Old Quarry, Nr. Crossgatehall, 2½ miles N.E. of Dalkeith, Scotland.

Type Horizon.

Lower Limestone Series, Lower Carboniferous.

Discussion of the genus and spécies.

The specimens described and figured by Jones and Kirkby (1886) were internal moulds with 3 sulci and nodes and are here considered to be the female form. These original specimens are now lost and so direct comparison is not possible.

Johnson (1936) described the females of the present collection as Jonesina fastigiata, but likened the male form to J. bradyana. This latter species however is much smaller than J. fastigiata and has a thicker shell with pronounced overlap and only a median sulcus.

The characters that are of generic significance in the previous description are; the dorsum not depressed posteriorly; the thin straight hinge with overlap at cardinal angles only; the deeply impressed median sulcus with a pit like base; and the bisulcate nature in lateral view. (Fig. 3.3) These characters were all emphasised by Cooper (1941, p.55-56) when he emmended and restricted the diagnosis of Jonesina. Specimens figured by Cooper (1941, Plate II, Figs. 36-39) as the dimorphic form of J.cratigera compare very closely with J.fastigiata illustrated in Fig. 3.3., differing only in the coarseness of punctition.

The British Museum specimens of J.cratigera from Kirkby's Collection do not compare with either the figures of Jones and Kirkby (1886a) or those of Cooper (1941), and may be specimens of the genus Geffenina Coryell and Sohn. The other specimens in the British Museum, labeled "Beyrichia" (Jonesina) bradyana, undoubtedly belong to the genus Sansabella, as indicated by Latham (1932), possessing the characteristic "sansabelloid" hinge.

iii) Conclusions on the genera Jonesina and Geisina. The genus Jonesina as defined and restricted here exists as a distinct genus for at least the two species J.fastigiata and J.cratigera. It is distinct from the genera Geisina and Hypotetragona Morey of the familyGeisinidae, on account of its bisulcate nature;

the dorsum not being depressed in the posterior half; the S2 sulcus being pit like and deeply impressed; and the hinge only having an overlap at the cardinal angles.

Therefore after a thorough examination of the genotype it does not seem possible to dismiss Jonesina as synonomous with Geisina or Hypotetragona, as has been done by Sohn (1961). However many species previously assigned to Jonesina (sensu lato) should be included in other genera. The characters of Jonesina suggest that it may belong to one of the families Beyrichopsidae or Sansabellidae rather than the Geisinidae.

The ostracod specimens from the Hopkins' Band however now to be described, undoubtedly belong to the genus Geisina Johnson and not Jonesina Ulrich and Bassler. The species "Cypris" arcuata, Bean should properly be called Geisina arcuata Bean.

SYSTEMATIC DESCRIPTION OF Geisina arcuata. Bean 1836.

Synonomy.

Cypris arcuata. Bean 1836. Mag.Nat.Hist., Vol.9 (1836), p.377, text Fig. 55
Geinitz 1845. Grund verst (1945-46(p.243.

Beyrichia arcuata. Bean. Jones and Kirkby (1865) Geol.Soc.Glasgow, Tr.2, p.217.
1886(a) Quart.Jour.Geol.Soe., Vol.42, p.496, and seq. table, p.511.
1886(b) Geol.Mag.dec.3, Vol.3, p.438, Pl.12, Figs. 12-14.
1889 Jones. Ann.Mag.Nat.Hist., ser.6, Vol.3, p.381. Pl.17, Fig. 7a-c.

Jonesina arcuata. Ulrich and Bassler 1908. U.S.Nat.Mus.Pr 35 (1908), p.324, Pl.44, Figs. 17-19.

Non. Harlton 1927. Jour.Palaeo., Vol.1, p.205, Pl.32, Fig.6a-c.
Knight 1928. Jour.Palaeo., Vol.2, p.243-246, Pl.31, Figs.6a-b, Pl.33, Fig.6.
Scott and Sumerson 1943. Amer.Jour.Sc., 1943, Vol.241, p.653-671.
Marple 1952. Jour.Palaeo., Vol.26, No.6, p.936, Pl.
Krempe and Grebe 1955. Geol.Jahrbuch Band 71, p.145-170, Pl. and text Figs.

Sansabella arcuata. Latham 1932. Roy.Soc.Edin., Tr.57, pt.2, p.366, txf.12.

Geisina arcuata. (Genus Johnson 1936. Nebraska Geol.Survey, Paper 11)
Cooper 1946. Mentioned p.110, Geol.Surv. of Illinois, Bulletin 70.

Limnoprimitia arcuata. (Genotype) Kummerow 1949, Neues Jahrb.Min.Geol.und Palaeo., Band 1-3, p.49-59.
Kummerow 1953. Beiheft.zur Zeit.Geol. No.7, p.15, Taf.1, Fig.7.

Limnoprimitia = Geisina = Jonesina. Krempe and Grebe 1955, p.161.

Lectotype : Female B.M. In 43596 , specimen 12.

Paratypes : B.M. In 43596 , specimens 1-7, 10, 18-23.

Figure : 3.4. Plate : VII, Figs. 1-6.

Type description (Personal)

Diagnosis: Carapace sub-ovate to sub-rectangular in lateral view. Dorsal margin straight; hinge line slightly depressed in the posterior half. Ventral margin convex and thickened, the overlap of the right valve may form a low ventral ridge. Ends rounded the anterior more than the posterior. The anterior cardinal angle is obtuse, falling away to a broadly rounded end. The posterior cardinal angle is 90 degrees or less, and falls straight at first then steeply to the ventral margin. Grestest height median, greatest thickness posterior of the middle, giving an almost ovate dorsal outline to the male and sub-ovate to the female.

S1 - anterior sulcus, weak or indistinct or absent. When it is present it is shallow, wide and short and does not extend below the anterio-dorsal area. Posterior to S1 there may be an indistinct node which fades towards the dorsum. S2 - median sulcus, prominent, located slightly anterior of with middle. It extends from the dorsal margin to the central area, parallel sided, deepest and widest in dorso-central area. Posterior to S2 there is a low swelling dorsally that extends just above the hinge line in a flat raised area and thus gives the hinge line its depressed appearance in the posterior half of the dorsum.

R. valve the larger, overlapping the L. on ventral and end margins. The R. valve possesses two distinct swellings, one on the central anterior border and the other posterior to the posterior cardinal angle (Fig. 3.4.b.) The anterior swelling is a low obtusely pointed bulb which swells anteriorly over the anterior contact margin and gives the anterior end of the R.valve a pointed appearance (Fig. 3.4., Pl. VII) The posterior swelling is a low rectangular bulb or tubercle, curling posteriorly and imparting a distinctly right angled appearance to the posterior dorsal corner. (Fig. 3.4. a, b and c).

This swelling is in a similar position to the short spine present on the genotype G.gregaria. The ventral edge of the R.valve is thickened and projects below the L. on overlap.

L. valve the smaller and without the swelling s, but distinctly rimmed. The overlap is prominent and even except along the hinge. The hinge line is straight, about 2/3 length of the dorsum, and with a prominent advance of R. valve over L. at both cardinal angles. The hinge line is not notched and grooved but of a primitive "sansabelloid" type, the actual hinge structure is only seen internally. Surface ornament is a reticulate pattern of polygonal pits, evenly distributed over the lateral surface of both valves.

Internal features: These features could not be observed on the lectotype so they are described from a complete specimen of the R. valve (Fig. 3.4.e.) from above the Flockton Coal of Yorkshire, presented by Mr. Goosens of the National Coal Board and fragments of the carapace from the Hopkins' Band of Durham. The hinge structure of these valves is of true Geisina type (Johnson, 1936). There is a twist in the hinge at the anterior cardinal angle so that R. valve overlaps the left around the rest of the free margin. The hinge structure based on the above material and thin sections is shown in Fig. 3.5. It will be seen that there is a narrow shallow groove in the dorsal contact margin of the R. valve into which the dorsal edge of the left valve fits. In the anterior half of the hinge of the R. valve the groove is wide and has the lower edge reflexed ventrally into a sloping flange. The anterior half of the hinge of the L. valve is reflexed upwards to overlap the flange in the R. valve. The slight twist or notch at both cardinal angles is seen on Figs. 3.4.c. and 3.5.

A wide evenly thickened rim runs internally around the contact margin of both valves. This rim may be the remains of the duplicature, said to be present in this genus (Sohn, 1961a). The actual contact edge of both valves is thin, but within the right valve there is a shallow groove in the thickened rim to accommodate the overlapped edge of the L. valve. In the ventral region of the rim of the R. valve there is a bar internally to the groove to prevent the L. valve slipping too far inside the R. valve, as seen in (Fig. 3.4.e.)

The median sulcus S2 swells and thickens slightly internally to form a ridge that fades by the central area.

Rarely two groups of faint ovate secondary muscle scars can be seen on this ridge. (Fig. 3.4.e.)

Dimorphism : This is seen in the greater relative thickness of the posterior of the female and differences in dorsal outline (Fig. 3.6.)

Dimensions of described and figures types.

In 43596 - 12 Length: 1.28 mm. , height: 0.81 mm. , posterior thickness: o.62 mm. (Fig. 3.4.e-d.)

(Fig. 3.4.e.) Length: 1.29 mm., height: 0.90 mm.

Locality and horizon of described specimens.

In 43596 - 12 : Uncertain probably near Newcastle from the Hopkins' Band, lower Modiolaris Zone, Lower Coal Measures.

Fig. 3.4.e. : Warncliffe Woodmoor Colliery, nr. Doncaster, Yorks. 10 ft. 6 in. above the Flockton Thin Seam, lower Modiolaris Zone, Lower Coal Measure.

Biometric study of a population of Geisina arcuata.

In order to extend and further elucidate the details of the species Geisina arcuata, described previously, a simple biometric study has been carried out on 180 well preserved specimens of this species from the shales of the Hopkins' Band, at Eppleton Colliery, County Durham. These specimens were extracted from the densest part of the ostracod band at Eppleton and the greatest number of fairly well preserved specimens obtained by hand picking. These specimens are preserved either with their shell attached or as calcite external moulds so that the features of external morphology that have been measured are comparable on all specimens.

A total of seven measurements were made on each specimen, using an eyepiece micrometer, the specimens being mounted in plasticine for correct orientation. The actual measurements are recorded in Appendix II, but of the seven originally made, only three seem to be of biometric value, namely, length height and thickness of the posterior.

It was hoped that this study would elucidate the typical dimensions of this species, size and number of moult stages or instars present in the Hopkins' Band population, and details of specific variation and dimorphism.

Many workers have included dimensions, especially of height and length, in their descriptions of the species G. arcuata and these are represented graphically and compared with those of the Hopkins' Band population from Eppleton in Fig. 3.7. The dimensions, or range of dimensions of certain allied or synonomous species are also included. About eighty per cent of the measured Eppleton species fall in the range, length 1.10 - 1.30 mm., height 0.60 - 0.80 mm., the mean of the population being at point F. (L: 1.17 mm. H: 0.72 mm.) and with a height and length ratio between 50 - 70% (Fig. 3.7.) This restricted size range would suggest that only one instar, presumable the adult, is present in the Hopkins'Band population, and this fact has been confirmed from faunas of Geisina arcuata in many of the localities examined.

This range of linear dimensions is not coincident with that of the other workers represented, but it is to be expected that the absolute size dimensions will vary between different populations of the same species depending on different factors of the environment, such as temperature (Elofson, 1941). The actual ratio of height to length, however, seems to be fairly constant for the species. This latter factor is further discussed in the Carbonita section. This population contains larger specimens than those described as Jonesina arcuata arcuata by Krempe and Grebe (1955), and is between their dimensions for this species and "Jonesina" robusta Kummerow. The actual holotype of Geisina robusta Kummerow (1949) however, falls well within the present range. The dimensions of the other worker, Harlton (1927), Knight (1928), Marple (1952) and Kummerow (1953), however, are referable with earlier moults of this species.

MOULTS.

There is a principle applying to the study of crustacean moults, proposed by Przibram (1926, p.26) stating that during ecdysis, crustaceans increase their weight to twice its former value. This principle has been applied to a study of the ostracods by several workers including Sohn, (1950, pp.427-34) Kesling (1952, 1953) and Kesling and Takagi (1961). In many of the studies the workers have considered volume synonomous with weight in this context and thus that if the volume (L x H x Thickness) is doubled at each moult then any linear dimension should increase by a factor of 1.26 (the cube root of 2). These workers have sometimes supported Przibram's Law and sometimes rejected it.

However Kesling (1952, p.773 and 1961, p.3) points out that an increase of 1.26 in any dimension of an ostracod in perfect accord with Przibram's Law, will only come about if the carapace does not change shape during ecdysis and that the carapace reflects the total increase in the mass of the animal during each ecdysis. Thus this factor would not hold with species showing strongly allometric growth or where dimorphism is expressed in a change of shape. The latest study of Kesling and Takagi (1961), applies the law in its original form by weighing the different moults of Welleria meadowlakensis from the Devonian of Saskatchewan, using the ingenious Cartesian diver technique. In terms of weight of the carapace Przibram's Law holds for these specimens.

By taking the mean (F) the adult population of Geisina arcuata from Eppleton and reducing this by the factor 1.26 on both the height and length dimension, the hypothetical positions of the mean dimensions for the earlier moults E - A are plotted on Fig. 3.7. These positions fall very close to specimens recorded by other workers and this further suggests that there are earlier moults of this species.

DIMOMORPHISM. Dimomorphism is a fairly common and perhaps universal feature among ostracods of the sub-order Kloedenellidocopina and according to Scott and Wainwright (1961) is shown in the inflation of the posterior part of the carapace of the female.

Johnson (1936) records dimomorphism in the genotype Geisina gregaria, the female being sub-ovate in lateral view and with an inflated posterior, while the male is sub-rectangular in lateral and lacks the inflated posterior.

The species Geisina arcuata shows dimomorphism simply in the posterior width of the female carapace, there being no discernible difference in lateral shape. The lectotype previously described is an adult female and the differences between the male and female in dorsal outline both in external and internal moulds are shown in Fig. 3.6, sketched from specimens in the Eppleton population. This dimomorphism however, which is easily seen in terms of dorsal outline is difficult to define or show biometrically.

The difference between the median and posterior thickness of the carapace would appear to be different in the male and female forms from Fig. 3.6., however when these dimensions are measured for the whole population and compared, a unimodal frequency is found, Fig. 3.8. Thus this character, referred to as the ratio TM/TP, is of no use for dimorphic distinction, despite its morphological appearance.

The ratio between the posterior thickness to the length Tp/L, shows a distinctly bimodal frequency (Fig. 3.9) and as only the adult is present, this must be a function of dimomorphism. The specimens with Tp/L ratio between 35 - 45% appear to be males, while those of the ratio 47.5 - 55% are females (Fig. 3.9.) When the ratio Tp/L is plotted graphically against the ratio H/L, Fig. 3.10, there is not apparent separation of the dimorphs in terms of H/L ratio, thus confirming that dimomorphism is not shown in terms of lateral dimensions or shape, but only in position thickness.

Discussion.

Morphology. Much has already been written to establish the validity of Geisina arcuata and it but remains to discuss its relationship to other members of the genus. Echolls and Creath (1959) record eight species of the genus known from the United States and two more by G. subarcuata and G. robusta, to be discussed later, are only recorded from Europe. The original descriptions of many of these species include morphological features seem here on G. arcuata but not recorded by Johnson (1936) on the genotype. G. Gallowayii Cooper (1946) shows the central thickening of the margin of the Right valve, the wide shallow channel or depression along the posterior part of the hinge, the twist or notch at the anterior cardinal angle and the flaring or fading of the S2 sulcus at the dorsal end.

The possession of the posteriodorsal ornament seen as a spine in the genotype and tubarcular bulb in G. arcuata does not seem to be persistent in the genus. G. subarcuata and G. gallowayii possess no such ornament and this distinction between this genus and Hypotetragona Moray is sometimes difficult. The presence or absence of this spine is the only distinctive character between the two recorded by Sohn (1961) in the Treatise, but in his original description Moray (1935) describes the hinge as having the R. valve overlapping the left in the anterior half, and in there being a ridge parallel with the free margins but separated from them by a narrow smooth border, two characters definitely not possessed by Geisina. It is possible, however, that certain species of the genus Geisina should be more correctly referred to as Hypotetragona Morey.

The Stratigraphic range and Geographical Distribution of G. arcuata.

The records of this species or homeomorphs are so many in number from at least two Continents and a wide range of horizons, that it is not posslbe to review them but just to give a brief summary.

The species was first recorded by Bean from Northumberland, near Newcastle, and it seems most probable that this was the horizon of the Hopkins' Band, so perhaps in this study we are dealing with the species at its type horizon. Other records from Britain range from the Lower Carboniferous of Scotland to the Upper Coal Measures, but it seems most probable that the species is really restricted to the Lower Coal Measures. The Scottish Lower Carboniferous forms may well belong to genera and as Sansabella or Geffenina while the higher Coal Measure forms generally seem to fall within the range of variants of G.subarcuata. The true range is probably indicated by such workers as Wright (1931) "G.arcuata - comes up from the Lower Coal Measures persists throughout the Ovalis (Communis) Zone and occupies the lower half of the Modiolaris Zone", or again Edwards and Stubblefield (1947) "Geisina arcuata is a common associate of mussels occurring below the Clay Cross Marine Band, but it seems to have been eliminated by the incursion of the Clay Cross sea". The latter authors add, however "Locally there are in strata associated with the later Marine Bands, a few representatives of this species or a near ally". (i.e. G.subarcuata.)

A similar stratigraphical range exists for this species in the European coalfields; Pruvost (1930) states "Beyrichia arcuata is an excellent zonal indicator characteristic of Lower Westphalia A", while Krempe and Grebe (1955) record it as occurring in Namurian C and Westphalian A, but not above the Katharina Marine Band, in the Coal Measures of the Rhur district.

The stratigraphical range of the species "Geisina arcuata in the United States is indicated by Echolls and Creath (1959) as being L & M. Pennsylvanian from the Morrowan Desmoinesian stage, broadly equivalent to the European Westphalian. Scott and Summerson (1943) howevar record - G.arcuata in abundance with species of Carbonita in the Hance Formation of Tennessee which they correlate with upper Westphalian A - the Modiolaris Zone - so perhaps even in America there is the greatest abundance of this species at about its type stratigraphical horizon.

The very general picture then seems to suggest that despite its world wide distfibution from Central and E. United States across Europe aven to the borders of the Russian coalfields, the species of ostracod Geisina arcuata has a limited stratigraphical range from the Uppermost Namurian to the Top of Westphalian A and is at a maximum in the Upper Westphalian A and the Lower Modiolaris Zone of the Coal Measures.

GEISINA SUBARCUATA. Jones 1862.

Synonomy:

Beyrichia subarcuata Jones 1862 Mon.Fossil Estheridae Pal.Soc., p.120, Plate 5, Fig. 15, 17.

Jonesina subarcuata Bassler and Kellett 1934. Geol.Soc.Amer.Special. Paper 1, p.347.

Types: Holotype material is not known.

Neotypes: Durham University Palaeo.Collections. Nos:

Locality: Claxheugh, nr. Sunderland, Co. Durham.

Fig. 3.11

Description:

Carapace sub-ovate to sub-rectangular in lateral view. (Fig. 3.11 a and b.) Sub-ovate in early moults, sub-rectangular in the adult. Dorsal margin straight or with slight convex median, curving of the valves above the hinge line.

Hinge line straight slightly depressed in the median posterior part.

Ventral margin convex, the thickened edge of the valves may form a low ridge on the ventral overlap.

Ends rounded unequally, the anterior more than the posterior.

Anterior cardinal angle obtuse falling away to a broad evenly rounded anterior end.

Posterior cardinal angle greater than 90° falls away in a shallow curve to give an obtusely rounded end.

(The posterior cardinal angle lacks the sharp right angled appearance of Geisina arcuata.)

Greatest height medium.

Greatest thickness or posterior of middle. The dorsal outline is ovate with maximum thickness medium in immature moults and adult male and broadly subovate - well to the posterior - in the adult female (Fig. 3.11. c. and d.)

S1. Anterior sulcus - rarely present, very wide, short and shallow.

Posterior to S1 the surface is curved and featureless.

S2 - Median sulcus. Not prominent but always present, shallow, narrow and slit like. It extends from below the dorsal margin to the edge of the dorso-central area, about 1/3 - 1/2 the way across the valve. The sulcus is deepest and widest mid-length, shallowing and narrowing towards the ventral and and opening slightly towards the dorsal end.

It is located anterior to the middle.

Posterior to the median sulcus there is a distinct swelling, more pronounced and timid on the adult female. This swelling may rise above the hinge line in the median posterior area, thus giving a slightly convex dorsum with the hinge slightly depressed in the posterior half.

R. valve the larger - overlaps the left on the ventral and end margins and it raised very slightly above it along the hinge line but does not overlap it.

Ventral overlap is the widest - but narrower than in G.arcuata. (Fig. 3.11. e. and f.)

The anterior margin of the R. valve is smoothly curved and does not possess the swelling of G.arcuata. The posterior dorsal corner is also rounded and lacks the low rectangular bulb of G.arcuata.

L. valve small less rectangular than the R. valve to allow overlap.

The valves are more alike than in G.arcuata.

The hinge line is straight with an apparent twist of the R. valve over the left as it advances to overlap at both cardinal angles.

The surface is finely granulae - probably with small pits.

Internal features.

The hinge is of normal Geisina type (see G.arcuata) but not so heavily thickened along the dorsal contact margin. The right valve may be raised very slightly above the left along the posterior half of the hinge and prominantly at the posterior cardinal angle.

The shell substance is thin, but is very slightly thickened internally to the sulcus.

This thickening leaves a fairly deep and wide impression of the sulcus, reaching almost to the dorsum, on the internal mould (Fig. 3.11. d.) The free edge of both valves is thickened to form a marginal flange within the free edge. (Fig. 3.11 e. and f.) This flange is narrower and less thickened than in G. arcuata. The muscle scar has not been seen but is probably on the base of sulcus internally.

Dimensions of figures specimens.

Female (Brown) Fig. 3.11a.

L. 1.60 mm. H. 0.90 mm.

Male (Green) Fig. 3.11b.

L. 1.66 mm. H. 0.84 mm.

	Female. Dorsal and V. Fig. 3.11. c & d.	Male Fig. 3.11 d. & f.
T. A	0.60 mm.	0.52 mm.
P	0.80 mm.	0.60 mm.
M	0.30 mm.	0.28 mm.

Moults. Fig. 3.12.

	L	H	T
A	0.46 mm.	0.26 mm.	0.22 mm.
B	0.56 mm.	0.36 mm.	0.26 mm.
C	0.78 mm.	0.48 mm.	0.36 mm.
D	0.98 mm.	0.60 mm.	mm.
E	1.24 mm.	0.76 mm.	0.60 mm.
F	1.60 mm.	0.90 mm.	

Dimorphism: Male and female forms can be recognised in the adult and perhaps preceding moult. (Fig. 3.11 and 3.12).

Female : H/L Ratio 60-70

Greatest width of middle dorsal outline.

Male: H/L Ratio 50-55

Greatest width median-elongate ovate dorsal outline.

The original description and figure of "Beyrichia" subarcuata. Jones (1862) seems to have been of the male form hence he says "nearly twice as long as broad". The H/L ratio of the figure, Fig. 16, is about 50%.

Instars or moult stages: A series of six moults or instar stages A - F , have been recognised in the fauna of Geisina subarcuata, collected from the Claxheugh Shell Band, (Fig. 3.12 and 3.26). The youngest moult A is very small, without a sulcus but distinctly Kloedenellid in the straight hinge line and pronounced overlap. A very small and shallow sulcus, almost median in position is present in moult B , and it develops and becomes more anterior relatively with the enlargement of the posterior half of the carapace in moults C and D . The carapace changes its lateral shape from sub-ovate to sub-rectangular as the posterior becomes more developed from moults C and D to the dimorphic later instars, E and F. The changes in shape and morphology between these instars is shown in Fig. 3.12.

Instar dimensions:	In terms of length
Instar A	0.45 mm.
B	0.56 mm.
C.	0.76-0.82 mm.
D	0.85-1.00 mm.
E	1.10-1.38 mm.
F	1.40-1.80 mm.

Further comments on these instars are reserved for the section of the Chapter on the ostracod populations of the Claxheugh Shell Bed.

Discussion: This species is distinguished from Geisina arcuata Bean on account of its narrow, shallow, sulcus not impressed into the dorsum, the more arched dorsum, and the lack of median anterior and dorsal posterior swellings on the right valve. This species generally shows a greater thickness in proportion to length and a thinner shell with finer pitting than Geisina arcuata Bean. The possible relationships of this species to the Geisina robusta Kummerow described from the German coal measures is discussed later.

Distribution: The original specimen of Geisina subarcuata. Jones (1862) came from above the Worsely Four Foot Coal, at Astley in Lancashire. This horizon is near the "Edmondia" Marine Band in the Upper Similis-Pulchra Zone of Middle Coal Measures. The specimens described here come from about 150 feet above the "Edmondia" or Wearmouth Marine Band of County Durham or below the Top Marine Band equivalent in North Staffordshire.

There are several other records of specimens of G. subarcuata recorded largely by the Geological Survey, from measures of the Upper Similis-Pulchra Zone of British Coal Measures, but no other detailed descriptions.

The Species Geisina (Limnoprimitia) robusta Kummerow.

Kummerow (1949, p.51) described an ostracod from the Coal measures of the Rhur district that he names Limnoprimitia robusta. This species, he said, is broader and more robusta than Geisina (Limnoprimitia) arcuata and has a more arched dorsum and a narrower and shallower sulcus. The genus he founded, Limnoprimitia Kummerow (1949), has been shown to be synonomous with Geisina [Jonesina] by Krempe and Grebe (1955), who thus place the species L. robusta in genus Jonesina or correctly Geisina.

The specimens described as Geisina [Jonesina] robusta by Krempe and Grebe are much larger than the holotype of Kummerow, but their photographs clearly show a form differing from Geisina arcuata as indicated by Kummerow.

Im populations that have been studied both from the Hopkins' Band of Durham and above the Flockton Coals of Yorkshire, there were variants, that were shallower sulcate and generally robust, superficially resembling G. robusta Kummerow. However these forms are clearly variants of Geisina arcuata Bean, on account of their size and the possession of the characteristic anterior and posterior swellings. All gradations exist from these forms to the typical Geisina arcuata so that the form G. robusta is not really present in this fauna.

Krempe and Grebe (1955, p.165) record the species Geisina robusta as occurring with G. arcuata at several horizona in the Lenisulcata, Communis and Modiolaris Zones of the Rhur Coal Measures. It occurs alone at one horizon in the middle of the Lower Similis-Pulchra Zone. This association with G.arcuata may support the idea that Geisina robusta is only really a robust and shallowly sulcate variant of Geisina arcuata (sensu stricto). If this were the case the occurrence in Lower Similis Pulchra Zone may be a variant of G.subarcuata as the original description of Kummerow very closely approaches that of the female form of this latter species. The exact validity and synonomy of this species as regards the evidence from the British Coal Measures is thus uncertain. It is surprising however that if this form does exist as a distinct species that it has not yet been found in the British Coal Measures as there is generally very close faunal similarity to these of the Rhur area of Germany.

b) The Carbonita Group.

Order : POPOCOPA Sars 1866.

Superfamily : Cypridaceae.

Family : Cypridae Baird 1850.

(Placed here by Cooper 1946, previously in Cytheridae by Ulrich 1894, p.632; Beyrichiaceae; Kirkbyidae by Bassler and Kellet 1934, p.237.)

Genus : Carbonita (Carbonia) Jones 1870.

(Preoccupied by Carbonia Robineau-Desvoidy 1863 = Carbonita strand new name (1926) 1928, p.41.)

Genotype : Carbonita (Carbonia) agnes. Jones 1870.

Genolectotype : Designated Anderson M.S. from Jones original material in the British Museum. Numbered PL.3191 specimen 6. (Formerly I43513).

Generic Diagnosis. After Jones (1879) but adapted personally in italics.

Carapace subovate, ovate oblong or elongate.

Greatest height usually in the posterior third.

Greatest thickness median to posterior.

Dorsal margin slightly to broadly convex.

Ventral margin straight to slightly convex.

Ends unequal, broadly rounded to acutely pointed.

Hinge in the middle third of the dorsal margin - straight.

Hinge simple; left valve usually raised very slightly above the right above the hinge line - closely appressed or with a narrow groove.

Right valve the larger - overlapping the left along the ventral margins and narrowly overlapping or over-reaching the left along the end margins. This end overlap is generally more pronounced on the posterior end.

Surface smooth to coarsely reticulate. The ornament may consist of longitudinal straie or faint ridges or coarse concentric reticulations, but is variable even within one species. Muscle scar circular - sunk into the shell - anterior or antero-ventral of mid-point. The main muscle scar encloses a variable pattern of irregular or elongated secondary scars. Shell usually thickened internally in a low ridge posterio-ventral of the muscle scar - when well developed this ridge is highest and narrowest posterio-median, fading and widening ventrally and leaving a faint to pronounced transverse furrow on the cast.

Other features

The height to length (H/L) ratio of the valves is usually constant between the different instars or moults of the same species (Fig. 3.25). Dimorphism is probably common in many species, being evident as differences in shape or the degree of inflation of the posterior.

Discussion

The genus as originally defined by Jones (1879) included specimens from the Lower Carboniferous and the Coal Measures of Great Britain. The generic diagnosis was fairly short and ommitted certain features included above, which have subsequently been used to found related genera by various American authors. (Holland 1934, and Scott and Summerson 1943).

Holland (1934) established the genus Whipplella for forms from the Permian Nineveh Limestone of West Virginia, which were sub-ovate in shape but had a pronounced overlap on the end margins as well as along the venter. However Cooper (1946) disagrees with Holland and after an examination of the type material of Holland, considers these forms to be conspecific, but earlier moults, of Carbonita fabulina inflata, Jones and Kirkby. The genus Whipplella however has been resurrected by Krempe and Grebe (1965) working on ovate forms from the Rhur Coalfield. These forms have a pronounced overlap on the ends, probably accentuated by crushing, but are perfectly compatable with British Coal Measure forms belonging to the species Carbonita humilis, Carbonita inflata, and perhaps Carbonita altilis.

A personal study of the type material of the genus Carbonita in the British Museum and a more exhaustive population study on faunas of Carbonita humilis and Carbonita cf. rankiniana from the Lower Coal Measures of County Durham, lead me to reject the marginal overlap as being a character worth of generic distinction. The degree of end overlap varies considerably between species of Carbonita, the true generic relationship being proved by the hinge and muscle scar as well as a ventral overlap, The overlap also varies very much in a population of the same species depending on conditions of burial, i.e. crushing or distortion, and preservation.

Scott and Summerson (1943) proposed that subovate smooth forms of Carbonita fabulina (sensu lato) group really belonged to the recent genus Cypridopsis Brady and that forms with a surface ornament of longitudinal straie or ridges should be placed in the new genus they erected Hilboldtina Scott and Summerson. This first proposal is not valid, as Cypridopsis Brady is largely defined in terms of the soft parts, and while the carapace is superficially similar, we cannot be certain of the synonomy. The second proposal is equally untenable as the surface ornament in Carbonita is very variable even between different specimens of the same species. Even in the forms Carbonita evelinae Jones and variants (Carbonita evelinae rugulosa and subrugulosa Jones and Carbonita cf. evelinae personal), this ornamentation of longitudinal straie is very variable in its degree of development and is frequently absent altogether. This latter character therefore is again not considered to be one of generic distinction.

Certain species of Carbonita have also been included in other genera by various workers. Cooper (1946) referred the species Carbonita bairdioides (Jones and Kirkby) and Carbonita slateriana (Jones and Kirkby) to the genus Candona, and the species Carbonita pungens(Jones and Kirkby) to Darwinula. The species Carbonita salteriana (Jones and Kirkby) was originally doubtfully referred to Candona Baird, 1846, by Jones on account of its elongate shape and pointed anterior but later transferred to Carbonita. The general character of the lectotypes in the

British Museum, especially of hinge, muscle scar and overlap, show them to be true members of the genus Carbonita, Carbonita salteriana being close in form to Carbonita rankiniana (Jones and Kirkby) a predominantly Lower Carboniferous and perhaps Lower Coal Measure species. The exact position of Carbonita pungens is not so clear as it is small and very thin shelled and does not show all the well developed Carbonita features. It is discussed at greater length, later and may have Darwinulid affinities in that it seems to occupy an ecological niche in Coal Measure and Lower Carboniferous environments, comparable with homeomorphic true Darwinula species in Mesozoic and recent non-marine environments.

Scott (1946a) erected the genus Gutschickia Scott for Permian specimens originally described by Holland (1934) as Whipplella. Cooper (1946) placed Carbonita subangulata Jones and Kirkby as Gutschickia subangulata. The original diagnosis of Gutschickia however states it to differ from Carbonita by; left valve being raised over the right along the hinge, there being no end marginal overlap, an inner margin flange and greater relative height. All these features are included in the previous amended diagnosis of Carbonita and so Gutschickia is considered synonomous.

Comparison: The genus Pruvostina Scott and Summerson, although founded on American specimens appears to be a large Cyprid close to Carbonita. It differs from Carbonita in having a wide and deep channel along the hinge and a pronounced overlap around the free margin.

Stratigraphical range of the Genus.

The lectotype Carbonita agnes comes from the Tenuis zone of the Upper Coal Measures of South Wales but the actual vertical range of the genus is much greater than this. It appears first in Lower Carboniferous Limestone and Calciferous Sst. series of Scotland where Carbonita fabulina is the dominant form together with Carbonita subangulata, Carbonita rankiniana, Carbonita subula, Carbonita secans and and Carbonita pungens. Scattered records occur throughout the Lower and Middle Coal

Measures of England and Scotland, Carbonita humilis being the dominant form with Carbonita cf. rankiniana, Carbonita cf. evelinae, Carbonita inflata, and rarely Carbonita altilis and perhaps Carbonita bairdioides. In the Upper Coal Measures the species Carbonita evelinae, Carbonita salteriana, and Carbonita inflata and dominant to be joined in the Tenuis zone by Carbonita agnes and Carbonita bairdioides and rarely in highest English Coal Measures, only recently discovered in bores under middle England, by Carbonita minima Kummerow.

The American species of the genus are said to range from the Atokan stage of the Lower Pennsylvanian to the Wolfcampian of the Lower Permian. (Echolls and Creath 1959).

SPECIES 1

Carbonita c.f. evelinae Jones 1870.

Synonomy: Carbonia evenliae Jones Geol.Mag.7 (1870), p.218, Pl.9, Fig. 4.

Carbonia agnes (evelinae Anderson) rugulosa (In part) " " "

Carbonia agnes (evelinae Anderson) subrugulosa (In part) " "

Hilboldtina evelinae Scott and Summerson 1943 Amer.Jour.Sc., Vol.241, p. 870.

Hilboldtina agnes rugulosa

Hilboldtina agnes subrulgulosa

Type specimen: Lectotype Anderson M.S. B.M. P.L.3196 (43519 IN) Specimen 9.

Speciman personally described Slide (2) no. 14, Hopkins' Band B.P.102, Fig: 3.13.

Description:

Carapace elongate, ends unequal.

Dorsal margin slightly arched, ventral margin straight to slightly convex.

Anterior end obtusely lower than the posterior.

Posterior end more acutely pointed, slightly twisted to the right, high and with a steep posterio-dorsal slope.

Greatest height posterior, greatest thickness median.

Dorsal outline lenticular.

Hinge straight less than half the length - the left valve is raised very slightly above the right along the hinge line and there is no groove.

Valves almost equal - over-reach or narrow overlap on free ends, right valve over left along the ventral margin.

Ventral overlap narrow, along over half the length of the ventral margin.

Shell surface ornamented with fine longitudinal ridge or costae that converge towards the ends. Probably there are longitudinal rows of very fine pits between these costae. Frequently these straie are poorly developed or absent and the surface is smooth. Internally the shell frequently possesses the thickened ridge just posterior to the muscle scar, leaving a transverse furrow on casts. Muscle scar circular, anterior of the middle, anterior to shell thickening, and containing a number of polygonal secondary scars.

Dimensions: (2) 14.

Height :	0.42 mm.
Length :	0.94 mm.
Thickness:	0.30 mm.
H/L Ratio:	44.7% or 2.2:1

Mean H/L Ratio for species: 43.5% or 2.3:1 .

Duscussion: This form may be a new species but has not been described as such on account of its resemblance to Carbonita evelinae Jones. This form is smaller than the lectotype of Carbonita evelinae, more elongate, but shared the distinct pointing of both ends and the ornament of longitudinal straie. As Carbonita evelinae (sensu stricto) is only known from the Upper Coal Measures of South Wales and central England this form has been provisionally referred to as "c.f." as it comes from the horizon in the middle Modiolaris Zone of the Lower Coal Measures of Durham. It differs from Carbonita evelinae (sensu stricto) in the more elongate shape, more pointed posterior end, smaller size and there being more than the characteristic three secondary scars in the muscle spot. A specimen similar to this species is in the collections of the Geological Survey, collected from 20 feet above the Yard Seam of Cumberland, Upper Modiolaris Zone, and is referred to Carbonita evelinae by Dr. F.W. Anderson of the Geological Survey.

This form is not of sufficiently common occurrence to enable it to be dimorphism and moult stages have been obtained.

Occurrende: This form has so far only been recorded from the grey shales and mudstones of the Hopkins Band of the Mid-Modiolaris Zone of the Coal Measures of County Durham and above the Yard Seam of Cumberland, again in the Modiolaris Zone but here above the Mid-Modiolaris Marine Band.

Associates: Other species of Carbonita - Carbonita humilis, Carbonita cf. rankiniana, Carbonita inflata, and Carbonita pungens, - Geisina arcuata. Various non-marine Lammellibranchs Carbonicola oslancis group and Ahthracisoa regularis group and Naiadites productus-triangularis, and Spirorbis pusillus.

SPECIES 2

Carbonita cf. rankiniana Jones and Kirkby 1879.

Synonomy:

Cythere rankiniana Jones and Kirkby 1867, Geol.Soc.Glasgow. Tr.2, p.217, (name only).

Carbonita rankiniana Jones and Kirkby 1879, Ann.Mag.Nat.Hist.Ser 54, p.34, Pl. 3, Fig. 1-8.

Carbonia rankiniana Dawson 1897. Canadian Rec.Sci. 7, No.5, p.396, Txf 10.

" " Pruvost 1911. Soc.Geol.Nord.Ann.40, Pl.2, Fig.9-11.

" " Latham 1932. Roy.Soc.Edin., Tr.57, Pl.2., p.385.

Carbonita agnes. Jones and Kirkby. Krempe and Grebe 1955, Geol.Jahb.Band 71, p.148, Fig. 1, Pl.16, Fig. 2.

Type Specimen: Lectotype Anderson 1960 M.S. B.M. I1741.

Specimen described below: Slide 10 , no.14418, Flocton B. - Hopkins' Band RYOB and BP . 18. 2½-3" .

Fig. no.: 3.14.

Description:

Carapace elongate subovate, somewhat tumid posteriorly.

Dorsal margin straight or slightly convex sloping posterior to anterior.

Ventral margin gently convex.

Posterior end higher broadly rounded, anterior lower bluntly pointed with a steep anterior dorsal slope.

The external anterior margin of the left valve bears a thickening showing as a low ridge inside the right valve over-lap, while a similar thickening is seen on the exterior posterior-ventral margin on the left valve as well.

Greatest height and thickness posteriorly.

Dorsal outline broadly subovate, the anterior being more acutely pointed.

Hinge line straight, curved slightly in lateral view, short about half of the

dorsal margin. The left valve is raised very slightly above the right along the hinge line, most of the hinge is posterior and there is no groove.
Right valve, the larger, overlaps the left on the ventral margin and very narrowly on the anterior end margin and the posterio-dorsal part of the posterior end.
Ventral overlap narrow even, and for over half the length of the ventral margin.
Shell surface corasely pitted with polygonal pits except over the muscle spot.
The pits tend to show a concentric pattern of arrangement, or appear parallel with the margins and not in rows that converge towards the ends.
Internally the shell thickens ventrally and prominently in low ridges on either side of the sunken muscle scar, the posterior ridge being the more prominent and giving the characteristic transverse furrow or internal moulds posterior to the muscle scar. Fig. 3.14.
Muscle scar circular, antero-ventral of mid-point and with irregular secondary muscle scars that may show a roseate pattern of arrangement.

<u>Dimensions:</u>	(10)(14	(10) 18	Flockton B.
Length :	1.00 mm.	0.91 mm.	1.04 mm.
Height :	0.55 mm.	0.45 mm.	0.57 mm.
Thickness :	0.43 mm.	0.35 mm.	0.47 mm.
H/L Ratio :	55.0 %	49.5 %	54.8 %

Species mean H/L.

<u>MOULTS</u>. As with <u>Carbonita cf. eveninae</u> this species is not of sufficiently common occurrence in the Hopkins' Band for any details of dimorphism to have been observed, but size variation of the fauna preserved (Fig. 3.15) would suggest that at least two perhaps three moult stages are present.

<u>Discussion</u>: This form resembles very closely the description of Jones and Kirkby (1879, p.34) and the figured specimen Pl.III, Fig. 6 and 7. Although it is slightly smaller in size than the dimensions for length given by Jones and Kirkby (1879), it is comparable with the size range given for Scottish specimens by Latham (1932),

(Fig. 3.15).

Carbonita rankiniana, as recorded by Jones and Kirkby (1879), occurs in the Lower Carboniferous and Calciferous Sandstone series of the Scottish Lower Carboniferous and the Coal Measure of both England and Scotland. Dr. F. W. Anderson (1961 personal communication) of the Geological Survey, who has recently revised the taxonomy of this genus and selected lectotypes, considers that Carbonita rankiniana (s.s.) should be restricted to the Lower Carboniferous and that homeomorphic forms occurring in the Coal Measure are probably related to Carbonita salteriana, Jones and Kirkby, and should therefore be named Carbonita cf. salteriana.

All the specimens I have examined from the Hopkins' Band of County Durham, Lower Modiolaris Zone, possess many more characters in common with Carbonita rankiniana, as described and represented by the lectotype material in the British Museum, than they do with the lectotype of Carbonita salteriana. These specimens resemble Carbonita rankiniana in the high and thick broadly rounded posterior rather than the more bluntly pointed posterior of Carbonita salteriana. The maximum thickness is also nearer the posterior as is Carbonita rankiniana. Further features in common with Carbonita rankiniana (s.s.) are the ventral thickening of the shell and prominent posterior ridge, the distinct raising of the left valve above the right along the hinge and the coarse pitting. None of these features are well developed in the type material, or other specimens, I have seen of Carbonita salteriana. Therefore these specimens are referred to as Carbonita cf.rankiniana.

It seems probable that Carbonita salteriana is a form fairly close to Carbonita rankiniana (Fig. 3.15) and may well have been included in Jones and Kirkby's early records of the latter species. Jones and Kirkby (1890), refer to both Carbonita roederiana (= Carbonita salteriana Anderson MS), and Carbonita salteriana as being near Carbonita rankiniana "in one or other of its forms". Even of the figures (Fig. 11-12) of Carbonita salteriana it is said "In Fig. 11, the inclination of the dorsal border anteriorly is suggestive of Carbonita *rankiniana* in its type form, though both these figures differ from the latter in their general compactness and neatness of outline" - perhaps not very well expressed differences.

The dimension graph for this species, Fig. 3.15, shows the similarity of the Hopkins' Band and Flockton specimens, but would suggest a distinction from *C. salteriana*. The form described as *C. agnes* by Krempe and Grebe (1955) would seem to belong to this species and has similar dimensions (Fig. 3.15).

Occurrence: This species occurs frequently in the mudstones and shales of the Hopkins' Band of County Durham and very well preserved identical specimens have been sent to me by Mr. Goosens of the National Coal Board, from black canneloid shale 10' 6" above the Flockton Thin Seam of Yorkshire at Warncliffe Woodmoor Colliery. This is also a Lower Modiolaris Zone horizon. Forms similar to this have been seen in studies on the shale containing ostracods above the Three Quarter Seam horizon in the Upper Communis Zone of County Durham.

Associates: Other species of ostracods as for *Carbonita cf. evelinae* and similar mussels in the Hopkins' Band. In the Three Quarter Band *Carbonita humilis*, *Carbonita pungens* and *Geisina arcuata* are the commonest ostracod associates and *Curvirimula* species the commonest genus of non-marine lamellibranch.

SPECIES 3

Carbonita humilis Jones and Kirkby 1879.

Synonomy: Carbonita fabulina humilis. Jones andKIrkby 1879. Ann.Mag.Nat.Hist. ser.5, Vol.4, p.31, Pl.2, Fig. 11-14.

Carbonia fabulina humilis. Jones and Kirkby 1884. Geol.Mag.n.s. dec.3, Vol.1., p.358, Pl.XII, Fig.9.

Non : Carbonita humilis Jones and Kirkby. Krempe and Grebe 1955. Geol.Jahb. Band 71, p.151, Pl.16, Fig. 1.

Type Specimen: Lectotype figure. Anderson MS. Jones and Kirkby 1879, Pl.II, Fig.14. Material not preserved. Neotype to be described.

Specimens described: Neotypes.

Female :	Slide (4) 10.	B.P.102	Fig.No.	3.16
Male :	Slide (9) 10.	R.Y.O.B.	Fig.No.	

Description (of female): Neotype.

Carapace tumid, subovate, dorsal margin gently convex, ventral margin straight to slightly convex. Ends rounded, posterior more obtusely so.

Greatest height just posterior of the middle.

Greatest thickness well posterior of middle.

There is a ridge of thickening externally, just posterior of the anterior ventral margin of the left valve in both sexes.

Hinge straight short, in the central third of the dorsal margin.

The left valve is raised above the right along the hinge line and there is a narrow knife edge groove along the hinge.

Valves distinctly unequal, right valve the larger, overlaps the left on ventral and both end margins.

Ventral overlap wide, maximum in median ventral, but exists prominently for over half of the ventral margin.

Overlap on both ends is distinct and fairly wide, and the right valve can be seen to advance over the left to overlap it at both ends of the dorsal hinge.

The shell surface is finely pitted with small polygonal pits.

Internally the valves are bordered by a narrow marginal rim. The external contact margin of the left valve is thickened to facilitate overlap (i.e. see end view and dorsal view.) (Fig. 3.16).

The shell may be thickened very slightly posterior-ventrally of the muscle scar. to form a short inconspicious sinous ridge which may leave a faint furrow on internal moulds.

The muscle scar is circular and contains an irregular arrangement of circular and elongate secondary scars, and is situated anterior of the mid-point.

The dorsal outline of the male is ovate, and the female sub-ovate.

<u>Dimensions</u>		<u>Female</u>	<u>Male</u>
		(4) 10	(9) 10
Length	:	0.74 mm.	0.81 mm.
Height	:	0.48 mm.	0.48 mm.
Thickness	:	0.43 mm.	0.41 mm.
Position of maximum thickness from posterior	:	0.31 mm.	0.41 mm.
H/L Ratio	:	65.o %	59.2 %
Form ratio L/H	:	1.45	1.69
T/L	:	0.42	0.505

<u>Dimorphism</u>

Dimorphism is very pronounced in this species in lateral shape, relative height and position of the maximum thickness. These characters are all well seen in Fig. 3.16.

		<u>Female</u>	<u>Male</u>
Shape	:	High subovate	Elongate ovate
		H/L ratio c. 70%	H/L ratio c. 60%

		Female	Male
Max height	:	Posterior of middle	median
Max. thickness	:	1/3 of length from posterior to anterior	median
Position of maximum thickness to length	:	c. 0.40 or 40%	c. 0.50+ or 50-60%

The two forms can easily be distinguished in some populations simply by plotting the H/L graph as in Fig. 3.17. In other populations of this species however bad preservation, atypical sampling or extraction, make recognition of the sexes difficult.

Moults or instars.

Three moult stages have been recognised in the population of this species from Hylton, Fig. 3.25, and these probably represent the adult and two preceeding instars. It is unlikely that earlier instars of such a thin shelled form would be preserved because of their fragile carapaces. (Scott and Smith 1951) In many faunas only the adult is preserved but this may be due to particular environmental conditions to be discussed later.

Discussion: The original description of Carbonia fabulina humilis Jones and Kirkby (1879), p.31. emphasises that it is an elongate variety of Carbonia fabulina (sensu lato), with a flatly convex dorsal border, rounded ends which are more nearly like than in the type apecimens of Carbonia fabulina, thus ovate shape, and a straight ventral border. These characteristics fit the male of the species as described above, and the original figure (Pl.II, Fig. 11-12.) would indeed seem to be of the male. The original figure of the lectotype Pl.II, Fig. 14. is relatively higher than the others, and sub-ovate with a blunter posterior and this although an internal mould is probably a female, so it seems that although only the male form was clearly described by Jones and Kirkby (1879), both sexes were recognised and figured.

The later description of Carbonia fabulin humilis Jones and Kirkby

(1884) mentions certain other characteristics not mentioned in the original desciiption. The shell is said to be thicker than the true Carbonia fabulina (sensu stricto), with distinct pitting and there is a "strong amount of overlap", a feature which has led to the erection of the synonymous genus Whipplella among species of the Carbonia fabulina (s.l.) group.

As originally described by Jones and Kirkby (1879) the species Carbonia fabulina (s.l.) and its "Varieties", are said to occur throughout the Carboniferous, namely the Lower Carboniferous of Scotland and Coal Measures of England and Scotland, Among these varieties Carbonia fabulina humilis was listed from both the Lower Carboniferous Limestone and Coal Measures of Scotland. Later workers such as Pruvost (1911, 1919), Wehrli (1933) and Kummerow (1949) have also recorded Carbonia fabulina (s.l.) from the Coal Measures of the Continent.

The typical form from the Coal Measures however seems to be C."Fabulina" humilis and for this reason the "variety" has been elevated to the specific level and the chosen lectotype is the original figure 14 of Jones and Kirkby (1879), that came from the Coal Measures at Pirnie Colliery, Fleven, Fife.

This distinction of C.fabulina, sensu stricto, from C.humilis and the restriction of the former to the Lower Carboniferous and the latter to the Coal Measures, has been suggested by Dr. F. W. Anderson in his unpublished revision of the genus. Anderson (MS.) has chosen the lectotype of C.fabulina (sensu stricto) (BM. I 1749) as coming from the Lower Carboniferous Limestone Series at Craigenglen in the Midland Valley of Scotland. This present study on populations of C.humilis from the Hopkins' Band conforms that it is a species in its own right.

The specimens of "C.fabulina" recorded by Jones and Kirkby (1879) from Ryhope Colliery, Sunderland are in the British Museum collections (i 1694), and possess the typical flattened dorsal margin of C.humilis. They are all internal moulds of the female form and thus appear smooth and lack the distinct punctuation and end overlap of C.humilis. Thus these specimens do appear very similar to C.fabulina s.s.

The form described by Krempe and Grebe (1955, p.151, Pl.16, Fig. 1) is not a typical example of this species. The figured specimen could be an extreme variant of the male, but the high posterior and sloping dorsum are atypical. The range of dimensions given is also larger than for typical males of this species. The form however described as Whipplella cenisa, Krempe and Grebe (Pk.16, Figs. 3 and 4) is probably the female form of C.humilis ss.

Wright (1931) described an ostracod from the Coal Measures in the Manchester region that he named Cytherella faveolata. This material has been re-examined by Anderson and is a specimen of C.humilis. The orientation given by Wright was inverted and the shape, punctation and overlap are typical of C.humilis.

Occurrence: This species is common throughout the Coal Measures although at its acme in the Modiolaris Zone at about the level of the Hopkins' Band. It is the dominent species of Carbonita in the Three Quarter Band in the Upper Communis Zone, and in the Ryhope Colliery fauna from the Upper Similis-pulchra Zone already mentioned. The "Faveolata" sub-zone of Wright, with the abundance of the mistaken C.humilis is also in the Upper Similis-pulchra Zone, below the "Euestheria" Band. The vertical range of this species in the Durham Coalfield, Fig. 3.23., gives some idea of the typical range of occurrence in the Coal Measures.

Associates: Besides the typical associated fauna of the Hopkins' and Three Quarter Bands, this species has been recorded in Durham (Armstrong and Price, 1953) as occurring with an Anthracosia phygiana fauna above the Hutton Seam. Rarely this species has been recorded associated with a marine fauna. In the Two Foot Marine Band of Nottinghamshire it is recorded along with Lingula, Edmondia and Hollinella cf. bassleri (Edwards and Stubblefield, 1947) while Hopkins (1934) records it in the fauna of Kirkby's Band at Ryhope Colliery. In both these occurrences however it is probably in a non-marine intercalation within the Marine Band sequence.

Species 4

"Carbonita" pungens. Jones and Kirkby 1879.

Synonomy: Cythere pungens. Jones and Kirkby 1867. Trans.Geol.Soc. Glasgow, Vol. 11, p.222.

Carbonia pungens Jones and Kirkby. Ann.Mag.Nat.Hist., Ser.5, No. 4, p,37, Pl. III, Fig. 21-23.

" " Provost 1911. Soc.Geol.Nord.Ann, 40, Pl.2, Fig. 13, 14.

" " Latham 1932. Roy.Soc.Edin.Trans. 57, pt.2., p.386.

Cythere (Darwinella?) pungens. Jones and Kirkby, 1884. Berwickshire Nat.Field Club. Procs., Vol.10, pp. 319, 325.

Carbonita pungens Bassler and Kellett, 1934, G.S.A. Spec.Paper 1, p.239.

Darwinula pungens. Cooper, 1946. Illinois Geol.Survey, No. 7, p.78, Pl. 10, Figs. 34, 40.

Darwinula hollandi. Scott, 1949. J.Palaeo, Vol. 18, p.146, Pl.24, Figs. 6-8. (referred here by Cooper, p.78).

Type specimen: Lectotype Anderson, MS., B.M.I. 1731, No. 6.

Personal Specimen: Slide (12), No. 9, B.P.105 ss. 0-1". Fig. 3.18.

Description:

carapace small, elongate, sub-cylindrical in shape, ends equal. Dorsal margin straight or flatly convex and sloping posterior to the anterior, ventral margin straight. Anterior end low and fairly pointed may have a steep antero-dorsal slope; posterior end high, rounded and somewhat tumid.

The greatest height and thickness are posterior - the height being less than half the length.

Hinge straight - low - longer than half the length.

The left valve is not raised above the R. and there is no groove.

The dorsal and ventral outlines are lanceolate, the thickness being approximately equal to the height.

Valves slightly unequal - the R. valve being the larger and overlapping the left on the ventral margin; ventral overlap narrow and uniform or slightly sinuous, maximum posterior of mid-point of the ventral margin.

Shell not preserved on Durham specimens; thin and smooth on type material.

Muscle spot uncertain, situated anterio-ventrally of mid-point - may be a circle of small secondary scars, but obscure (Fig. 3.18).

Dimensions:		(12) 9	(12) 10	(12) 14
Length		0.53 mm.	0.44 mm.	0.57 mm.
Height:	Ant.	0.22 mm.	0.17 mm.	0.22 mm.
	Post.	0.26 mm.	0.19 mm.	0.29 mm.
Thickness		0.22 mm.	0.18 mm.	0.19 mm.
H/L Ratio		49.2%	43.2%	50.8%
		2.04	2.31	1.97

Dimorphism and Moult Stages.

No evidence is available from the Hopkins' Band specimens as regards dimorphism. Two or more moults probably are preserved in these faunas at certain levels but are described in the population section.

Discussion.

The earliest record of this species as Cythere pungens Jones and Kirkby (1867), records it as occurring in the Lower Limestone of the Midland Valley of Scotland but it is not described and figured until Jones and Kirkby (1879). The forms described here are smaller than the original material that was described and have a steeper and blunter anterior point than the original figures. These forms h however are comparable in size to the dimensions given by Latham (1932), i.e. 0.58 mm. to 0.63 mm. in length, and 0.25 - 0.30 mm. in height.

The actual generic relationships of this species seems to have been in doubt since its earliest description. In 1884, Jones and Kirkby record this species as Cythere (Darwinella?) pungens - referring doubtfully to the genus Darwinula [Darwinella preoccupied] Brady and Robertson (1872) although they had already described it as a species of Carbonia five years earlier. Subsequently it was referred to as Carbonita [Carbonia] until Cooper (1946) placed it as Darwinula pungens after studying some American forms from the Pennsylvanian of Illinois. Cooper (1946) distinguished it from Carbonita as the values meet evenly along the hinge, the L. valve not being raised above the R., and the overlap is maximum at the ends and decreases along the ventral margin.

The only specimens of this species obtained from the Coal Measures of County Durham have been internal moulds preserved in calcite, although vast numbers of this species do occur as moulds or impressions in the black shale close above the coal seam. These specimens are similar in shape to the type material of this species in the British Museum so the description and conclusions on the Durham material has been made by comparison with the type specimens.

The shape of this species is distinctly Darwinulid - although the form ratio 2.0 - 2.2 is lower than the typical recent Darwinula sp. which is about 3.0. The hinge is narrow and flat, one valve not being raised above the other as is typical of Carbonita and the two valves may meet evenly. This condition of hinge structure however is that of extreme simplicity that would be expected in such a small thin shelled form as C. pungens. The true Darwinula itself, has an extremely thin shell - one layered, except where the Inner lamella is present near the anterior margin (Swain, 1961).

The overlap of the type specimens of "C" Pungens is apparently least on the ends and narrow and uniform along the venter - the converse of the true Darwinula. However the internal mould of the specimen from County Durham, Fig. 3.18, has a distinct groove on the posterior and suggestive of the overlapping rim of the R. valve so this character may be variable. The actual nature of the muscle scar is also inconclusive. Jones and Kirkby describe the muscle scar as sinuate and anterior of the mid-point, while Scott (1944) and Cooper (1946) describing Pennsylvanian and Permian Darwinulids - did not observe or describe the muscle pattern. The type specimen does not show its muscle scar, but the internal moulds (12) 9 and (12) 10 both show minute circular marks - arranged approximately in a circle (Figs. 3.18) in the approximate position of the muscle scar and these might be the secondary muscle scars. The true Darwinulid muscle scar is a circular group of radiating elongate secondary scars about twelve in number anteroventral of the mid-point. Here again the evidence of true genus of "C" pungens is inconclusive.

It therefore seems probable that the species "Carbonita" pungens is in many ways homeomorphic with the genus Darwinula but the evidence is not conclusive enough for it to be undoubtedly indluded in the latter genus.

The presence of a "Darwinulid" like form in the non-marine ostracods of the Coal Measures is not surprising as similar forms, unboubtedly referred to Darwinula in Mesozoic, Tertiary and Recent faunas, frequently occur in a fauna of non-marine ostracods (Jones, 1885, Kaufmann, 1900, Harper and Sutton, 1935, Swain, 1955). A remarkable occurrence of Darwinula sp. in coal bearing strata is recorded by Mandelstam (1956), from the Upper Permian rocks of the Kuznetsk coal-field of Siberia where he names forty new species of the genus Darwinula.

Occurrence: The type specimen comes from an ironstone in the Upper Coal Measures on the north coast of the Firth of Forth at Methil in Fife. Several other occurrences are recorded by Jones and Kirkby, (1879) from the Coal Measures, and two localities in the freshwater limestones Craigenglen and Crossgatehall in the Carboniferous Limestone Series of Scotland. Although this is stated to be a common form in Scottish Carboniferous it is said to be rare in England. Later however Jones and Kirkby (1890) record it occurring abundantly in the shale of the Upper Coal Measures, probably Tennuis Zone at Slade Lane, Manchester. Further examples are also recorded from the Upper Similis-pulchra Zone associated with the two foot M.B. of Nottinghamshire and Derbyshire, by Edwards and Stubblefield (1947).

In this present study this species is found occurring in great abundance on the bedding planes of the blackshale overlaying the Harvey Seam of County Durham and at the base of the main Hopkins' Band and again in the black shale rich in ostracods of the Three Quarter Seam horizon of the Upper Communis Zone of Durham. These are the first clear records of this species in the Lower Coal Measures and from their abundance, but smallness in size, they are not easily observed in the hand specimens, it seems probable that the species occurs throughout the Coal Measures.

Associates: At the type locality this form is recorded as occurring in black band ironstone with C-rankiniana, Leaia leidyei, Spirorbis carbonarious, Anthracomya, sp. ganoid spines and scales and Stigmaria rootlets. In the Scotting Carboniferous Limestone Series it is associated with C.rankiniana, C.fabulina, Spirorbis sp., Lingula squamiformis and fish remains.

In the first recorded English occurrence at Slade Lane, this species is associated with a typical Upper Coal Measures ostracod fauna of C.secans, C.salteriana, C.bairdiodes, and perhaps C.humilis and C.inflata. The unusual occurrence in the Two Foot Marine Band of Nottinghamshire and Derbyshire it has the same marine associates mentioned for C.humilis.

The mid-Modiolaris specimens from Durham occur mostly in black shale, where it is the dominant form, with scattered C.humilis and fish remains as associates. The species is present however in the Hopkins' Band proper sparsely scattered in shales and mudstone containing, Geisina arcuata, Naiadites sp, Carbonicola sp., Anthracosia sp. and the ubiquitous Spirorbis sp.

Thus its range of associates would seem to indicate a non-marine brackish to freshwater habitat for this species.

SPECIES 5

Carbonita inflata. Jones and Kirkby, 1879.

Synonomy: Carbonia fabulina inflata. Jones and Kirkby, 1879. Ann.Mag.Nat. Hist., Ser.5, No.4, p.31. Pl. II, Figs. 15-19.

Bythocypris tumidus. Upson, 1933. Neb.Geol.Sur.Bull. 8 (2), p.24, Pl. 2, Fig. 11 a - c.

Carbonita (?) tumida. Kellett, 1935. Jour.Palaeo., Vol.9, p.160, Pl. 16, Fig. 9 a - d.

Whipplella cuneiformis. Holland, 1934. Carnegie Museum Am., Vol.22, p.344, Pl.25, Fig. 5 a - c .
cf. Scott, 1944, Jour.Palaeo., Vol.18, p.143, Pl.24, Figs. 18-20.

Whipplella depressa. Holland, 1934 idem; p.345, Pl.25, Fig. 7 a-c.
Scott, 1944, J.P., Vol.18, p.143, Pl.21, Fig.21-23.

Carbonita inflata. Cooper, 1946., Bull.Geol.Surv., Illinois. Bull. 70, p.66, Pl.8, Fig. 40-42.

Type Specimen: Lectotype Anderson MS. B.M.I 1745.

Specimen described: Slide (14) 8 . Hopkins' Band, Hylton Colliery, Figure 3.19.

Description.

Carapace tumid, obese, high and subovate.

Dorsal margin distinctly convex, ventral margin straight to slightly concave.

Ends rounded almost equally but anterior slightly more obtuse and the posterior distinctly tumid.

Greatest height and thickness posterior - which appears inflated.

The thickness is almost equal to the height.

Dorsal outline subcuneiform of broadly subovate.

Hinge short about one third of Dorsal margin, depressed in a distinct by shallow groove. The L. valve is not raised above the R. along the hinge line or only very slightly so. (cf. Cooper, 1946, p.66).

Valves unequal - R. valve larger overlaps left around ventral and end margins. Overlap begins where hinge stops (cf. Whipplella cuneiformis, Scott, 1944, p.143) and is most pronounced on anterior end, Fig. 3.19a. and anterior end of venter, Fig. 3.19d. (cf. Whipplella cuneiformis, Scott, 1949, p.143).

The L. valve possesses a low thickened ridge antero-ventrally. Fig. 3.19a and d. (cf. Carbonita? tumida, Kellett, 1935).

The ventral overlap is not very wide and the ventral margin is flattened along the area of the overlap. Fig. 3.19d. The ventral overlap may be sinuous at its anterior end. Fig. 3.19d (but broken). (cf. Cooper, 1946, Pl.8, Fig. 43).

Shell fairly coarsely pitted, linear-concentric arrangement?

Shell generally thick and may have slight marginal thickenings.

Muscle scar circular, slightly antero-ventral of mid-point.

Dimensions:

Length	0.97 mm.	Lp = 0.36
Height	0.68 mm.	LH = 0.38
Thickness	0.63 mm.	Lo = 0.43

H/L = 70.0% or 1.43

T/L = 65.0% or 1.54

T/H = 92.5% or 1.08

Dimorphism and Moults. This species is a rare form in the Hopkins' Band of County Durham and so only a total of twelve specimens have been found from the two localities. No information as to dimorphism and moult stages has been obtained.

Discussion.

The form described here is very similar to Carbonita fabulina inflata as described by Jones and Kirkby (1879, p.31) and is almost identical with the lectotype material designated by Anderson MS from specimens from the original locality of Jones and Kirkby. The thick shell, coarsely pitted, obese form with inflated posterior, nearly equal to the height and the short and depressed hinge, are all features characteristic of this species. This form seems to be of sufficiently common occurrence and distinctly different in character from C.fabulina ss., as for it to be elevated to a distinct species Carbonita inflata rather than a variety of C.fabulina S.l. (Jones and Kirkby, 1879).

The American species included in the above synonomy are referred here with some hesitance as the type material has not been examined personally but this is the synonomy of Cooper (1946) who examined all the American type material. (Fig. 3.20). The similarity of these forms to C.fabulina inflata is at once apparent from the various figures, by the lateral shape, posterior inflation and coarse pitting of the shell, and a more detailed examination of the various descriptions reveals certain other similarities. Kellett (1935) redescribed Bythocypis tumida, Upson, 1933 and assigned it to Carbonita ? In this description she mentions "a short marginal ridge at the antero-ventral corner (Pl.16, Fig. 9d)" and the flattening of the ventral margins, both characters seen on the specimens of C.inflata, described above. The descriptions of Whipplella cuneiformis and W.depressa of Holland (1934) and Scott (1944a) emphasize the short grooved hinge, with overlap, R. over left beginning at each end of the hinge and the greatest marginal overlap being on the anterior end. These characters are seen on the described specimen Fig. 3.19c. Although the anterior overlapping margin of the R. valve is broken off dorsally and emphasised by displacement in Fig. 3.19a.

The actual description and figure of Carbonita inflata, of Cooper (1946), fits very closely with those given here, especially in the raising of the L. over R. valve along the hinge and the sinuous twist in the ventral overlap at antero-ventral corner. (cf. Cooper Pl.8, Fig. 42, and Fig. 3.19a). In this discussion of the synonomy, p.67, Cooper draws a height-length diagram Fig. 32, and redrawn here as Fig. 3.20, and decides that the other North American species are three moult stages of a single species and conspecific with C. inflata. Actually the dimensions of C.fabulina inflata, as given by Jones and Kirkby (1879) are not those recorded by Cooper and the latter ones replotted are coincident with these of W.cuneiformis, Holland as quoted by Cooper. The height-length dimensions of the described specimen above, and another from the Hopkins' Band at Eppleton to not fall on the line as shown by Cooper. It seems probable however that there are three moults of the species C.inflata Jones and Kirkby present on Cooper's diagram the adult being coincident with W.cuneiformis Holland . (4) of Cooper. (Fig. 3.20).

Occurrence.

The type specimen comes from the Coal Measures Pirnie Colliery in Fife, but the exact level with the Coal Measures is not recorded. In Durham this species has been recorded from the Hopkins' Band, and possibly is included among the variants of C.fabulina (sensu lato) from Ryhope Colliery but it has not been found in the Three Quarter ostracod Band.

This species is the dominant form in a large fauna of Carbonita sp. collected, personally from the shales above the Bassey Mine Coal of North Staffordshire in the Phillipsi Zone. The Slade Lane locality of Jones and Kirkby (1890) seems to possess forms close to this species, Fig. 7 and 8b - although the inflation is not very pronounced. This horizon is in the Phillipsi zone and it seems probable that C.inflata is at its acme in this zone although it occurs sporadically throughout the Coal Measures.

Associates.

In the type locality of the only recorded associates are stem fragments of Calamites which the ostracod fill internally as well as being in the matrix. (Jones and Kirkby, 1879, p.32). The Durham specimens occur within the "Geisina Phase" of the Hopkins' Band and are thus associated with

C.arcuata, C.humilis, C.cf.rankiniana, C.cf.evelinae, scattered C.cf.pungens and Naiadites sp. and Spirorbis and perhaps rarely Carbonicola sp. in the Phillipsi zone horizon that was examined from above the Bassey Mine coal of North Staffordshire this species was associated with C.humilis, C.altilis?, C.salteriana, C.bairdiodes, Anthraconauta phillipsi, Euestheria sp., and fish remains. Thus its associates suggest a distinct non-marine habitat.

SPECIES 6

Carbonita secans. Jones and Kirkby.

Synonomy: Cythere secans. Jones and Kirkby, 1867. Trans.Geol.Soc.Glasgow., 1867, Vol.11, p.222.

Carbonia secans. Jones and Kirkby, 1879. Ann.Mag.Nat.Hist., Ser.5, Vol.4, p.37, Pl. III, Fig. 15-20.

" " Jones and Kirkby, 1890. Manch.Geol.Soc.Tr., 21, Pt.3, p.138, 141, Pl. Fig. 3, 4.

Carbonia secans. Latham 1932. Trans.Roy.Soc.Edin. 57, Pt.2, p.385.

Type Specimen: Lectotype: Anderson MS. BM. I 27, No. 3.

Personal Specimen: Slide (15) 9 , B.P.105 1-2" (Internal mould of L. valve in shale - badly preserved).

Fig. 3.21.

Description (of type specimen personal compared later).

Carapace mytiliform in shape - compressed externally.

Dorsum high and arched gently convex sloping posterior to anterior.

Ventral margin flat to slightly concave.

Posterior end high and broadly rounded - tumid.

Anterior low elongate and acutely pointed.

(The dorsal margin may not be a smooth convex slope but may show a distinct steepening anteriorly to the pointed anterior end).

Hinge curved on dorsal margin indistinct - and the L. valve does not appear to be raised above the R. along the hinge line.

Valves slightly unequal R. larger and overlaps the left very narrowly along the concave ventral margin but not around the ends.

greatest height and thickness posterior.

Dorsal outline elongate- lenticular.

Shell smooth - and thin.

Muscle scar not seen.

Specimen (15) 8.

The specimen is a shale cast or internal mould of the left valve and so although identifiable the description is short.

Description.

Shape mytiliform.

Dorsal margin broadly arched, long convex antero-dorsal slope - short sharply curved posterio-dorsal shape.

Ventral margin gently and evenly concave.

This concavity is present in whole of the central ventral area of the internal mould and shallows towards the median line.

Anterior end slightly broken but acutely pointed.

Posterior end broadly and evenly rounded.

The greatest height and thickness is posterior.

The dorsal outline is elongate - lenticular.

The surface of the cast is smooth shale but bears impression of interior surface of shell.

The muscle scar cast is not preserved.

Dimensions	(15) 8
Length	1.00 mm.
Height	0.43 mm.
Thickness	0.32 mm.
Length/posterior	0.42
H/L Ratio	43.0% or 2.32.

Discussion.

This species is extremely rare in the Hopkins' Band or else vary rarely preserved as only one specimen has been found. This specimen is typical in shape and similar to the lectotype preserved in the British Museum. The most interesting feature of the cast is the concavity of the whole ventral half of the specimen, which increases towards the ventral margin. This concavity is typical of the species and is probably what Jones and Kirkby meant by "compressed" in their original description.

This specimen is longer than the dimension given by Jones and Kirkby (1879) 0.80 mm. and lower relatively and more elongate than the dimensions given by Latham (1932) for the Scottish specimens, length 0.60 - 0.65 mm. and height 0.37 to 0.40 mm. This relative elongation is found in other Coal Measure forms of this species (Jones and Kirkby, 1890), compared to the type specimen from the Lower Carboniferous Limestone of Scotland.

Occurrence: The specimen from County Durham occurs in black shale 2 inches above the Harvey Seam Below the measures of the Hopkins' Band proper. It has been recorded by Jones and Kirkby (1879) from an ironstone in the Coal Measures west of Sunderland probably from the Claxheugh exposure of beds near the top of the Upper Similis-pulchra Zone. Another record of it from a similar horizon mainly in the Two Foot Marine Band of Nottinghamshire and Derbyshire (Edwards and Stubblefield, 1947).

Jones and Kirkby (1890) record this species from the ostracod fauna of the shales of the Phillipsi zone at Slade Lane, Manchester but otherwise consider it to be of rare occurrence.

The type material came from the freshwater limestone of the lower Carboniferous limestone series at Craigenglen, nr. Campsie in Lanarkshire.

In the Coal Measures of this form seems to be commonest at the top of the Upper Similis-pulchra Zone and in the Phillipsi zone, but it may occur otherwise sporadically throughout the Coal Measures, as the occurrence in the Hopkins' Band suggests.

Associates: In the black shales above the Harvey Seam, C.secans is found in association with a dense fauna of Cpungens, rarer C.humilis, Curvirimula? and fragments of plants with attached spirorbids. At the Hylton locality it is said to be in association with C.rankiniana. The record from the two foot M.B. seems to indicate C.humilis (i.e. fabulina sl.), C.salteriana (i.e. rankiniana sl.), and C.pungens as the associated ostracods with a marine fauna of Hollinella cf. bassleri and Edmondia as mentioned previously. The Slade Lane associated fauna is as described for C.inflata.

The overall impression is that this species seems to have an association with a similar to, the "Darwinulid" Carbonita pungens and predominently non-marine.

SPECIES 7

Carbonita concava. Vangerow nom.nov.

Synonomy: cf. Carbonita ? sp. nov. (d). Vangerow 1957. Geol.Jahr. Bd. 73., p.457-506.

Type Specimen: Vangerow 1958, p.499, Pl.20, Fig. 26. Specimen no. 248/53/400.

Personal Specimen: Slide (11). 10-12. (Internal moulds from Bearpark).

Fig: 3.22.

Description:

Lateral shape, blunt, sub-ovate, Fig. 3.22a.

Dorsal margin gently convex and sloping posterior to anterior.

Ventral margin straight to slightly concave with a distinct concavity in anterior third (hence name).

Ends rounded, posterior high and broadly rounded.

Anterior bluntly pointed with a steep anterior dorsal slope.

Greatest height posterior.

Greatest thickness slightly posterior, so dorsal outline just sub-ovate.

Hinge not seen as internal mould but probably restricted to sloping part of dorsum about half length.

Indication of overlap, right valve over left at each end of hinge - Fig. 3.22.

Ventral overlap, right over left probable. Fig. 3.22c.

Valves probably unequal, right valve larger and overlapping the left around ventral and end margins (see previously).

Muscle scar and shell unknown.

Dimensions:	(11) 10	(11) 11	(11) 12
Lenght	0.59 mm.	0.52 mm.	0.56 mm.
Height	0.36 mm.	0.31 mm.	0.38 mm.
Posterior thickness	0.31 mm.	0.24 mm.	0.35 mm.
H/L Ratio	1.64	1.67	1.47
	61%	59.6%	68%

Discussion: Only three specimens of this species have been found and they are all internal moulds, and come from grey mudstone above the ostracod Band at the type locality of Bearpark.

The form described by Vangerow (1957) as Carbonita?sp nov d. is very close to the above in shape and description, (p.467, Pl. 20, Fig. 26), and is characterised by the ventral concavity; to quote "The remarkable vaulting of this species distinguished it from other species of similar shape". His specimens, however, are distinctly larger 0.76 - 0.98 mm. in length, and 0.49 - 0.61 mm. in height with an H/L ratio 1.5 - 1.6, while that of the Figure 26 is much nearer 1.34.

The description of the Hopkins' Band specimens is naturally limited as they are all internal moulds, but their shape and ventral concavity are sufficiently distinct for them to be compared with Vangerow new species, rather than the internal mould of a more familiar species of Carbonita. The new name Carbonita concava has been tentatively given to this species, as being more meaningful than Carbonita sp. nov. d. of Vangerow, but a full specific description should await the discovery of better preserved material.

Although the hinge, overlap and muscle scar have not been seen on these specimens, it seems from general morphological inference that they do belong to the genus Carbonita.

Occurrence: The specimens here described have only been found in the grey shaley mudstone occurring between 0-9 inches above the main ostracod band at Bearpark (i.e. between 4 - 1'1" above the Harvey Seam.) Even in this occurrence the species is very rare and scattered.

Carbonita sp.nov.d. is recorded by Vangerow from two horizons in the Coal Measures near Aachen in Germany, in the Gouley Group and the Anna I Group. The latter horizon Anna I is in the equivalent of the Lower Modiolaris Zone, below the Katharina Marine Band and so is fairly comparable with the record from above the Hopkins' Band.

Associates: At the level that these specimens were found the fauna is fairly sparse and consists of scattered ostracods, Carbonita humilis, Carbonita pungens and Carbonita cf. evelinae, isolated Naiadites sp. and Spirorbis tubes.

2. THE POPULATIONS OF OSTRACODS.

The species of ostracods previously described all come from the three main ostracod-mussel bands that have been studied within the Northumberland and Durham Coalfield, and so the latter part of this chapter is concerned with the multispeciate populations that occur in these bands.

Ostracods have been recorded by various authors from many horizons within the Northumberland and Durham Coal Measures, as shown in Fig. 3.23. Apart from the three main ostracod-mussel bands studied here, most of these records, such as those above the Victoria, Hutton and Low Main seams are single occurrences of one or two species. The exact specific identification of some of the ostracods recorded in Fig. 3.23. has been difficult to confirm due to synonomy and outdated names. The specimens recorded as Carbonita "fabulina" from Ryhope Colliery by Jones and Kirkby (1879), for instance, have been re-examined as described in the discussion of the species Carbonita humilis, and referred to this latter species. Other records of Carbonita cf. fabulina (sensu lato) have likewise been included as Carbonita humilis.

Although the Hopkins' Band was first described in detail by Hopkins (1928) there are earlier records of ostracods having been found at this stratigraphical horizon. The original specimens of C. arcuata described by Bean (1836) probably came from this horizon, as did the records of C. arcuata Jones and Kirkby (1865) and C. cf. "fabulina" Jones and Kirkby (1879) from Prestwick Colliery, Northumberland.

TABLE 3.1.

Vertical distribution of the ostracods at Bearpark.

Sampling Series B.P. 17	Sampling Series B.P.105	Geisina arcuata	Carbonita 1	Carbonita 2	Carbonita 3	Carbonita 4	Carbonita 6	Carbonita 7
c.1'2½"	1'0"-1'2"		1		2			
	9½"-10"							
	8"-9½"				4			
7"-8½"	7½"-8"		15 10		23 8			3
	6"-7½"		3		12			
5½"-6½"	6"-6"		4 2		20 15			
4½"-5½"	4½"-5½"	1 8	6 8		7 29			
3"-4½" (Geisina Band)	3"-4½"	43 58		3 2	20 18	1		
	2"-3"				6			
	1"-2"			2	29	12	1	
	0"-1"			2	6	25		
Height above Seam								
Total number of specimens extracted		110	49	8	199	38	1	3

Except for Geisina subarcuata all the species of ostracods described in this chapter have been found in the Hopkins' Band, and the mean H/L dimensions for all species and moults found are represented in the "typical population" diagram of Fig. 3.24. Not all species have been found at any one sampled locality, but except for Carbonita secans, Carbonita inflata and Carbonita concava their occurrence is universal and absence is due to a typical sampling or difficulties in extraction.

a) The Hopkins' Band.

Vertical variation in the ostracod population of the Hopkins' Band.

In order to study the vertical variation in the ostracod population of the Hopkins' Band, two series of microfaunal extractions have been carried out on samples obtained throughout the vertical thickness of the Hopkins' Band, from Bearpark Colliery, County Durham. Five samples were broken down in the first sampling series, BP. 17 ss, while in the second series, BP. 105 ss. a total of seventeen samples were examined for microfauna. Ostracods proved to be extractable or present only in the lower ten samples. The heights of the samples and numbers of specimens of the various ostracod species extracted are shown in Table 3.1.

Despite difficulties in extraction, there seems to be a distinct vertical change in the species of ostracods present in the Band. This is independent evidence of the validity of faunal phases within the Hopkins' Band to be discussed in detail in Chapter V. Geisina arcuata is restricted vertically occurring only in the "Geisina Band" proper - where it is by far the dominant species. Carbonita humilis occurs throughout the vertical sequence, probably in a fairly persistent density, numerical variations being due to sampling. The small Darwinulid ostracod Carbonita pungens is most abundant in the 3 inches of mudstone and shale immediately above the coal, but it does not persist vertically as seen in the faunal phase charts (Fig. 5.2-5.8). It cannot be extracted however as the valves are usually disarticulated and thus not able to form a calcite filled

TABLE 3.2

Vertical distribution of moults of various ostracod species in Bearpark sampling series B.P. 105.

Height above Seam	Geisina arcuata	Species of Carbonita				
		1	2	3	4	6
1'0" - 1'2"		A				
8½" - 9½"				A, 1A		
7½" - 8 "		A		A, 1A		
6" - 6 "		1A		A, 1A		
4½" - 5½"	A	A		A, 1A		
3 " - 4½"	A		A	A	A	
(Geisina Band)						
1" - 2"			1A,2A	A	A	A
0" - 1"			A	A, 4A	A,1A	

<u>Legend</u>: A = adult.

1A = instar next before adult, penultimate.

2A = two instars before the adult and so on ....

mould as on the other articulated ostracod specimens. The most interesting antipathetic relationship between the species Carbonita cf. evelinae, and Carbonita cf. rankiniana is suggested from this study. Carbonita cf. evelinae is restricted to the grey shaley mudstone above the "Geisina Band", while C.cf. rankiniana occurs within this band and in the black shale below, but not in the grey mudstone above. This relationship could not have been observed in the lateral sampling series as usually the ostracod band includes shale from above and below the "Geisina Band" proper. Carbonita cf. evelinae seems to show a distinct increase within the population between 7 - 8 inches in both sample series on Table 3.1 and it rivals C.humilis for dominance of the ostracod population.

A measurement of the height and length of the various specimens extracted from the second sample series (BP 105 series), has made is possible to determine how many moult stages of different species are present in the populations at the various levels. The information as to moults shown on Table 3.2. In this table A represents the largest moult measured, presumably the adult, while 1A, 2A, 3A indicate the moults or instars preceeding the adult (i.e. 3A is third instar before the adult, not necessarily third instar as the total number of instars is not known).

The lowest two inches of the black shale contains at least two moults of C.pungens and C.humilis and three or more of C.cf.rankiniana. The "Geisina Band", Geisina and all the species of Carbonita are present as adults only, a fact which may be of ecological importance to be discussed later (Chapter VIII). In the five inches of grey shaley mudstone that succeeds the "Geisina Band", Carbonita humilis persistently has at least two moults, perhaps more, while C.cf.evelinae is present usually only as the adult but rarely as the preceeding instar as well.

These facts of the number of instars in a population are of particular importance when considering whether the ostracod faunas are truly a "life assemblage" (Boucott 1953) or perhaps a "death" of drifted assemblage, and thus relevant when considering the detailed palaeoecology.

TABLE 3.3

Ostracods extracted from the Geisina Band at various localities.

Localities	Geisina arcuata	Carbonita 1	2	3 F	3 M	5	Total
Follonsby (4)	99		2	2	3		106
Pelton (5)	177	6	2	62	36		283
Bearpark (6)	57	2	6	23	15		103
Whitworth (7)	24	6	1	13	5		49
Ferryhill (8)	97			7	6		110
Washington (12)	65	1	3	7	4		80
Hylton (13)	24	3	1	18	5	7	81
				(+23)			
Silksworth (14)	122	4	3	79	77		285
Ryhope (15)	120	1	4	23	18		166
Durham Main (18)	34	1	1	9	1		50
				(+4)			
Eppleton (19)	212	1	11	111	34	5	374
Bowburn (20)	32		1	12	6		51
TOTAL (Durham)	1063	25	35	366	210	12	1738
Broughton Moor	56	1		217			273
	A24			A125			
Cumberland	1A 26			1A 77			
	2A 3			2A 5			

F = female
M = male

Lateral variation in the ostracod population of the Hopkins' Band.

As well as the vertical changes in ostracod population that have been studied at the type locality at Bearpark, samples of the Geisina Bands, have been collected and broken down for extraction, from twelve localities in County Durham, and one in Cumberland. The details of the number of identifiable specimens are from the boreholes at Lambley in the Midgeholme coalfield, now in possession of the Geological Survey, but detailed extraction of ostracods was not possible.

Despite the wide range of numbers of specimens obtained from similar extraction techniques on an approximately equal amount of shale from each locality, it is not possible to detect or postulate any numerical variation in the ostracod populations. The majority of these differences are attributable to the type of preservation of the ostracods in the various localities, and differences in the ease of extraction.

However the twelve localities from Dounty Durham, from which 1738, well preserved ostracod specimens were extracted, when taken together do enable certain generalizations to be made as to the proportions of the species in the "typical" Hopkins' Band fauna. In the actual Geisina Band, Geisma arcuata forms approximately, 61⅓% of the ostracod fauna, Carbonita humilis about 34% and the other five species of Carbonita the remaining 5%. Of this last 5%, Carbonita cf. evelinae and Carbonita cf. rankiniana form about 3% and the other species C.pungens, C.inflata, the remaining 2%, being rare. The fragile and thin shelled form C.pungens, although present as separated values in the Geisina Band, could not be extracted because of its fragile nature, but probably forms less than 2% of the population at this level.

The H/L dimension graphs of the ostracod populations from the various localities that are shown in Figs. 3.17 and 3.25 illustrate different points. The Hylton (13) graph shows the presence of younger moults of C.humilis. This is a rare feature and is perhaps due to some of the overlying shale being included in this extraction sample. The presence of dimorphic forms of C.humilis in the Band is seen on the Silksworth graph. From Table 3.3 it can be seen that male and female forms of C.humilis have been recognised in most of the population samples but that the ratios of male to female vary considerably. In localities like Silksworth and Ryhope the numbers are approximately equal as would be expected in situation of a strongly dimorphic form, but even in the mean value for all the localities, the females seem to form 63.5% of the population of C.humilis and the males only 36.5%. This may possibly be a real situation or may be explicable in terms of the males being less easily preserved, or where measurements of dimensions have not been made, the pre-adults instar being present and similar in shape to the female dimorph of the adult, a common situation is ostracods, so that it has been included with the females of the adult. The reason however, may simply lie in a typical sampling of the populations.

The presence of two younger instars than the adult in the Hylton fauna is of interest because, this is one more than is recorded in the vertical section of the Bearpark situation from the strara above the "Geisina Band". This is a similar situation to that of the ostracod fauna from above the Eighteen Inch Seam of Cumberland at Broughton Moor, (included in Table 3.3) where three moults of Carbonita humilis and also three of Geisina arcuata are discernable. It has not been possible to establish the number of moults present in the material examined from the Midgeholme bores but in the 3 inch ostracod band recorded in Lambley No. 14, Geisina arcuata occurs in abundance with spirorbis sp. and rarer specimens of C.humilis.

The only general lateral variation in the Hopkins' Band that seems to be supported by the population sampling is a general thinning and reduction of numbers of ostracods in the Geisina phase - towards the south and south west of the Durham coalfield. The densest and richest ostracod faunas have been extracted from the shales in the centre of the coalfield - Pelton (5), Follonsby (14), Eppleton (19), Silksworth (14) and Ryhope (15). The localities, Durham Main (23) Bowburn (20), Ferryhill (8) and Whitworth Park Opencast Site (7) do seem poorer in well preserved specimens, but this is a very generalised conclusion based more on stratigraphical and lithological evidence. The paucity of ostracods in the Band has been especially evident in the detailed study of a large amount of material from Whitworth Park Opencast site, but here the Geisina Band itself is reduced to less than 1/4 inch in thickness.

The presence of ostracod bearing shales to the south west of Bishop Auckland as indicated on Fig. 1.8 of Chapter I is based on isolated records from boreholes which generally confirms the fading and impersistence of the ostracod band to the south and south west but no population details are available for this area.

b) Three Quarter Seam Ostracod Band.

A total of five species of ostracods have been found in this band as indicated in Fig. 3.23 and they show similar phase relationships to the Hopkins' Band Fig. 5.9.

The dominant species and longest ranging one is C. pungens, which occurs throughout the Band. In the lowest slickensided black shale this species occurs in distinct pockets or groups and althouth it is rarely well preserved its minute shells are often collected into distinct "coquinas" on the bedding planes in the black shale. Carbonita humilis has a similar vertical range to C. pungens and in fact may slightly outlive the latter, but it never occurs in the same density and is best preserved in the grey shales and mudstone. higher. In these grey shaley mudstones both male and female forms occur, 13 male and 22 female specimens being extracted from 1 foot of shale, between 435' 9" and 436' 9" in Borehole Fishburn (6), Fig. 5.9., together with specimens of at least two earlier moults.

The remaining species of Carbonita, C. cf evelinae and C. cf. rankiniana both occur as rare and scattered individuals.

Geisina arcuata, the dominant ostracod of the Hopkins' Band, occurs in the Three Quarter Band but is never dominant or abundant. It shows a similar vertical restriction as in the Hopkins' Band, in comparison with C.pungens and C.humilis, but does not form the distinct "Geisina Band" so typical of the Modiolaris Zone horizon. The specimens of G.arcuata occur as scattered but complete carapaces, either in the Carbonita "coquinae" or on bedding planes in the black shale. Only adults have actually been recognised but younger moults are probably present as well.

This ostracod horizon in the Communis Zone possesses the same species and many features of population distribution similar to the Hopkins' Band, but quite distinct from the following Claxheugh fauna.

c) The ostracod fauna of the Claxheugh Shell Bed.

All the faunal lists for this locality include the ostracod "Beyrichia arcuata", Kirkby, Stobbs and Trueman, or Geisina? subarcuata Calver in Armstrong and Price, while the earlier records include Carbonita [Carbonia] sp. as well. Jones and Kirkby (1879) record that the species Carbonita humilis, Carbonita secans and Carbonita rankiniana have been found here, as in Fig. 3.23, but the authorities for such records are not given and these species do not appear in any of the aforementioned faunal lists.

The ostracods are best preserved in the ironstones, from which they can be extracted with difficulty.

The ostracods fauna extracted proved to be simply of the one species Geisina subarcuata Jones, althouth up to six moults were found. The H/L dimensions of 46 specimens are shown in Fig. 3.26, and the frequency of specimens expressed in terms of the absolute length. The hypothetical positions of the instar means dimensions are included by extrapolating back with the Przibram Growth Factor of 1.26, from the mean of the largest instar F, presumably the adult. However, accurate or inaccurate this dubious growth factor may be, the specimens do seem to fall into six distinct instars with decreasing numbers at the lower instars as is common in fossil ostracod populations, (Scott and Smith, 1961). There seems to be a certain amount of overlap of the last two instars E and F and a greater dispersion of these specimens in terms of the height. This dispersion is thus of height and can be explained by the presence of dimorphic forms, the female having greater relative height than the male, as described in the previous systematic section of this chapter. In this population dimorphism therefore may be present in the last two moults (See systematic section).

The preservation of these six moults in the ironstone suggests very quiet conditions of sedimentation where the fragile thin shells of the young forms were not broken up before burial.

The younger moults of G. subarcuata described here appear at first glance very similar in size and shape to Carbonita "fabulina" (sensu lato) and so it seems possible that some of the ostracods recorded by earlier workers as the latter species of Carbonita sp. may have been young moults of this monospecific population.

In order to confirm the specific details of the species Geisina subarcuata and to help elucidate the exact horizon of the Claxheugh fauna, a comparable fauna of Geisina is included on Fig. 3.26. The specimens were identified by Mr. Calver of the Geological Survey and are from the highest beds of the Upper Similis pulchra Zone in the North Staffordshire Coalfield. This latter fauna seems to contain three distinct moults, the lower two coincident with moults C and D of Claxheugh, but the upper moult falling below the moult E of Claxheugh. The North Staffordshire fauna is not so strongly dimorphic as Claxheugh and so it may not contain many adults. The close coincidence of the slope of the two growth lines, tends to confirm that both populations are of the same species. Unlike the Claxheugh fauna two distinct specimens of Carbonita salteriana Jones, a Upper Coal Measure species of Carbonita, have been found as associates.

The similarity of the ostracod faunas from Claxheugh and North Staffordshire tends to confirm their similar horizon, as suggested by the non-marine lamellibranch faunas (Chapter II).

The dominance of both ostracod faunas by Geisina subarcuata suggests that they are within the Upper Similis pulchra Zone, as this species does not generally occur above the Top Marine Band, that indicates the base of the overlying Phillipsi Zone (Calver 1962, personal communication). The species Geisina subarcuata seems to show a similar relationship to the Top Marine Band as, G.arcuata does to the mid-Modiolaris Marine Band, occurring abundantly below but not above it. The ostracod faunas of the Phillipsi Zone, as mentioned previously are dominated by species of Carbonita.

The ostracod fauna of the Claxheugh Shell Bed therefore differs from that of the two LowerCoal Measure ostracod-mussel bands described, both in faunal composition and number of instars preserved. The former of these differences is due to its higher stratigraphical horizon, while the latter is explained later in terms of ecology.

CHAPTER IV

SERPULIDS, FISH AND PLANTS

In addition to the non-marine lamellibranchs and ostracods the other fossils of the ostracod-mussel bands are serpulid worms, fish and plants. Of these however only the serpulid worms occur in suggicient abundance to make them a major constituent of the fauna.

1. SERPULIDS.

The serpulid worm Spirorbis pusillus Martin was recorded by Hopkins (1927, 1 928, 1929 and 1930) from Division (2) of Hopkins' Band. This present study has shown that this worm is a major constituent of the microfauna in all three divisions of this Band.

Throughout the Coal Measures this worm is of common occurrence, usually in association with non-marine lamellibranchs and plants and only very rarely does it occur in marine bands. In the Upper Coal Measures the abundance of this worm is such as to form the well known "Spirorbis Limestones" of the Midlands. The position of an annelid worm of the genus Spirorbis in non-marine strata is enigmatic, as all its living relatives are marine, and so the ecological implications of its presence are quite important.

The species Spirorbis (Concholithites) pusillus was first described by Martin (1809) from an ironstone nodule in the Coal Measures near Chesterfield, then it was figured subsequently by Murchison (1834). The subsequent history of its confused taxonomy was ably reviewed by Etheridge (188o). Since Etheridge's paper there has been no other detailed description of this species, despite several papers discussing its habitat and mode of life (Barrois 1904, Malaquin, 1904, Cox 1926, and Trueman, 1942). In this present study therdfore a large fauna of well preserved worms from the Hopkins' Band has been studied to amplify the description of Etheridge (1880) and determine the range of variation and perhaps the ecology of this genus.

1. Systematic Description.

Spirorbis (Microconchus) pusillus Martin

Synonomy: This has been very thoroughly reviewed by Etheridge (1880) and only references of historical importance are included here.

Concholithites (Helictes) pusillis Martin 1809. Pet.Derb., p.52, Figs. 2 & 3.

Microconchus carbonarius Murchison 1839. Sil.Syst. p.84, f.D1-D10P.

Gyromyces ammonis Goppert, 1853. in Germar's Verstein. Steinkohlen. von Wettin v. Lobejun heft 8, p.29, t39, f. 1-9.

Spirorbis pusillus Eichwald 1860. Lethaea Russica, p.670.

Palaeorbis ammonis van Bededen abd Coemans, 1876, Bull.l'Acad.R. Bruxelles 2mme ser xxiii, p.390, plate f.1-4.

Spirorbis (Microconchus) pusillus Martin-Etheridge 1880. Geol.Mag. Dec II, Vol.VII, No.3, p.113 et seq. pl.7, f.1-8.

Historical. Martin (1809) described this species as a mollusc, and Murchison (1839) whole commenting on its Planorbid nature noted the flattened side of attachment like Spirorbis. In both Britain and American it was truly recognised as a serpulid worm by Binney (1852) and Dawson (1845), but the German palaeontologist Goppert (1853) was sufficiently unaware of the contemporary literature to call it Gyromyces, a fungus burrowing in the leaves of plants. Van Beden and Coemans (1867) were unable to reconcile this fossil with a non-marine habitat and so "We are led to regard Gyromyces as a terrestrial Gasteropod mollusc, allied to the Hellicidae, and living attached to the leaves and stems of ferns or other Coal plants, in a similar manner to the existing Spirorbis or marine plants and animals." (Quote from Etheridge 1880, p.216) Etheridge (1880) placed the species in the sub-genus Microconchus, differing from Spirorbis simply because of it making a depression or groove in the surface of the sustaining body". The validity of such a criterion and the generic position will be discussed later in the light of the ammended description that follows.

Description of specimens from the Hopkins' Band.

(This description is of the specimens figured as Figs. 4.1 and 4.2 unless otherwise stated).

Tube sinistrally coiled; (When viewed conventionally from the dorsal side; previous descriptions from the ventral side thus describe it as dextral. c.f. Etheriedge 1880, p.114).

Attached by one side, the dorsal, and coiling ventrally, irregularly planorbiform or with the last whorl becoming free and coiling helicoidally. (See Fig. 4.1.) Coil up to 4.2 mm. in diameter; convex volutions, $1\frac{1}{2}$ - 3 not in the same plane but elevated ventrally so that the later whorls obscure the earlier ones. Flat or concave dorsally where all whorls are visible; last whorl or last two whorls may be a free tube that grows away from the earlier planorbid whorls in a helicoid spiral. Fig. 4.1(b).

Umbilicus prominent but may be partially obscured by the last whorl; aperture circular or slightly elongate and curves sigmoidally, up to 1 mm. in diam. The cross section of the tube is circular or slightly oval; the external surface is finely granular and ornamented with close, regular, transverse growth striae or ridges. These striae may vary in their strength of development; tube wall is of lamellar calcite and thickens towards the aperture, where exceptionally it may reach 0.2mm. in thickness. The tube wall is probably thinner on the dorsal attached surface.

Internal features: Internally the tube is not chambered but decreases in diameter distally; the inner tube wall is smooth but may bear certain longitudinal ridges and projections; a longitudinal ridge is present internally on the inside of the coil of the last whorl and this leaves a furrow on internal moulds (Fig. 4.2a); occassionally tooth like projections are present inside the last whorl. (Fig. 4.3a) These are closely appressed to the wall and point away from the aperture. The presence of an internal projection or ridge is seen in the cross section of the tube in Fig. 4.3b. (The patches of pyrite inside this tube may represent the area of local reduction around the decaying body remains when the tube was buried.) The inner surface of the tube is granular with many minute tubercles, sometimes arranged spirally parallel to the growth striae. This granular surface may leave a fine pitting on the internal moulds. (Fig. 4.3 and 4.3). The distal end of the tube consists of a small bulbous chanber seen in Fig. 4.2b.

The structure of the tube wall.

The microscopic structure of the tube wall has been examined and compared with that of living Spirorbis as evidence of the relationships that are to be considered later.

In cross section the wall is seen to be composed of lamellar calcite, the individual lamellae having a discontinuous fibrous appearance (see Fig. 4.3a, b and c). Although the wall is impunctate it appears to contain many small air cavities, which cause the slight swelling of the inner tube surface in the form of the fine tubercles, Fig. 4.3a and c. Both the inner and the outer surfaces of the tube are covered by a thin brown perhaps chitinous sheath, Fig. 4.3a and c.

The tube wall in living Spirorbis is two layered with an inner layer of porcellaneous calcite and an outer one of lamellar calcite. In longitudinal section, Fig. 4.3 c, there are distinct transverse growth layers in the lamellar layer continuous with the external growth striae or ridges, and indicating the successive positions of the collar and aperture at the time of deposition of the tube. The tube wall of Spirorbis pusillus, as reconstructed here, Fig. 4.3d, lacks both the distinct two layered nature and the growth layering. It is possible however that both these structures could have been obliterated in S. pusillus by recrystallisation of the calcite of the wall during fossilization.

2. The Generic assignment of "*Spirorbis*" (*Microconchus*) *pusillus*.

The inclusion of these non-marine Carboniferous annelids in the genus of living marine serpulid worm *Spirorbis* is a dubious one. There are marine tubicolous worms, identical with *Spirorbis*, known from the Lower Palaeozoic and these are attached to undoubted marihe organisms. For instance Ager (1961) records *Spirorbis* sp, among the epifauna of the Devonian brachiopod *Spinocyrtia iowensis*.

Etheridge (1880) suggested the separation of this species into the genus *Microconchus* on account of it making a depression in the substrate to which it is attached. Such a suggestion is one of convenience and the genus cannot hold true, as the depth of impression will depend on such factors as; the duration of attachment, the host reaction to the attached worm, and conditions of preservation. The first two of these objections have been supported by Trueman (1943, p.313), where he believes that the impression in the shells of *Naiadites*, caused by Spirorbis, is due to the growth of the worm on the uncalcified periostracum of the lamellibranch, and then subsequent deposition of the host shell around the worm, rather than the burrowing of the worm into the shell as suggested by Etheridge (1880, p.111). These conclusions of Trueman, are supported by the specimens studied from the Hopkins' Band, where depth of impression is seen to increase with the size of the worm. This indicates that the older worms are more firmly embedded in the shell substance of the host. Worm tubes that were once adhering to the leaves and stems of plants may become further embedded in the soft tissue of their host simply by the weight of overlying sediment before compaction. Thus for these two reasons the genus *Microconchus* as proposed by Etheridge must be rejected.

Cox (1926) reviews the generic position of this worm and as the name *Microconchus* Murchison is still available, he suggests that it should be used to include all Carboniferous non-marine forms. His separation from *Spirorbis* sensu stricto is thus on the basis of their different habitats. Trueman (1942, p.117) further reviews the name without coming to any definite conclusion. Referring to the separation into the genus Microconchus on ecological grounds he says "It is uncertain whether any morphological basis exists for this, although a more detailed examination of well preserved specimens from different Carboniferous habitats might afford sufficient evidence for this distinction". The previous detailed examination of the morphology and internal anatomy of the Hopkins' Band specimens is an attempt to meet Trueman's suggestion.

Evidence of generic affinity from the Hopkins' Band specimens.

To study this problem specimens of "S" pusillus from the Hopkins' Band have been compared with specimens of S.borealis and S.pagenstracheri collected from the sea shore at Hartley Bay in Northumberland. The tubes of both the fossil and living worms have been studied by X-rays, staining techniques, microscopical examination and thin sections. In both cases the tubes are made of calcite, but certain differences are apparent.

i) Wall structure. When stained with Copper sulphate both tubes reveal a typical two layered serpulid wall as described by Wrigley (1951). However in section the wall structure is very different as already described and illustrated in Fig. 4.3.c and d. The fossil specimens lack the distinct inner porcellaneous layer and growth layering of "S".borealis but have the small air cavities in the lamellar layer. It is possible that some of these differences could be due to recrystallization of the fossil wall as already mentioned, but the fresh appearance of the fossils and the well ordered mature of the cavities does not support such a fundamental change in structure.

ii) Internal features. The tubes of S.borealis and S.pagenstracheri are perfectly smooth and structureless internally. Some of the fossil tubes however have a granular internal surface and several internal spines and ridges. Such differences might be of generic significance but it is difficult to assess how ubiquitous they are.

iii) Differences of habitat. Generic distinctions based solely on differences of ecology, as suggested by Cox (1926), would seem to be very doubtful now that more is known about the ecology of living serpulids. When discussing this problem, Barrois (1904, p.70) wrote, "This last family (the Serpulids) in particular, appears to be susceptible to a very rapid adaptation, and to be able to aclimatise itself to a very great change in the salinity of the water." Several euryhaline tubicolous serpulids are now known. In the past hundred years the species Marciella enigmatica Fauvel has achieved a world wide distribution as well as changing its habitat from marine to brackish water. (Fauvel, 1933). It was first thought that this species could only breed in sea water despite its colonization of the brackish estuarine environment but Fischer Piette (1937) has shown that it is perfectly adapted to breed in brackish water. Thus if such an ecological adaptation is possible in a short period of historic time, then a previously marine genus could certainly become adapted to the brackish or non-marine conditions of the Coal Measure swamps in the eons of the Upper Carboniferous.

Conclusions. Thus while this study suggests a possible generic distinction between the fossils and living species, such a distinction cannot be supported on ecological grounds. A solution has been indirectly suggested by Stubblefield (1961), where he described the genera as Microconchus (Spirorbis)(Ordovician to Carboniferous), and thus by inference Spirorbis (Mesozoic? to Recent). This solution is followed here as it is believed that there are morphological distinctions between Microconchus Murchison, an Upper Carboniferous non-marine genus, and Spirorbis Daudin, a recent marine genus.

The species under discussion now therefore becomes Microconchus (Spirorbis) pusillus Martin.

TABLE 4.1.

	a) M. pusillus	Form b)	S. helicteres
1.	attached on dorsal surface.	attached, at least on periphery.	unattached.
2.	whorls closely coiled 2 or 3.	early whorls closely coiled, 1 or 2 whorls free.	2 whorls loosely coiled later whorls an open helix.
3.	Tube with growth striae only.	growth striae only.	Tube with strong rugae.
4.	Whorl section circular.	Whorl section circular.	whorl section laterally compressed.
5.	Aperture circular.	? Aperture circular.	Aperture oval.
6.	Tube aseptate	? ?	Tube septate.

3. Variation in Microconchus (Spirorbis) pusillus in the Hopkins' Band.

Many workers have recorded "Spirorbis sp." from Coal Measure non-marine faunas, but few have attempted a specific identification and no one has previously described the variation of this genus at one locality and horizon.

The commonest species recorded by Etheridge (1880) is M.pusillus Martin. He does record one occurrence of S.helicteres Salter from a non-marins mussel band in the Coal Measures at Newton Cambusland in the Midland Valley. In Coal measure Marine Bands only two occurrences are recorded, S.cf.ambiguous from the Pennystone Marine Band of Coalbrookdale (mid-Modiolaris marine band) and "S" cf.pusillus parasitic on the Limuloid arthopod Prestwichiella rotunda from the Somerset Coalfield. Trueman (1954, p.69) however suggests that Prestwichiella may be of non-marine habitat, thus explaining the presence of the non-marine M.pusillus.

In the Hopkins' Band there are two distinct forms of Microconchus and a wide range of intermediate variants,(see Fig. 4.1.a) Form a) is the normal M.pusillus as previously described, while form b) closely approaches S.helicteres Salter as described by Etheridge (1880, p.260-261.) These species are difficult to separate at times according to Etheridge (1880, p.261), and so the characters of these two species and form b) are compared in Table 4.1.

From this comparison it appears that form b) has many more characters in common with M.pusillus than with S.helicteres, so it is considered to be the extreme uncoiled variant of M.pusillus.

An explanation of the cause and ecological significance of this uncoiling may parhaps be found in recent work on living Spirorbids. The living species are frequently determined on characters of the soft parts and host preferences rather than the morphology of the tube. (cf. Key to British species, Knight-Jones and de Silva, personal communication 1961).

Hedley (1955) working on the histochemistry of the tube formation in Pomatoceras trigueter, a common littoral species of tubicolous serpulid, showed that the form of the tube may depend on environmental competition. This species usually forms a strgight distinctly ridged tube enclosing the body on two sides, the third side of the tube is formed by the surface of the substrate to which the animal closely adheres. When there is fierce competition for food or space on the substrate however the animal may form a complete three sided tube which grows vertically and freely away from the substrate. This observation suggests that the uncoiled forms of M.pusillus might have developed due to competition for space on the substrate, when the coil could not expand laterally.

Another possible explanation for the uncoiled forms is that they are distinct biological species, defined in terms of the soft parts and host preferences, and the tube morphology reflects the different hosts. In their revision of living British species de Silva and Knight-Jones (1962) record certain species with very marked host preferences. S.corallinae occurs solely on the Red Alga Corallina officinalis, while the species S.granulatus and S.tridentatus only occur on stones and shells and never on algae. Thus is is possible that the uncoiled form of M.pusillus may have a different host than the closely coiled forms. This possibility has been examined by considering the substrate material of M.pusillus at various levels in the Hopkins' Band.

M.pusillus is believed to have attached itself to both plants and the shells of non-marine lamellibranchs in Coal Measure times. Barrois (1904) records its attachment to Neuropteris, Alethopteris and Sphenopteris, while Trueman (1942) discusses its supposed commensal relationship with the non-marine lamellibranchs.

The correlation between, lithology, relative abundance, growth forms and hosts of M.pusillus in the Hopkins' Band is shown in Fig. 4.4. In the Basal Black shale the worm is found attached to the plants Lepidodendron and Sigillaria, while in the highest grey mudstones and siltstones the tubes occur on the scattered leaves of Calamites and Cordaites. (Fig. 4.5) Where mussels are present in the shales the worms are most commonly attached to Naiadites, but also to Carbonicola and Amthracosia. No specimens have been observed on Ahthraconaia (Trueman, 1942, p.312). The number of worm tubes attached to one shell of Naiadites in the Hopkins' Band is not as great as that shown by Trueman, (1942, Fig.1 c and d.) twenty four and twenty six worms respectively, but shells with ten tubes attached are quite common. The growth forms of the worms shown on Fig. 4.4. indicate that the uncoiled variants are only common in the mussel rich shales above the Geisina Band.

The correlation of growth forms and hosts shows that the normal form occurs where the hosts are plants and/or mussels while the uncoiled forms only occur where the hosts are mussels. This suggests that the worm can only uncoil when its earlier whorls are firmly fixed to a solid substrate such as a mussel shell. When adhering to a plant as in Fig. 4.5 the worm must coil tightly for support on the soft plant tissues. A similar situation is seen in the living worm S. borealis, where tubes attached to the Brown Algae Fucus are tightly coiled and those adhering to the shell of the large gasteropod Haliotis are more loosely coiled but not uncoiled. Trueman (1942, p.318) suggests that Spirorbis settled on the posterior ventral edge of the uncalcified periostracum of Naiadites within the area of influence of the incurrent water streams. Such a position would therefore be of advantage to the worm as regards feeding. However once the worms were fixed and the Naiadites grew the Spirorbis would become further removed from the area of the mantle edge and influence of the feeding currents. Elongation of the free tube however would give a wider feeding cone for the tentacles and head of the worm, Fig. 4.6., and thus remove such forms from being in direct competition for food with the younger, better placed worms near the mantle edge. The advantage of such an enlarged feeding cone of the uncoiled form can be seen in Fig. 4.6.

Thus is is concluded that the variation in the growth form of Microconchus, seen in the Hopkins' Band, is die to different host preferences rather than the presence of more than one species.

2. FISH.

Scattered fish remains occur in association with the ostracods in all three of the ostracod-mussel bands studied. These remains are mostly scales and spines of Palaeoniscid, Crossopterigian or Acanthodian fish and are contained in the black shales as the base of the band.

In the Hopkins' Band identifyable fish remains havebeen found at six localities. Rare scales of the large Crossopterigian Megalichthys sp. have been found in the black shales with ostracods and Naiadites at Silksworth (14) and Whitworth Opencast (7). A well preserved dorsal spine of Strepsodus sp. has been found at Silksworth. The only other remains from the Hopkins' Band proper are scales of Rhadinichthys cf. monensis and Acrolepsis sp. from Bearpark and a small group of scales of Rhizopsis ? sp. from Pelton (5).

The richest fish fauna at the level of the Hopkins' Band is from the fish band, recorded in Fig. 1.6., in association with the ostracod bearing cannel shale at Hedley Park (9). The remains from this band include Strepsodus sp., Elonichthys sp., Acrolepis sp. Rhadinichthys sp., and Acanthodian spines, preserved in a cannel shale. Even in this band however the remains are separate and no complete specimens have been found, comparable with those from the well known specimens of cannel shale fish bed above the Low Main Seam at Newsham in Northumberland.

Fish scales are fairly abundant in the black shales of the Three Quarter Ostracod Band, more so than in the Hopkins' Band, but here again the range of genera is limited. Scales of Elonichthys sp. occurred in borehole Fishburn 6 and Bowburn while Rhadinichthys, Strepsodus ? and Acrolepis ? were also recorded from the Fishburn bores. A crushed maxilla, perhaps of Gonatodus cf. parridens, was found found in the Bowburn bore.

No fish remains have been found in the specimens of the Claxheugh Shell Bed examined in this study, but Calver (in Armstrong and Price, 1953) **records** the following specimens; "Diplodus tooth, Elonichthys sp. scale, Palaeoniscid scale indet., Rhabdoderma sp. (scale), cf. Rhadinichthys wardi (acale) and Rhizopsis sp. (Scale)"

The fish faunas recorded from these three Bands are thus similar and are typical of the "facies fish fauna" of the Coal Measure swamps as described by Westoll (1944). These fish are believed to have been exclusively non-marine inhabiting the lagoons, pools, and meandering streams of the vast Coal Measures swamps and were quite incapable of migrating by the sea.

The Hopkins' Band fauna is very similar to one described by Baird (1962) from the Coal Measures of Nova Scotia. He recorded (p.27) Haplolepis (Parahaplolepis) aff. anglicus, Gyracanthus, Megalichthys, Strepsodus and Elonichthys, in association with an invertibrate fauna of Anthraconaia modiolaris, Anthrapalaeomon dubium, ostracods and Spirorbis. The occurrence of Anthrapalaeomon and Anthraconaia together with fish is interesting, as according to Weir (1945) these two genera of non-marine lamellibranchs are indicative of fresh rather than brackish water conditions. The fish band in the cannal shale at Hedley Park may be similar in origin to those in cannal shales at Newsham, Northumberland, and Linton, Ohio, discussed by Westoll (1944, p.103-109). Such cannel shales, he believes, can be likened to the deposits forming today in the stagnant tropical freshwater swamps of the Paraquayan Chaco. They indicate temporary pools of very shallow stagnant water, rich in accumulated plant debris, and have a very low oxygen content, a high carbon dioxide content, and a pH of less than 7. Westoll further suggests that black carbonaceous shales with a fine grained detrital content, such as that below the Hopkins' Band, are just cannel shales where slight waterr circulation has brought in a little detrital sediment.

3. PLANTS.

Plant remains occur at two levels in association with the Hopkins' Band, in the black shales below the Geisina Band and in the siliceous mudstones and siltstones above Division (3).

In the mudstone conglomerate and the black carbonaceous shale below the Geisina Band, the plant remains are all of the arborescent type that form the major constituent of the underlying coal. The actual top of the coal seam is frequently fusainous with recognisable Lepidophyllum leaves and Lepidodendron bark, while in the overlying mudstone conglomerate a lafge Stigmaria root, 3" in diameter, has been found at Whitworth Opencast (7), and several Lepidophyllum leaves at East Holywell (3). Most of the plant material however has been found in the basal half an inch of the black shale. At this level, Lepidodendron bark has been found at Whitworth, Fenwick and Bearpark. Sigillaria bark occurred at Bearpark and Follonsby (4), Lepidostrobus cones at Whitworth, East Holywell and Silksworth and Lepidophyllum at Bearpark. One specimen of a crushed Calamites stem has been found at this level at Bearpark, but this genus is commoner at higher levels.

The plant material in most of the black shale is very finely divided but rarely macroscopic fragments of Lepidodendron occur. Within the Geisina Band a well preserved Cordaites stem was found at Bearpark, but generally plant matter is very finely divided in this Band and in the overlying mussel rich shales.

In the upper mudstones and siltstones above the Hopkins' Band scattered plant remains occur that are of a different type to those in the black shale. These are usually leaves of Cordaites and stems of Calamites, often with attached Spirorbids. The largest flora has been collected from Whitworth Opencast at two distinct levels. At about 8-9 inches above the Geisina Band, both Cordaites leaves and Calamites stems occur with attached spirorbids. Rarer rootlets and Naiadites without attached spirorbids also occur, The higher level is about 12-13 inches above the Geisina Band, and here _Calamites_ stems occur but without attached worms. One specimen of _Calamites_ has also been found at about 12-13 inches above the Geisina Band at Bearpark.

These two types of flora that occur above and below the Hopkins' Band are or ecological significance. The basal flora is essentially an autochthonous one, the plant remains being the relicts of the pre-existing coal swamp that were preserved at or near their place of growth by the unundation of the swamp. The higher fauna however is allochthonous, consisting of light herbaceous fragments that were carried into the area of deposition along with the enclosing sediment.

The Hopkins' Band and overlying strata are replaced in north-west Durham by cannel coals and plant bearing siltstones and sandstones, Figs. 1.6, 1.7. No recognisable plant fragments have been seen in the cannel coals and shales at Hedley Park (9) or Chopwell (10), but plant remains are abundant in the siltstones and sandstones at Leadgate (16), Tanfield Lea (11), and Lanchester (17). The main flora of these sediments consists of _Calamites_ and _Cordaites_ but allochthonous Pteridosperm fragments occur as well. _Neuropteris_ pinnules have been found at Tanfield Lea (11), Leadgate (16) and Blaydon Burn (25), and _Alethopteris_ pinnules at Leadgate. Neither the pteridosperm pinnules nor the _Cordaites_ and _Calamites_ in these sediments have attached spirorbids.

The appearance of allochthonous terriginous pteridosperms in these coarser grained deposits, indicates a closer approach to the terrestrial source area and consequently different conditions of deposition than in the main ostracod-mussel lagoon. The absence of attached spirorbids on these plants may be due to rapid deposition in turbulent waters rich in detrital sediment, thus unfavourable to the filter feeding worms. Another possible explanation for the absence of the spirorbids is that the environment was virtually fluviatile and the salinity too low for the worms to flourish. This is a further interesting floral contribution to the elucidation of the palaeoecology.

CHAPTER V

FAUNAL PHASES

The fossils that have been described in the three preceding chapters are associated in the ostracod-mussel bands into distinct "faunal phases". These faunal phases are really particular faunal assemblages that are distinct from the phases above and below by the presence or dominance of a particular genus or species. The transition between such phases may be sudden or gradual and may or may not coincide with a change in the lithology of the enclosing rocks. Distinct faunal phases have been seen in both the Hopkins' Band and the Three Quarter Band, but not in the Claxheugh Shell Bed, as here the fauna is restricted to the thin ironstone horizons.

The faunal phases or faunal succession of Coal Measure non-Marine lamellibranchs were first recognised by Robertson (1932) in the mussel bands above coal seams in South Wales. In the past fifteen years however the exhaustive researches of Dr. R. M. C. Eagar in the Pennine Coalfields have elucidated a more detailed succession of faunal phases in mussel band, in Namurian, Lower and Middle Coal Measures strata. These results have been Briefly summerized in Eagar (1961) but the more detailed accounts appear in his other papers describing: Namurian C (Eagar 1952b, 1953a), Lenisulcata Zone (1947, 1952a), Communis Zone (1956), Modiolaris Zone (1961) and Lower Similis-pülchra Zone (Eagar and Rayner (1952). Whilst most of this work is concerned with the detailed faunal succession of non-marine lamellibranchs that in the Modiolaris Zone (Eagar 1961) is particularly relevant to the Hopkins' Band and so is considered in more detail later.

The purpose of this chapter is to describe the vertical succession and association of the fossils, within the ostracod mussel bands. A complete series of rock and fossil samples from the two feet or so of strata that compose the ostracod mussels band have been collected from each of the localities on Fig. 1.4. These samples have been examined for their macro and microfossil content by being cleaved into this laminae, 1/8 - 1/4 inch in thickness, and then these examined thoroughly under a binocular microscope. The results of this examination are presented in the diagrams Fig. 5.2-5.9 and the key to their interpretation as Fig. 5.1. As most of the sampling is from underground localities, it is restricted and thus the results are rather subjective. Due to the restricted sampling it has not been possible to give a quantitative estimation of the density of the fossils that is meaningful, so the relative density shown on Fig. 5.1, reflects more the distribution pattern of the fossils rather than their numerical density on any one bedding plane. The relative terms, Rare, Scattered, Common and Abundant, have been used, and these designations represented by columns of differing thickness on the actual faunal phase charts, (Fig. 5.1 - 5.9). The orientation of the mussels and ostracods as relevant to the ecology, has also been observed and represented on the diagrams.

The symbolism of the fossils is self explanatory. The two species Carbonita cf. evelinae and cf. rankiniana are included in the same column on the faunal phase diagrams as the species had not been separated taxonomically when this survey was carried out. The actual vertical distribution of these species however would appear to agree with that described in Chapter III, although it is not represented on the diagrams.

1. The Faunal Phases of the Hopkins' Band.

The seven faunal phase diagrams (Fig. 5.2 - 5.8) illustrate the faunal succession at some of the localities shown in Fig. 1.4. The four localities, Bearpark (6), Whitworth Opencast (7), Fenwick (3) and Silkworth (14), exhibit a typical faunal and lithological succession of the Hopkins' Band while Bates, Blyth (2), Hedley (9) and Lanchester (17) illustrate lateral changes at this horizon. From the diagrams it is possible to discover the vertical distribution of the fossils.

a) Vertical range of the genera and Species.

Although an approximate vertical distribution of the fossils has been given in the preceeding descriptive chapters, a more accurate range of the genera and species can be given here following a study of the Faunal Phase diagrams, Figs. 5.2 - 5.8. The term "range" here refers to the minimum and maximum thickness of strata within which the fossils occur and not to the heights above the coal seam. The ranges are related to the seven types of lithology, lettered A - G , recognised in the "type section" at Bearpark (6), on Fig. 5.2. The level of maximum density, faunal associations and faunal antipathy, are also recorded in this section to prepare for the subsequent description of the detailed faunal phases.

i) Carbonita pungens. This species has a vertical range within 11-16 inches of strata, in all lithologies from the basal mudstone conglomerate to the grey mudstone (lithologies A - E), but generally shows maximum density in the black shale, lithology B. Throughout its range this species is closely associated with other species of Carbonita, although it may be slightly longer ranging than these others. There is no marked faunal antipathy of this species.

ii) Carbonita evelinae and rankiniana. Although specimens of these two species are rarer than C.pungens and C.humilis the vertical range seems to be much the same up to 13 inches is recorded. Generally these species occur in lithologies D - E but rarely from B - E . Taking into account the restriction of C.rankiniana to below Geisina Band, lithology G, and C.cf.evelinae to strata above the Band, revealed in Chapter III, it would seem that C.cf.evelinae is a common er species than C.cf.rankiniana in this study.

iii) Carbonita humilis. The range of this species is recorded from 6 - 16 inches although usually it is nearer 12 - 16 inches and this is very close to that of C.pungens. The lithological range is from lithology A - E, with a maximum density in the black shale lithology B. There is no marked faunal antipathy of this species as it occurs with all the other fossils at different levels within the Hopkins' Band.

consists of a few sparsely scattered *Naiadites*, frequently associated with fragments of *Cordaites* and *Calamites*. The ostracods also disappear at the top of Phase 5, but the few spirorbid worms that survive are usually found attached to plant matter rather than to *Naiadites* (Chapter IV, Fig. 4.5 and 4.6).

These six phases of the Hopkins' Band are very similar to those described by Eagar (1961, p.146) from the strata above the Flockton Thin and Flockton Thick coals near Wakefield in Yorkshire.

The succession of phases he described is as follows:

	Fauna	Lithology
(5)	*Naiadites* only, relatively sparse	Pale grey mudstone
(4)	*Anthracosia* abundant. Relatively high H/L ratio *Naiadites*. *Anthraconaia* occasional.	Grey typically ferruginous mudstone with little carbonaceous matter.
(3)	*Carbonicola* abundant. relatively H/L ratio. *Naiadites*. *Anthraconaia* occasional. *Geisina* (*Jonesina*) very abundant.	Dark fine grained richly carbonaceous shale marked by prolific quantities of ostracods mainly of *Geisina* group. Macroscopic pyrite may occur notably towards the base.
(2)	*Anthraconaia* abundant with less common *Naiadites*. *Geisina* (*Jonesina*) very abundant.	
(1)	*Naiadites* and *Geisina* (*Jonesina*) very abundant.	
(0)	Fish scales abundant.	

Phase 0 of this succession lacks the ostracod and spirorbis recorded in the basal phase of the Hopkins' Band but possesses similar fish remains. Elsewhere (p.144) he records the association of "*Whipplella*" (*Carbonita cf.humilis* probably) with *Geisina*, and *Carbonita humilis* and *C.cf.rankiniana* have been identified personally from specimens of this dark carbonaceous shale from above the Flockton Thin coal at Warncliffe Woodmoor Colliery, Nr. Doncaster. It is probably therefore that species of *Carbonita* are present in this succession in Yorkshire although not recorded by Eagar. Phase (1) of Eagar appears to correspond to Phase 2 and 3 of the Hopkins' Band. The persistance of abundant specimens of

Geisina into phases (2) and (3) of Eagar, in association with Anthraconaia and Carbonicola, would appear to be related to the richly carbonaceous nature of the enclosing shales. As in Hopkins' Band Geisina dies out where the carbonaceous shales change to a grey ferruginous mudstone, at the base of phase (4) of Eagar.

The abundance of Anthraconaia in phase (2) of Eagar, has no direct counterpart in the type section of the Hopkins' Band phases but the faunal association of Anthraconaia, Naiadites and Geisina is similar to that seen near Bates, Blyth (2), Fig. 5.6. The distinction of Carbonicola with a low H/L ratio and Anthracosia with a high H/L ratio in Eagar's phases (3) and (4) can be matched with phases 4 and 5 of the Hopkins Band. The Carbonicola Fauna at this level in both these studies belongs to the C. oslancis group (Eagar, p.143), Fig. 5, here Chapter II, Fig. 2.1) with a low H/L ratio, while the Anthracosia fauna (Eagar, p.144, Fig. 6, here, Chapter II, Fig. 2.2.), consists of the small elevated forms of Anthracosia regularis group with a high H/L ratio. This distinction can be seen by comprising Fig. 2.1, and 2.3 in Chapter II of this present study.

The uppermost phase in both the Flockton Succession and the Hopkins' Band consists of sparsely scattered Naiadites in a pale grey mudstone.

Thus in both sequence and faunal content the faunal phases of the Hopkins' Band and the Flockton succession are very similar the differences would appear to be due to a different emphasis in the two studies. Dr. Eagar is more concerned with the sequence of the non-marine lamellibranchs, while this great study emphasises the changes in the micro-fauna.

Changes in the Faunal Phases of the Hopkins' Band.

While most of all of the Hopkins' Band Faunal phases can be recognised at many localities in Northumberland and Durham, the thickness of the various phases and degree of development varies considerably as illustrated in Fig. 5.2 - 5.8.

At the type of locality, Bearpark, Fig. 5.2, all six phases are well developed and show a "typical" thickness, phase 1 - 2½ inches, phase 2 - 1½ inches, phase 3 - ½ inch, phase 4 - 6 inches, phase 5 - 18 inches and phase 6 - more than 6 inches. The only unusual features at this locality are the very short vertical range of Geisina arcuata, C.humilis and the presence of cordaitid plant remains in phases 1 - 3 .

Whitworth Opencast, Fig. 5.3, shows a distinct thickening of the basal two phases, phase 1 - 6 inches, and phase 2 - 4 inches where compared with Bearpark, but a thinning of the Geisina Phase 3 to 1/4 inches. This thickening is due to the thickening of the mudstone conglomerate and black shale lithologies to the south of Durham as described in Chapter I. Phase 6 cannot be distinguished as small Anthracosia sp., largely "Carbonicola" carissima, survive with Naiadites and plants to the top of the faunal succession. Phases 4 and 5 are similar in thickness to Bearpark 4½ inches and 16 inches respectively.

Phases 1 and 2 cannot be distinguished at East Holywell, locality (3), Fig. 5.4, due to the early appearance of Geisina and Naiadites and the range of fish remains from phase 1 to phase 3. Phase 3 - 1 inch thick is thicker here than to the south but phase 4 is of similar thickness to Bearpark, 6 inches. Phase 5 is probably not completely sampled and so phase 6 has not been recognised either.

To the north of East Holywell at locality (2), near Bates, Blyth (Fig. 5.5), phase 1 - 3 are normal despite a slight ecological change (Chapter I). Phase 3 thickens slightly to 1½ inches due to presence of more shale laminae between layers of ostracod - Naiadites coquina. Although the thickness of phase 4 has not been determined here there is the marked faunal change as Anthraconaia replaces Carbonicola in this phase. Phase 5 is represented by a thin band with Carbonita, Naiadites and Anthracosia about 2 foot 6 inches above the Beaumont Seam.

The faunal succession of the Hopkins' Band in the east of Durham Coalfield is illustrated from locality (14) Silksworth, Fig. 5.6. Here phase 1 and 2 cannot be readily distinguished but together are about 2 inches thick. Naiadites does not appear in this succession until the base of Phase 3. Phase 3 reaches its maximum thickness of 1½ inches in this locality but the ostracod Geisina arcuata also appears sparsely in Phases 4 and 5 . An ostracod-mussel band ½ inch in thickness appears here in Phase 5 about 12 inches above the seam. Phases 4 and 5 appear to be of normal thickness, 5 inches and 9 inches respectively, but there is an anomalous appearance of Curvirimula recorded in these phases. The vertical persistence of Naiadites more than 1 foot 6 inches above the coal indicates the presence of Phase 6 .

At other localities in North east Durham, where the Hopkins' Band has been sampled, Pelton (5), Follonsby (4), Washington (12), Hylton (13), Eppleton (19) and Ryhope (15) the lithological and faunal successions are similar to Bearpark and Silksworth. An ostracod-mussel band with G.arcuata, Carbonita, Naiadites and Anthracosia,presumably in Phase 5 has been recorded from the four localities, Follonsby, Washington, Hylton and Harton (24).

The most distinct and persistent Phase of the Hopkins Band throughout Northumberland and Durham is Phase 3, the "Geisina Phase or Band". This shows certain regional thickness changes. In south Durham it is generally thin, 1/4 inch in at Whitworth Opencast, and ½ inch at localities (6), (8), (18), (19), (20) and (21). The thickness in north-east Durham is greater than 1½ inches at localites (4), (12), (13) and (14) while there is some suggestion of thinning to the east, ½ inch being recorded at Harton (24) and 1 inch at Ryhope (15), but generally to the north this phase is between 1 and 1½ inches in thickness as at localities (3) and (2). These thickness changes are related to changes of ecology in the environment of deposition (Section C).

The changes in lithology and ecology at the level of the Hopkins' Band in North west Durham, already referred to in previous chapters, are seen in the faunal phases. The fossils at Lanchester (17) (Fig. 5.7), about 4 miles north west of Bearpark, lack the distinct phase succession of the Hopkins' Band. A fauna of ostracods and Naiadites, occurring in a black shaley seat earth about 9 - 12 inches above the Harvey Seam, may be equivalent to phases 2 or 3 at Bearpark but correlation is uncertain. In seven inches of mudstone between 1 foot 7 inches and 2 foot 2 inches, above the seam, there is a scattered fauna of Naiadites, Anthracosia and Carbonita but no Carbonicola, so that this may be equivalent to phase 5 of the normal succession. It appears from a comparison of Figs. 5.2 and 5.7, that north west of Bearpark, phases 1 and 2 are replaced by a thick seat earth and phase 4 by a plant rich silty shale. No fauna apart from plants has been recorded from localities (11), Tanfield Lea and (16) Leadgate, and the succession here seems to indicate a further thickneing of the plant bearing silts and silty shales that are seen at Lanchester (Figs. 5.7). The only features reminiscent of the Hopkins' Band in these localities are the change of colour of the strata vertically, black to pale grey, and the presence of ironstone bands (Fig. 1.6 and 1.7).

The faunal succession in the cannel coal and associated strata of north-west Durham is shown here at Hedley Park (9), Fig. 5.8. Here again distinct faunal phases are not apparent but a well preserved fauna is present at three levels. Between 6 - 9 inches, above the main bituminous coal of the Townley Seam, scattered Naiadites fragments occur in the cannel shale, but in the overlying 3 inch band of black highly carbonaceous shale, Carbonita, Geisina, Naiadites and Carbonicola occur. This faunal assemblage can be likened to a mixture of phases 4 and 5 of the Hopkins' Band but it more truly represents phase (3) of Eagar, (1961) from above the Flockton Coals of Yorkshire. The association here of Geisina and Carbonicola, not seen in the Hopkins' Band, would seem to be due to the extremely carbonaceous, but silt free, nature of the enclosing sediment.

The faunal horizon between 1 foot 9 inches and 2 foot 0 inches above the Townley Seam, consists of a fish band and black band ironstone. The fauna in the black band ironstone is similar to that at the lower level except that Anthracosia occurs rarely. In the dark grey shale above the upper cannel coal, 2 foot 6 inches - 2 foot 8 inches above the seam, scattered Naiadites, Anthracosia and plants occur, similar to phase 5 of the Hopkins' Band. An equivalent faunal horizon with scattered mussels in a dark gray siliceous shale or mudstone, if found overlying the thin cannel coal at bolt chopwell (10) and Blaydon Burn (25). Above this faunal horizon the strata changes to laminated plant bearing siltstones, at Hedley, Chopwell and Blaydon Burn.

The distinct faunal phases of the Hopkins' Band are thus only developed in the central and north-eastern area of the Northumberland and Durham coalfield, as indicated in terms of lithologies on Fig. 1.8. In equivalent strata to the west and north west however, isolated faunal assemblages occur that resemble at least some of these faunal phases.

2. Faunal phases of the Three Quarter Seam Ostracod-Mussel Band.

Although this ostracod-mussel band has been studied in three boreholes, as mentioned in Chapter I, only the faunal plases of the borehole core, Fishburn (7), are illustrated here in Fig. 5.9. The lithologies of this Band are very similar to those of the Hopkins Band so similar lettering is used in their representation (Fig. 5.2 and 5.9). Lithology C - the distinct "Geisina Band" of the Hopkins' Band however has no counterpart in the Three Quarter Band.

The method of description of this Band is similar to that used previously for the Hopkins' Band.

a) Vertical ranges and faunal associations of genera and species.

The faunal information from this Band has been obtained from all three of the borehole cores studied.

1) Carbonita pungens. This species has a very long vertical range being one of the first to appear at the base of the Band and it is only survived by Carbonicola.

The vertical range from 10 - 27 inches is much greater than in the Hopkins' Band, but the lithological range and faunal associates are similar. C.pungens occurs in all lithologies A, B, D and E and is most commonly associated with Carbonita humilis, Curvirimula and fish remains. The maximum density of this species, as in the Hopkins' Band occurs in the carbonaceous shale, lithology B.

ii) Carbonita cf. evelinae and rankiniana. The ranges, lithological and faunal associations, of these species are similar to those of the other species of Carbonita. The overall range is 5 - 16 inches and the maximum density is in the carbonaceous shale B.

iii) Carbonita humilis. Despite the similar range of this species 10 - 24 inches to that of C.pungens the maximum density occurs in lithology D rather than lithology B. The lithological range is slightly shorter than C.pungens, lithologies B, D and E as it does not appear at the actual base of the Band, lithology A.

iv) Geisina arcuata. As in the Hopkins' Band this species has a more restricted vertical range than species of Carbonita. It occurs mainly in $4\frac{1}{2}$ - 6 inches of strata of lithology B but its density here is not comparable with that in the Hopkins' Band. Fig. 5.9 shows that the range can be much greater as here it is $15\frac{1}{2}$ inches, but specimens in lithologies D and E are rare. Within the carbonaceous shales this ostracod is associated with Carbonita, Curvirimula and fish remains.

v) Microconchus (Spirorbis). This worm is not very common in this Band. It has a vertical range of up to 14 inches in Borehole Fishburn (6) and although it occurs in lithologies B, D and E, it is commonest in lithology B where it is associated with plant fragments. None of the Curvirimula fragments in this Band bear evidence of attached spirorbis so that it appears that the worms were only attached to plants. Trueman (1942) does not record attachment of spirorbis to Curvirimula (Anthraconauta minima group) although attachment to Anthraconauta s.s.

in the Upper Westphalian is very common. Probably the Curvirimula shells were too small and thin to form a suitable substrata for Microconchus.

vi) Curvirimula. This is the commonest lamellibranch in this Band and in terms of its range and associations it seems to occupy a position in the fauna comparable to Naiadites in the Hopkins' Band. The vertical range is up to 22 inches, within lithologies B, D and E . The maximum density occurs in lithologies B and D where the associates are ostracods and fish remains. In all three borehole cores of this Band there is a distinct antipathetic relationship of this genus with Carbonicola, Fig. 5.9

vii) Carbonicola. This genus has a short range at the top of the faunal sequence of this Band. A vertical range of up to 7 inches is recorded but always in lithology E, the genus dying out at the base of lithology F, the siliceous mudstone. A few scattered specimens of Carbonita may occur in association with Carbonicola but it shows a distinct antipathetic relationship with the commonest fossils of the Band, Curvirimula and fish remains.

viii) Fish. These remains are much commoner and of wider vertical range in this Band than in the Hopkins' Band. The densest fish remains are in lithology B, although the wide vertical range of up to 26 inches includes all lithologies A, B, D and E . As in the Hopkins'Band and the commonest associates are ostracods and Curvirimula.

ix). Plants. Unlike the Hopkins' Band macroscopic plant remains are very rare in the Three Quarter Band despite the richly carbonaceous shales of lithology B. Very scattered remains of both Lepidodendron and Calamites types have been recognised however in lithology B.

Comparison of Faunal features of Three Quarter and Hopkins' Bands.

The ostracod faunas of these two bands are extremely similar but there are distinct differences in the non-marine lamellibranch faunas. The genera Naiadites, Anthraconaia and Anthracosia are all absent from the Three Quarter Band although well represented in the Hopkins Band. The genus Curvirimula that is rare in the Basal part of the Hopkins' Band is the dominant mussel in the Three Quarter Band and it occupies a long ranging position here, similar to Naiadites in the Hopkins' Band.

The Three Quarter Band is slightly thicker than the Hopkins' Band, and so ostracods of the genus Carbonita have a larger vertical range but show similar faunal association. The ostracod Geisina arcuata has a fairly short range and is restricted to the more richly carbonaceous shales in both the ostracod-mussel bands.

There is a larger vertical range of fish remains in the Three Quarter Band but the associated fossils are similar to those in the Hopkins' Band. The relative scarcity of spirorbid worms in the Three Quarter Band is due to the restriction of its hosts to the sparsely scattered plant remains. The non-marine lamellibranch Carbonicola occurs in similar lithology to two bands, but in the Three Quarter Band it has a more restricted vertical range and fewer associated fossils than in Phase 4 of the Hopkins Band.

These distinct faunal differences between the two ostracod-mussel bands are due more to their occurrence at different levels in the Lower Coal Measures than to differences of ecology.

b) Detailed Faunal Phases.

Three distinct faunal phases, as in Fig. 5.9, can be recognised in each of the Three Quarter Band borehole cores.

	Faunal phases	Lithologies
3	Carbonicola common, Carbonita rare	Grey mudstone
2	Carbonita and Curvirimula common Geisina and fish remains rare	Grey mudstone with ironstone bands
1	Carbonita and Curvirimula abundant, Geisina and fish remains common	Grey shale, black shale and mudstone conglomerate.

Phases 1 and 2 in this Band are not distinguished by different faunal compositions but by a marked difference of faunal density. Carbonita and Curvirimula occur abundantly in Phase 1, but their density is distinctly reduced in Phase 2. Geisina, fish and plants occur commonly in Phase 1, Fig. 5.9, but only rarely in Phase 2. There is a marked faunal change between Phase 2 and Phase 3 as Curvirimula rapidly dies out and Carbonicola suddenly appears. Carbonita pungens and humilis occur rarely towards the base of Phase 3 but soon die out vertically.

The total thickness of the Three Quarter Band at Bowburn is only 15 inches compared with 25 inches at Fishburn (6) and 28 inches in Fishburn (7), but the three phases are well developed in all these bores.

Phase 1 at Bowburn is slightly thinner than in the Fishburn bores, 5½ inches as against 7 inches and 7½ inches. respectively, and the fauna occurs in just the one lithology of a dark grey shale and not in the three litholigies of Fig. 5.9. Geisina arcuata is restricted to Phase 1 in both, the Bowburn bore and Fishburn (6) but at Fishburn (7) it occurs rarely in Phase 2 as well. The fish remains occur densely in Phase 1 in all three bores, but are absent above this phase at Bowburn, althouth they occur sparsely at Phase 2 in both of the Fishburn bores.

The sparser fauna of Phase 2 occurs throughout 11 inches and 15 inches of pale grey mudstone in Fishburn (6) and (7) bores but in only 3½ inches of similar strata at Bowburn. It is possible that this marked difference in thickness may be due to incomplete recovery of the borehole core at this level. The fauna of Carbonita pungens, C.humilis and Curvirimula, however is very similar in all three of these boreholes.

The boundary between phases 2 and 3 is distinct in all these bores with the abrupt disappearance of Curvirimula and appearance of Carbonicola. Phase 3 is 6 inches thick at Bowburn, 7 inches at Fishburn (6), but only 4½ inches at Fishburn (7), Fig. 5.9. The top of this phase is indicated by Carbonicola dying out when the mudstone becomes siliceous, lithology F.

The three faunal phases of the Three Quarter Band do show some broad similarity with those of the Hopkins' Band. Phases 1 - 3 of this band have very similar ostracod faunas to Phases 1 - 3 of the Hopkins' Band although the mussels are very different. Phase 1 of the Hopkins' Band shows a very close similarity to Phases 1 and 2 of the Three Quarter Band in the association of Carbonita, Curvirimula and fish remains.

The sudden appearance of Carbonicola is similar in both bands, as is its association with Carbonita in Phase 4 of the Hopkins' Band and Phase 3 of the Three Quarter Band. In other features however these phases are not comparable.

Eagar (1961, p.146) records a succession of five faunal phases from a mussel band in the Lower Lenisulcata Zone of the Pennine Coalfields, that shows close similarity with that of the Three Quarter Band.

	Faunas	Lithologies
(4)	Shells with outlines of Carbonicola and occasionally of Anthraconaia . H/L ratio high, tending to increase upwards	macroscopic pyrite at top. Relatively coarse grained mudstones, often richly ferruginous tending to increase in grain size upwards.
(3)	Elongate Carbonicola like forms.	
(2)	Shells with outlines of Anthraconaia and Carbonicola, Anthraconaia greatly predominating. H/L ratio low.	Relatively fine grained mudstone and shale, very rich in carbonaceous matter.
(1)	Curvirimula (C."minima-subovata" group) and occasionally Geisina sp.	
(o)	Fish shales abundant.	
Base:	Lingula.	Macroscopic pyrite at base.

Phases (0) - (2) of Eagar are similar to Phases 1 - 3 of the Three Quarter Band. As in the Three Quarter Band, Naiadites is not recorded by Eagar from the Lenisulcata Zone, and the species of Curvirimula, "minima-subovata" group is similar to that recorded from the Three Quarter Band (Chapter 2).

The "Anthraconaia like" mussels in Phase (2) of Eagar are not represented in the Three Quarter Band but in both bands the earliest Carbonicolas have a low H/L ratio. The species of Carbonicola declevis, acuta, and cristi-galli all recorded from Phase 3 of the Three Quarter Band are forms with a low H/L ratio. The mussel forms in Phases (3) and (4) of Eagar are not represented in the Three Quarter Band.

Ostracods of the genus Carbonita are not recorded by Eagar but as in the case of his studies in the Modiolaris Zone mentioned previously they may be present in the microfauna, but have not been thoroughly studied.

The overall difference between the faunal phases of these ostracod mussel bands, Hopkins' Band, Modiolaris Zone, Three Quarter Band, Upper Communis Zone and Soft Bed-Bassey Mine succession of Eagar from the Lower Lenisulcata Zone, appear to be due more to the different mussel faunas than to differences in the ostracod populations. The common feature in all these Bands is the dominance of the lower phases by a fauna of Carbonita, Geisina and thin shelled lamellibranchs, contained in a lithology of dark carbonaceous shale.

Conclusions on Faunal Phases.

The causes of the distinct succession of faunal phases in these ostracod mussel bands would seem to be changes in the fossil environment. These changes may take place due to either biological or sedimentological causes and can only really be understood when something is known about the palaeoecology of these environments. The succeeding chapters attempt to study the detailed palaeoecology of the Hopkins' Band, by all available lines of evidence, and from this to elucidate some of the causes of faunal phases within the ostracod-mussel bands.

SECTION B

"The Evidence for the Palaeoecology of the Hopkins' Band".

CHAPTER VI

PETROLOGICAL EVIDENCE

There is very little published work on the petrology of British Coal Measure sediments. Dunham (in Edwards and Stubblefield, 1947) has described briefly the petrology of the various sediments of the cyclotherms containing the Mansfield and Edmondia Marine Bands in Nottinghamshire. Apart from this most petrological description has been confined to detailed coal petrology (Raistrick and Marshall, 1939, p.178) or the structure of sandstone (e.g. Heard, 1922, Pennant sandstone of South Wales). The work of Eagar (1947, 1952b and 1953) and more recently Broadhurst (1959), on the palaeoecology of mussel bands in the Pennine Coalfields, has contained some descriptive petrology. However, the Pennsylvanian sediments of the United States have been fairly well described (e.g. Potter and Glass, 1958) and, although they differ slightly in type and environment of deposition from those of the Coal Measures, they furnish some comparison.

Petrological work in the Northumberland and Durham Coal Measures is limited to one paper by Kellet (1927) on the heavy minerals, and an unpublished thesis by Jones (1955), on the sandstones of south east Northumberland.

Most of the sediments that have been examined in this present investigation are fine grained and of clay or silt grades, and thus their very nature makes petrographic work rather difficult. Such rocks are very friable or fissile and so special techniques of cutting and impregnation have had to be used in the preparation of thin sections, as described in Appendix I. The richly carbonaceous nature of many of the shales, masks the presence of such minerals as pyrite and clay minerals, and the fine grain size and frequent loss of quartz during grinding, makes micrometric measurements of the detrital constituents difficult. However, 70 thin sections have been prepared and examined from the rocks of the Hopkins' Band and these are described briefly in Appendix III. Particular attention has been given in this examination to such features as; texture, grain size and shape, nature of the matrix and the detrital minerals, evidence of mineral alteration and replacement and the preservation and orientation of fossil remains. These features have provided evidence for the palaeoecology of the Hopkins' Band.

1. The Sediments of the Hopkins Band.

The various lithologies of the sediments associated with the Hopkins' Band have already been described in Chapter I and these lithologies indexed A - G and related to faunal phases in Chapter V. Detailed petrographic examination of these rocks supports the distinction of the various lithological types.

Five feet of sediments at the "type locality" at Bearpark have been examined by two adjacent vertical series of samples, 25 in one and 15 in the other, and the petrological descriptions that follow are largely these sediments, but amplified by examination of a further 26 thin sections from six other localities within the coalfield.

i) <u>Mudstone conglomerate</u>. The rock type was first recorded by Armstrong and Price (1953, p.886) as "a pseudobrecciated ankeritic siltstone" above the Harvey Seam in a borehole at Spanish Battery, Tynemouth. In this study it has been found immediately above the Harvey Seam and underlying the Hopkins' Band throughout the coalfield. It varies in thickness from $\frac{1}{2}$ inch at East Holywell (3) to 6 inches at Hylton (13) and Tuersdale (21), but usually it is between 2-4 inches thick. There is a lateral variation in the carbonate content.

At Bearpark this lithology is 2 inches thick and the detailed petrology has been examined and can be seen in slides 921, 800, 801, and 802 (Appendix III). The lowest inch contains lenticular fragments of pre-existing mudstone in a pale coarse clay mineral cement (Plate, XI), Fig. 1. In the upper inch the included lithic fragments are smaller, up to 0.3 mm., and consist of mudstone or carbonate rock, that are contained in a dark argillaceous matrix, rich in finely divided carbon, and with a carbonate cement (Plate XI, Fig, 2). Detrital grains of subangular and subrounded quartz make up about 5% of the rock, while flakes of detrital "book" kaolinite, and patches of spongy and framboidal pyrite also occur within the matrix. Fossil remains of ostracods, Naiadites and spirobids are confined to the more carbonaceous upper inch (Plate XI, Fig. 2).

The carbonate occurs in the fine argillaceous matrix of the upper inch and in cloudy or recrystalline rock fragments. It is shown to be ankerite on grounds of the x-ray and geochemical evidence presented in Appendix III.

This lithology is separated from the overlying black shale at Bearpark by a 1/4 inch band of coalfield plants (Slide 802).

The thicker development of this rock type at Whitworth Opencast, recorded in Chapter I and shown on Plate IX, f.1, contains larger lithic fragments, up to 1 cm. in length, exclusively of mudstone, no carbonate being present. The lower part of this lithology is leached (Plate IX) and the upper part as at Bearpark, is a black earthy mudstone overlain by a carbon parting with recognisable Lepidendron bark.

In the east of the Durham Coalfield at Eppleton (19) there are four inches of this conglomerate, and the included fragments are of a pale buff carbonate rock, approaching a pure "calcilulite", and rarely of a black shale. Although only 1 inch in thickness north-east of Bates, Blyth (2) the rock consists of fresh carbonate fragments as at Eppleton (19).

There are many features of similarity between this rock type and the Mansfield "cank" described by Durham (1947, p.251). Both have the same detritals, pyrite, abundant carbon, a little collophane phosphate and dense ankerite cement. Like the upper part of the mudstone conglomerate, the Mansfield "cank" has no visible macroscopic bedding and has a wide lateral persistence. The "cank" however lies well within the apparently marine sequence of the Mansfield Marine Band and is overlain by a shale with Lingula. The presence of this lithology at the base of a succession is also similar to the presence of carbonate rich siltstones at the base of many Pennsylvanian cycles (Payton and Thomas 1959).

Despite these apparent similarities it is difficult to be certain of any environmental significance in the presence of the ankeritic conglomerate at this level as much of the crystalline ankerite is either in derived fragments or secondarily recrystalline. However the restriction of the rare fragments of the lamellibranch Curviriumla to this level (Chapter V) might indicate more Marine conditions (Weir 1960) as will be discussed in Chapter VIII. Perhaps the conditions immediately following the inundation of the coal seam, may have approached those at the beginning of a marine incursion, i.e. the base of a marine band, but they did not persist vertically.

ii) Black shale. Throughout the coalfield the lowest division of the Hopkins' Band, namely the "Geisina Band", is underlain by a rich carbonaceous shale with scattered ostracods, plants, Naiadites and Spirorbids. It has been examined in slides 803-805, 171, 172, and 181 from Bearpark, 703, 704 from Whitworth Opencast and 731 and 732 from Bates, Blyth. This shale is 2 inches thick at Bearpark but is thicker to the south reaching a maximum of 4½ inches at Whitworth (7) and Ferryhill (8).

The shale has a fine "cryptophyllite" texture (Durham 1952), parallel arrangement of clay minerals, and small micaceous "illite" flakes. The carbonaceous matter occurs as fine carbon streaks, parallel to the bedding, and near the base there is some indication of carbon lamination but this is usually obscured because of the blackness of the shale. Quartz occurs in detrital grains of two types. Small subangular grains predominate, with a mean gain size of 30 - 40 microns, and a maximum of about 75 microns, and may form up to about 6 % of the rock. Larger subrounded, eroded and cracked quartz grains also occur generally greater than 100 microns in size.

Detrital Kaolinite occurs in the form of "lozenge" crystals, flakes of "book" Kaolinite with rounded ends, usually greater than 100 microns in length and orientated parallel to the bedding.

No pyrite has been seen in this shale but its presence is masked by the dense carbon. Sections of Naiadites shells, ostracod carapaces and spirorbid tubes in many orientations have been seen in slides of this shale.

There is an indication of a slight change in depositional conditions at the top of this shale, as cross laminations can be seen in hand specimens, and the slides (990) show an increase in the amount of detrital Kaolinite and up to 10% of detrital quartz is recorded.

In the north east of the coalfield, at Bates, Blyth, there is a pronounced increase in the detrital constituents of this shale, 12% of detrital quartz being recorded. (Plate XII, Fig. 1).

The association of dense carbonaceous matter and detrital quartz makes this rock very similar to the type described by Eagar (1961, p.139), Band III, from above the Flockton Coals of Yorkshire.

iii) Geisina Band. This band is characterised by a dense ostracod-*Spirorbis*-*Naiadites* coquina, with discontinuous shale laminae, as shown in Plate XIII, Fig. 1). It varies in thickness from ½ - 1½ inches as reviewed in Chapter V for the "Geisina Phase".

The lowest shell lamina frequently has a flat base at the top of the underlying black shale, but the top of the Band is often undulating and overlain by grey laminated shale.

The lower shale laminae in this Band are very similar in composition to the Black shale below, but in the higher part of the Band the laminae are of a pale grey shale similar to the succeeding grey shaly mudstone. The shell laminae are a dense shell coquina with included detrital minerals and carbon but no clay minerals (Plate XIII, Fig. 1,2.). In the lower part of the Band the shell laminae consist mainly of crushed and separated *Geisina* values and fragmented *Naiadites* shells, but higher up the laminae are of a purer ostracod-spirorbis coquina, with a higher proportion of uncrushed and complete ostracod carapaces (Plate XIII, Figs. 1 & 2). Ostracod remains may also occur either grouped into distinct pockets near the top of the black shale, underlying the Band, or as at Eppleton (19), Slide 725 (Plate XII, Fig. 2) be grouped into lenticular shaped pockets within the band itself. Pyrite is occasionally present in the shell laminae, but is associated with the plants and not the ostracods, and is commonest near the top of the Band.

Table 6.1 shows a comparison of the grain sizes and volume % of quartz within the Geisina Band at five localities in the Northumberland and Durham Coalfield, and from the similar lithology at Broughton Moor, Cumberland.

TABLE 6.1

Petrographic details of the Geisina Band

Locality	Quartz Grain Size			Volume % Quartz
	Mean	Max.	Large eroded grains	
Bearpark	30-40 mic.	75 mic.	125 mic.	5, 7 & 10
Eppleton	35 mic.	55 mic.	-	3
Follonsby	30 mic.	65 mic.	108 mic.	7
Whitworth	c.48 mic.	98 mic.	132 mic.	6
Bates, Blyth	c.45 mic.	105 mic.	153 mic.	13
Cumberland	32 mic.	55 mic.	125 mic.	2

The mean volume percentage of quartz for the Band in Northumberland and Durham is about 7% and is thus very close to that of the black shale below. This similarlty of quartz percentage may indicate that the fossil remains of the Band replace the clay minerals of the shale below but not the detrital constituents. The increase in the volume percentage of quartz to the north east of Blyth is seen in the Geisina Band as in the black shale below. The increase on both mean and maximum grain size of quartz towards Blyth and Whitworth may indicate an approach towards the respective sediment sources in these directions, but at Whitworth there does not appear to be an increase in the percentage of quartz. The Geisina rich shales from Cumberland are generally very similar to the Geisina Band of Durham.

The mean grain size of quartz is very similar to that in the Durham Band, but the maximum grain size and volume percentage are distinctly lower. The larger eroded grains are present in both Bands although the Cumberland shale is less carbonaceous and contains well crystalling collophane that is not present in Durham.

iv) Grey shaley mudstone. The Geisina Band is overlain by two inches of Grey finely laminated mudstone that passes vertically into grey mudstone with ironstone bands and nodules. This succession of mudstone, lithologies D and E of Chapter V, has been examined petrographically in slides 807-812, 19 , 192 and 201, from Bearpark, slide 705 from Whitworth, 720 from Eppleton and 734 from Bates, Blyth.

The basal two inches of this mudstone consists of a pure clay mineral rock of grain size about 5 microns, with less than 1% of detrital quartz grains of the types seen in the underlying sediments (Plate XIV, Fig. 1.). Very rare detrital Kaolinite about 100 microns in length also occur but there is no coarse detrital carbonaceous matter. The clay mineral matrix has a poor "cryptophyllite" texture, appearing to be largely homogeneous, but the orientation of the constituent minerals is disturbed around fossil remains (Plate XIV, Fig. 1). There is a distinct colour lamination visible in the band specimens of this mudstone, with darker laminae up to 2 mm. in thickness indicating the presence of finely divided carbonaceous matter of clay mineral grain size. (Plate XIV, Fig. 2.). Pyrite is present as scattered granules or rare fromboidal masses up to 30 microns in diameter. The fossil remains include scattered ostracod and spirorbis shells (Plate XIV, Fig. 1 & 2), preserved in calcite, and mussel shells that are replaced by Kaolinite.

Following the appearance of the lowest ironstone the colour laminae in this mudstone fade, detrital quartz and Kaolinite disappear completely, and plants and mussel shells are replaced by pyrite. The ironstone appears to form by replacement of the clay minerals in the matrix bu a dense mass of sphaerosiderite granules. Framboidal pyrite occurs as rare masses in this mudstone but more usually the pyrite forms the core of a siderite module.

Examination of the slides from Whitworth, Eppleton and Bates, Blyth, suggest that there is very little lateral variation in lithology of this mudstone.

It is noteworthy that, Band II of Eagar (1961, p.139), and the quieter phase of the Puchella Band of Broadhurst (1959) closely approach this lithology in the absence of detrital minerals in a homogeneous pale mudstone.

This succession of mudstone with ironstone bands gradually passes vertically into the next distinct lithology, the grey siliceous mudstone.

v) Grey Siliceous mudstone.

About 1 ft. above the Harvey Seam at Bearpark (slides 813-818) the grey mudstone develops a coarse textured appearance, a subchonchoidal fracture, and a slightly soapy feel. Although this lithological change is gradual the resulting rock type has a characteristic "flinty" fracture and so has been termed "siliceous mudstone".

The clay minerals matrix of this rock is coarser than that of the rocks below, the constituent grains being between 10-15 microns, long. The distinctly micaceous grains have only a very faint parallelism (Plate XV, Fig. 1). There is no coarse detrital quartz but fine quartz present in the matrix with a grain size of about 10 - 20 microns (Plate XV, Fig. 2). Ironstone bands continue to be common, and there may be associated framboidal pyrite masses 50 - 100 microns in diameter. Fossils are rare and scattered, solely Naiadites and plants, and both are frequently pyritized. The Naiadites shells often have attached or associated, large subangular or subrounded quartz grains and very rarely "book" Kaolinite.

There is a slight coarsening of the clay mineral matrix and the reappearance of scattered detrital quartz grains about 2 ft. above the Harvey Seam. Rare patches of collophane phosphate have also been seen at this level.

As with the mudstone below, slides from Whitworth (704) and Follonsby (728) indicate very little laterally variation.

This rock type is very similar to that described by Eagar and Rayner (1952) as "pale grey slightly soapy mudstone" and containing a sparse fauna of Naiadites, from the lower Similis-pulchra zone of Yorkshire.

vi) Laminated silty mudstone and siltstone. These lithologies occur at Bearpark from 2 ft 3 in to 5 ft above the Harvey Seam and have been examined in slides 819-821. Although the lithologies grade up from the siliceous mudstone below they can be recognized even in the hand specimen by the visibly coarser texture, the sparkle of quartz grains, and the distinct thin discontinuous laminae of silt that thicken and coarsen upwards.

The silty mudstone has a coarse clay mineral matrix of flakes 15-20 microns in length, distinctly random in orientation and containing scattered detrital quartz grains, subangular or subrounded, with a mean grain size less than 60 microns but a maximum up to 85 microns. At a height of about 2 ft. 7 in. above the Seam the detrital quartz makes up about 3% of the rock but the proportion probably increases upwards but could not be measured because of the laminated texture. (Plate XVI, Fig. 1). Finely divided pyrite and carbonaceous matter also occur in this rock.

The quartz or silt laminae are composed of equignanular quartz and muscovite. At about 2 ft. 6 in. above the seam these laminae are up to 0.4 mm. thick and 3 cm. in length but they thicken and coarsen upwards.

In the lower laminae the quartz grains are about 50-60 microns in size but coarsen to 80-90 microns at about 4 ft. 8 in. above the seam while the muscovite flakes increase in length from 85-100 microns over the same vertical interval. Some of the quartz grains in the laminae have an almost interstitial shape suggesting that there may have been recrystallization perhaps following pressure solution during compaction.

At about 3 ft above the seam macroscopic plant matter reappears and above this level the laminae thicken and some show a slight grading (Plate XVI, Fig. 1), with coarse quartz and muscovite at the base, and fine carbon and clay mineral material above. Some of the coarser sandstone laminae show fine cross bedding. (Plate XVI, Fig. 1).

In a coarse sandstone lamina 3 mm. thick, about 4 ft. 4 in. to 4 ft. 5 in. above the seam, the quartz now has a grain size of 120 microns, and occurs with abundant muscovite, and less abundant Biotite, both up to 180 microns in length. This sandstone lamina is overlain by a dense plant rich layer, where muscovite flakes reach 1.75 mm. in length.

The top of the siltstone succession is seen at Bearpark at a height of about 5 ft. above the seam (slide 824) where there is a disturbed sequence of siltstone with mudstone pellets and evidence of worm boring (Plate XVI, Fig. 2), disconformably overlain by an even bedded white sandstone with an obviously erosive base.

Throughout this three foot succession of silty mudstone and siltstone, pale discontinuous bands of ironstone are seen but these do not contain the same dense aggregation of siderite granules that occur in the finer grained mudstones below.

The slides from Follonsby (727), Bates, Blyth (735, 736) and Whitworth (711) indicate similar lithologies. At Bates, Blyth, however, the siltstone appears earlier, just 1 ft. above the seam, while at Whitworth Opencast there is a transition from siltstone to cross bedded sandstone at some 3 ft. 3 in. to 3 ft. 4 in. above the seam. The earlier occurrence of these lithologies, at these localities is indicative of more marginal conditions as suggested previously from the Geisina Band.

vii) Sandstone. This lithology, although widespread, has only been sampled in the 4 inch sandstone at Whitworth Opencast mentioned above (slide 710) Plate XVII, Fig. 1 and 2). This is a buff cross bedded quartz-mica sandstone (Plate XVII, Fig. 2) with cross bedding outlined by fragments of Cordaitid and Neuropterid plant matter and clay minerals (Plate XVII, Fig. 1). The maximum quartz grain size is about 173 microns. One significant fragment of well twined, plagioclase felspar of perhaps andesine-labradorite composition was seen. This sandstone suggests a short period of strong current action with a supply of coarse terrigenous sediment.

ix) Plant bearing siltstones and sandstones. These lithologies have been seen as Lanchester and Tanfield Lea, north west of Bearpark and have been examined because they represent lateral equivalents of some of the Hopkins' Band sediments, and thus illustrate lateral ecological changes.

At Lanchester (17), about 1 ft. 2 in. above the seam the dark plant bearing siltstone has been sampled, slides 942 and 943. This siltstone contains quartz grains up to 110 microns that form 15% of the rock, large fresh "book" Kaolinites up to 151 microns in length and muscovites up to 250 microns, in a disordered matrix of carbonaceous matter and coarse clay minerals. The presence of this characteristic association of "book" Kaolinites and carbon would suggest that this siltstone might be equivalent to the black shale at Bearpark, just five miles to the east-south-east. The Kaolinites seen at Bearpark are smaller and have rounded ends, thus suggesting that they have been carried further from the source than those at Lanchester.

The laminated siltstones and sandstones seen at Tanfield Lea (slides 960 and 961), cannot be so easily correlated with the lithologies of the "type section" at Bearpark but their strongly banded nature suggests lagoonal or lacustine deposition. It is possible that these sediments may be the lateral equivalent of much of the typical shale, mudstone and siltstone succession of the Hopkins' Band but nearer the source of the sediment and the periphery of the main "Hopkins'Band lagoon".

TABLE 6.2

TABLE OF PETROLOGICAL DETAILS FROM BEARPARK TYPE SECTION

Slide No.	Height above seam	Geochem. Sample	Quartz Grain Max.	Quartz Grain Mean	Quartz Grain Large	Vol.	Clay grain size	Pyrite	Siderite
824	4'11"-5'6"	V	58		80		5-10		
823	4' 4"-4'5"	U	80		125				
822	3' 4"-3'5"	T	40		70				
821	3' 0"-3'1½"	S	50		80				95mu.
820	2' 7"-2'8"	R	60	45	60	3	15-20		
819	2'2"-2'3"	Q	65		60		15-20		
818	1'11"-2'0"	P	32		50		10-15		
817	1' 4"-1'10"	O	46		86		c.10		
816	1' 6"-1'7"	O	10		50		10	0.55mu.	10-20mu.
815	1' 5"-1'6"	-	25		113		10	Gran.	
814	1' 3"-1'3½"	N	10				10	50mu.	
813	1' 2"-1'2½"	N	10				10	70mu.	
812	11 - 12"	L	20				10	Framb.	
811	9½ - 10"	K	5				5	Framb.	
810	8½ - 9½"	J&H	5(53)	24	65		5	100mu.Fram.	
809	7 - 7½"	J&H	5(19)				5	Gran.	7-20mu.
808	5 - 6"	G	5(77)	30	125		5		
									Kaolinite
807	4½ - 5"	F	86	30	140	0.5	5		67,204
806	4 - 4½"	E	62,75	30	125	7,10	5?		-
805	3 - 4 "	D	75	-		5	5?		112mu.
804	2¼ - 3 "	C	65	30		3.4	5?		100
803	2 - 2¼"	C	72	30	(113)	6	5?		105,140
802	1 - 2½"								
801	1 - 1½"	A2&B	96		103	4	5?		
800	½ - 1"	A2	78			6	5?		120mu.
(921)		A1	53					200mu.	Framb.

Gran. = granules.

Framb. = framboidal.

2. Features of palaeological significance in the sediments of the Hopkins' Band at the "type locality", Bearpark.

The major petrographic features of the sediments at Bearpark are summarised on Table 6.2. and related to X-ray mineralogical data on Fig. 6.1. Certain of these features are related to, or dependent on, the physical and chemical conditions of sedimentation and so such features are briefly reviewed below.

a) Sedimentary textures.

i) Mudstone "conglomerate". The important feature of this rock is whether the texture is "pseudobrecciated", as described by Armstrong and Price (1953), or truly "conglomeratic". Pseudobrecciation might have occurred in place by desiccation or some organic agency, for example rootlets. However, it is termed a conglomerate here as it contains primary lithic fragments of various sizes and degrees of roundness, that are believed to have been transported as fragments into the area of deposition. The irregular base to this lithology, as is shown on Plate IX, Fig. 2., and the variation in thickness throughout the Coalfield, further support the conglomerate like nature.

This lithology is believed to have been formed from lithic fragments that were carried into the area of deposition by rapid currents following the initial inundation of the coal seam or swamp. These fragments filled up pre-existing hollows in the swamp surface. The decrease in the fragmental nature of this lithology in the upper part would seem to indicate that conditions of sedimentation became increasingly quieter.

ii) "Cryptophyllite" texture. This texture, seen in the black shale and grey shaley mudstone, is due to a primary or secondary parallel orientation of the clay minerals. Dunham (1952) believed that this texture is often due to diagenic recrystallization of clay minerals under the load of the overlying sediment, but other workers, such as White (1961), suggest that it is due to orientation of the clay mineral flakes on deposition under non turbulent conditions.

The prominent fissility of the black shale is not solely due to "cryptophyllite" clay mineral texture, but partly due to the parallel orientation of the large detrital kaolinites, and the high content of organic carbon. Payton and Thomas (1959) have shown a direct relationship between fissility and organic carbon content in Pennsylvanian black shales.

iii) Colour lamination. This "varve" like appearance seen best in the lower part of the grey mudstones - is suggestive of quiet deposition in a lagoonal or lacustrine environment where there is a periodic, perhaps seasonal, variation in the supply of fine sediment.

Another possible explanation is that due to chemical inhibition the clay fraction is held in suspension while the finely divided carbon settles out.

iv) Quartz laminae and arenaceous bands. In the siltstones this texture is believed to be due to current action winnowing out the fine clay minerals and concentrating the detrital quartz and muscovite into pockets or restricted patches. The suspension of silt in such strongly turbulent conditions would suppress the benthonic fauna, thus explaining the absence of fossils from these sediments. Similar sedimentary textures have been described by Van Straaten (1954) from recent silts of the tidal flats of the Wadden Sea.

v) Disturbances by burrowing organisms. Disturbances of the lamination and bedding of the upper siltstones by burrowing organisms have been seen at two levels shown on Plate XVI, Fig. 1. and 2. The lower example, (Plate XVI, Fig. 1.) is 3 ft. above the Harvey Seam and the wide burrow with its abrupt lower end, might suggest that it was caused by a mullusc rather than a worm. The upper burrow (Plate XVI, Fig. 2) is at the top of the siltstones, about 5 ft. above the seam. It is a curved burrow which descends from a thick siltstone band through at least the one inch of the underlying shale and siltstone. No bedding is preserved in the burrow which is rich in subangular quartz and it was probably caused by a worm. The presence of these burrows in the siltstones suggests shallow water conditions with intermittent periods when a slower sedimentation permitted a sparse benthonic fauna to flourish.

kaolinite is the diminant clay mineral in the fluviatile environment and is most common in continental or near shore sediments. The association of this detrital kaolinite with abundant drifted plant matter might suggest that it is derived from the contemporaneous erosion of the soil of a swamp, of seat earth type, as kaolinite is the dominant clay mineralin these soils (Schultz 1958).

Fine "illite" mica is a major constituent of clay mineral matrix of the black shale and has a distinct "cryptophyllite" orientation. The abundant fresh muscovite and more rarely biotite that is associated with quartz in the upper siltstones, indicates a different source for these sediments than for the lower black shale.

iii) Carbonaceous matter. According to Broadhurst (1959) and Eagar (1961) both autochonous and allochthonous carbon are common in Coal Measure sediments. Both these types were described from the sediments of the Hopkins'Band in Chapter IV. The presence of these two different type of carbonaceous remains is further exidence in favour of different source areas for the black shale and siltstones, mentioned above.

c) Matrix constituents.

i) Clay mineral grain size and orientation. The grain size of the clay mineral matrix is about 5 microns throughout the black shale and grey mudstone, Table 6.2. White (1961) suggests that the characters of these rocks, parallel mineral orientation, lamination, and resistance to disintegration in water, are indicative of formation by slow sedimentation. The coarsening of the grain size to 10-20 microns above 1 ft. 9 in., Fig. 6.1. and Table 6.2., indicates an increased supply of coarser sediment. The clay minerals in the siliceous mudstone and siltstone were probably deposited in the flocculated state under turbulent conditions, as the rocks possess the typical characters of random mineral orientation, no lamination, and friability, described by White.

ii) Presence of ankerite. The presence of this mineral is not diagnostic of any particular environmental conditions at the time of deposition of the sediments, as much of it could be of secondary origin or have recrystallized under favourable physico-chemical conditions during diagenesis.

iii) Pyrite and Siderite. Pyrite occurs in the black shale but only becomes preminent petrographically in the sediments from 8 in. to 2 ft. above the Seam. From about 9 in. to 1 ft. 7 in. this mineral replaces Naiadites shells. Only rarely does the pyrite occur as framboidal masses, Fig. 6.1., and it is usually in association with siderite, probably having a similar origin.

Siderite occurs in impersistent bands and nodules from $7\frac{1}{2}$ in. to 5 ft. above the Seam. The siderite granules generally replace the clay mineral texture, not disturb it, but frequent slickensiding around the nodules indicates that their formation was precompaction in date. The fact that the siderite persists vertically above the pyrite, Fig. 6.1., and occurs in the upper siltstones and sandstone, that were obviously deposited under turbulent oxidizing conditions, suggests that its formation was post depositional. Most probably it was formed in mildly reducing conditions in the sediments below the sediments water interface after deposition. Similar reducing conditions are described by Van Straaten (1954) in the silts of recent Dutch tidal flats. More detailed physico-chemical conditions of siderite formation are considered in Chapter VII.

d) Sediment - fossil relationships.

i) Bedding and compaction. The disturbance of clay mineral orientation by included fossils in the grey laminated shale suggests slow deposition of the clay around the fossils. Similarly the presence of Naiadites with both valves attached presdrved in ironstone in slide 815, Appendix III, indicates quiet conditions of sedimentation and pre-compaction formation of the ironstone. Further details of the orientation of fossils is discussed in Chapter VIII.

ii) Grouping and fragmentation of fossils. The concentration of the ostracod into distinct pockets at the base of the Geisina Band and fragmentation in the lower part of this Band, suggests the action of currents or turbulence in agreement with the evidence of the detrital minerals already presented.

iii) Replacement of shells. The fossils in the black shale are preserved in their original calcite, while mussels in the overlying grey shaley mudstone have their shells replaced by kaolinite or pyrite. This suggests distinctly different physico-chemical conditions in the environment at the respective times of deposition of the two sediments or else different courses of post depositional changes.

CHAPTER VII

THE GEOCHEMICAL EVIDENCE.

The sediments described in Chapter VI have been further studied by x-ray diffraction and geochemical techniques to confirm their mineralogical composition and to attempt to reconstruct the physico-chemical conditions at the time of their deposition. Twenty-five rock samples from the type locality at Bearpark have been powdered and analysed as described in Appendix I and the various analytical results are included in Appendix III.

Many American workers have used x-ray diffraction techniques in the study of Pennsylvanian sediments, for example Potter and Glass (1958) and Paynton and Thomas (1959), but such techniques have only been applied to Coal measure sediments to confirm the overall mineralogical composition (Broadhurst, 1959 and Nicholls and Loring, 1960). Greensmith (1958), published a preliminary account of a geochemical comparison of marine and non-marine sediments from the Coal Measures, but more recently there has been several other workers in Carboniferous sedimentary geochemistry. Degens, Williams and Keith (1957 and 1958) have demonstrated the use of trace elements as environmental indicators in Pennsylvanian shales and Loring (1958) has studied the geochemical variation in one Coal Measure cyclothem. Cation exchange has been used as an indicator of the rate of sedimentation by Nicholls and Loring (1960) and more recently (Nicholls and Loring, 1962) they have described the variation in Eh - pH conditions and the trace element content in the same cyclothem.

The work of VanAndel and Postma (1954) and Hirst (1958 and 1962) on recent deltaic and gulf sediments where environmental factors could be measured, gives a useful comparison with Coal Measures sediments.

1. X-ray diffraction.

Each rock sample, indexed A - V , has been examined as a normal powder mount in a Phillips X-ray defractometer using CuK radiation. A series of typical defractometer traces is shown in Fig. 7.1. and the nature and details of the minerals identified is given in Appendix III. As only qualitative or relative details of the mineralogy of these rocks was required in this study, the more refined techniques of treated or heated mounts were not attempted. Due to the even texture and depth of powder examined in these mounts the relative peak heights reflect the relative amounts of the various mineral species present. Figures 6.1 and 7.2 show the variation of these peak heights in the two series of samples measured.

The details of the various distinct mineral species identified are described below.

Clay minerals. Kaolinite and mixed layered Illite are the dominant clay minerals throughout the succession but a little Chlorite is detectable at certain levels. This clay mineral composition is similar to that of the shales and mudstones of the Similis-Pulchra Zone, described by Broadhurst (1959), and those of the upper Modiolaris Zone of Nicholls and Loring (1960). There is no apparent vertical change in the clay mineralogy of these sediments.

On both Figure 6.1. and Figure 7.2. the Kaolinite varies similarly to the Quartz at all levels, confirming that it is largely detrital in origin, as has been suggested from the petrography in Chapter VI.

The "Illite" (001) has a wide basal peak, Fig. 7.1., indicating that it has a mixed-lattice, but it has not been possible to distinguish the various Mica species. In the black shale and siltstone the "illite" peak generally follows the quartz and kaolinite (Fig. 7.2.) but in the grey shale and mudstone above the Geisina Band it naturally increases at the expense of the coarser detritals.

Chlorite was difficult to detect in the untreated samples that were used as the kaolinite (001) peak coincides with the major Chlorite (002) peak and so masks it, but the chlorite (001) peak at 14.3°A was seen weakly in the black shale and siltstone.

Quartz. This mineral occurred prominently in all samples. It correlated with kaolinite at all levels (Figs. 6.1. and 7.2.) and occurs at maximum with organic carbon in sample C (compare Fig. 6.1. with Fig. 7.3.). This correlation confirms the detrital nature of much of the carbon at this level. The maximum volume percentage of quartz, measured petrographically, and the greatest x-ray abundance, agree in the black shale immediately below the Geisina Band, as can be seen on Figure 7.2. All the variation of the height of the quartz x-ray peak is thus explicable as true variation in the quartz content of the sediment, rather than effects of differences in grain size or orientation.

Feldspar. A very weak peak on the charts of samples P to U indicates the presence of this mineral in the siltstones. The maximum height of this peak is in sample S, shown on Fig. 7.1., and this coincides with the maximum Sodium percentage in this sample, Fig. 7.3. The d- spacing of this feldspar, 3.20°A , further suggests that it is near Albite in composition and thus quite sodic.

Calcite. As might be expected from the fossil content this mineral is only present in any amount in the black shale and Geisina Band. There is a maximum calcite content in the Geisina Band and in the basal part of the black shale the calcite peak appears to be suppressed in the presence of Ankerite.

Ankerite. This carbonate is only present in samples A2 and B and its nature is discussed in Appendix III. The restricted occurrence of this mineral at the top of the mudstone conglomerate indicated by the petrography is thus confirmed by the x-ray evidence.

Pyrite. This mineral is only present in quantity in the black shale and Geisina Band. The greatest peak heights occur in samples C and E and thus correlate with the maximum sulphur percentages on the geochemical data chart in Appendix III.

Siderite. The first appearance of this mineral is about 6½ inches above the coal at Bearpark, sample J, but at higher levels it becomes a major rock forming mineral, i.e. from samples L to U . On figures 6.1. and 7.2. it shows a slight inverse correlation with quartz and clay minerals, but this is better seen chemically by comparing Figures 6.1. and 7.3.

Lateral Mineralogical variation.

Two samples of the Geisina Band, one from Washington (12) and the other from Pelton (5), have been x-rayed and compared with sample E from Bearpark, in order to detect any major mineralogical change laterally. The only difference was the presence of Ankerite at both these localities, presumably due to secondary replacement.

A sample of black shale with Lingula from the Harvey Marine Band at Hartoh Colliery (22), has also been X-rayed and compared with the Bearpark non-marine sediments. Despite the difference in fauna and presumed environment, the only mineralogical difference detected was a greater pyrite content in the Lingula shale. This is a similar finding to that of Nicholls and Loring (1962) from marine and non-marine shales above the mid-Modiolaris Marine Band in North Wales Coalfield.

2.Geochemical Analysis.

The powdered shale samples from Bearpark have been analysed chemically for certain elements and compounds that might be used as indicators of environment. The sodium - potassium ratio, as used by Nicholls and Loring (1960), may be indicative of the rate of sedimentation. Total iron, sulphur, carbonate and phosphate when considered together may suggest certain physico-chemical conditions of sedimentation (Krumbein and Garells 1952 and Nicholls and Loring 1962). The organic carbon content might suggest the availability of food for the animals in the environment, while the trace element Boron, has much been used as an indicator of palaeosalinity (Lindergren, 1945, and Eagar, 1961).

The absolute contents of these elements and compounds found in these sediments are given on the large table in Appendix III and the vertical variation is shown in Fig. 7.3.

Sodium and Potassium.

The sodium content of these sediments varies from 0.22% in sample A1 to 0.47% in sample S, while the potassium is at a minimum of 1.34% in the Geisina Band, E, and at a maximum of 2.64% in sample K of the grey mudstone. These two elements are sited either in detrital felspar or in Illite- muscovite clay minerals.

The increase in the content of both these elements in samples A1 to F is believed to be due to the gradual increase in the "illite" content of these sediments. There is a greater increase in the Potassium content due to a large percentage of fresh Hydromuscovite, that show optical properties similar to muscovite, compared with the low percentage of degraded illite that contains the Sodium. The low Potassium content of the Geisina Band, sample E, is due to the reduction in the proportion if clay minerals in this Band, Chapter VI.

The rapid increase in the Potassium content from 1.35% to 2.55% from samples E to F is due to the sudden increase in clay mineral content of the sediments with the reduction of the detrital constituents. Whilst the Sodium content is fairly constant from samples J to P, the Potassium shows an inverse correlation with the total Iron and carbon dioxide, as on Fig. 7.3. This inverse correlation indicates the reduction of the clay mineral content, and replacement by Siderite, in the ironstones.

The increase in Sodium from samples P to S is due to the presence of a little detrital sodium felspar, as confirmed by the X-ray evidence, Fig. 7.1. The truly detrital nature of this felspar is confirmed by the agreement of the increase of Sodium and detrital quartz and kaolinite, seen by comparing Figure 6.1. with Figure 7.3. The relatively constant Potassium content from sample P to sample U suggests that there is no detrital potassium felspar present and that the fresh muscovite in the siltstones replaces the clay minerals virtually volume for volume.

Sodium: Potassium ratio.

When very little detrital felspar is present in sediments, variation in the ratio of the alkali elements may be due to variation in degree of cation exchange in the degraded illites (Hurst, 1958 and Nicholls and Loring, 1960). This cation exchange is usually in the form of Na^+ being replaced by K^+ in the ratio 3:2 or vice-versa (Nicholls and Loring, 1960), so that the actual ratio of the elements from the Hopkins' Band sediments have been multiplied by a factor of 3/2 to give the values recorded here (Appendix III and Fig. 7.3). For these sediments this ratio varies between 0.16 to 0.36 and it is exactly similar to that recorded by Nicholls and Loring (1960) from the Bersham sediments.

The alkali contents of the sediments described previously do not show a very great enrichment in Sodium with respect to Potassium in the degraded illite as described from modern deltaic sediments by Hurst (1962), so that cation replacement of Na^+ by K^+ during sedimentation would not be expected to be very great. The initial increase from A1 to B in this ratio is due to the increase in the proportion of clay minerals in the sediment, while the slight fall B to D may indicate some cation exchange under slow conditions of sedimentation, but could be explained by the presence of a greater proportion of potassium rich clay minerals. The high value of 0.36 for the ratio in the Geisina Band, shown in Fig. 7.3., may reflect slight turbulence prohibiting cation exchange as well as the low proportion of clay minerals sediment.

The pronounced falling of this ratio from samples E to G suggests increased cation exchange during a period of slow sedimentation forming the laminated mudstones. The fluctuation in the ratio from samples G to P reflect the variation in amounts of ironstone and perhaps periods of intermittent turbulence or more rapid sedimentation. From samples P to S the ratio shows a prominent increase that is not necessarily due to decreased cation exchange but to the presence of detrital felspar. The rise in this ratio in sample S correlated with the rise in the detrital content and the organic Carbon and may therefore indicate increased current action and consequently a faster rate of sedimentation. The fall in the ratio from U to V reflects the decrease in the rate of sedimentation from a siltstone to a grey mudstone.

Thus while variations in the Aklali ratios of these sediments are not always attributable to cation exchange, the changes in the rate of sedimentation that have been deduced are in agreement with those deduced from petrographic evidence.

Total Iron.

Only the total iron content of these sediments has been found by analysis irrespective of whether the iron was originally present in the ferrous or ferric state. The content varies from 2.24% in sample F to 17.75% in sample T, and is largely contained in the minerals siderite, pyrite and chlorite, but with a small amount in the other clay minerals and ankerite.

The value of 2.7% in the mudstone conglomerate is believed to be contained in pyrite and clay minerals, while the 2% increase in sample B is due to the high iron content of the ankerite, thus correlating with the high CO_2 content. The iron content is fairly constant in the black shale and the slight rise in the Geisina Band is due to the higher pyrite content at this level.

The minimum iron content of 2.24% is sample F would seem to all be contained in the clay minerals as no pyrite or siderite is present here, Figs. 6.1 and 7.2. A content of 2% of iron in the clay minerals is high but not unusual (Hurst, 1958) if the sediment was deposited in an oxidizing environment, as is suggested here by the presence of a benthonic mussel fauna. The sudden rise of 6% from sample H to J is due to the appearance of siderite and on Figure 7.3. this rise can be seen to correlate with the high CO_2 content and fall in the K_2O of the clay minerals. In the ironstones, samples J, L, O, there is about 9-10% of iron showing a direct correlation with about 4-6% of CO_2, a ratio of approximately 2:1 as in siderite. The lower Fe_2O_3 content from samples O to S, about 6-8%, reflects the sparser formation of ironstone in the coarser grained rocks, due probably to the greater water circulation in these sediments after deposition and consequently a higher Eh value below the sediment water interface. In Figures 6.1 and 7.3. this lower iron content shows a distinct inverse correlation with the detritals. Sample T with the maximum iron content is a pure ironstone but the fall from sample U to V may have been due to aeration of the sediment by the sparse mussel fauna and benthonic worms.

Carbon dioxide.

This compound indicates the variation in the carbonate content of these sediments. In the lowest sediments, samples A2 to B, both ankerite and calcite are present, while in the black shale above the variation in CO_2 indicate variations in the fossil content. The ostracod coquina of the Geisina Band naturally gives the highest carbon dioxide value and the minimal values in samples F to H indicate that the fossils in these sediments are not preserved in calcite. All the variation in CO_2 from sample H to V is directly related to the iron content, Fig. 7.3., and thus indicates that all the carbonate is present as siderite.

Sulphur.

Due to analytical difficulties it was not possible to analyse all twenty-five samples for this element. Five samples, representing all the lithologies except the upper siltstones, have been analysed by the Coal Survey Laboratory, Newcastle, and the results are included on the table in Appendix III. The sulphur content of these samples varied from 0.10% in sample J to 0.96% in sample E and these various contents support the X-ray evidence for pyrite in these rocks. The highest sulphur in the black shale and the Geisina Band suggests association with organic carbon, although the sulphur content being in the Geisina Band may be due to association with decaying animal matter as well as plants. The X-ray data, however, Figs. 6.1. and 7.3. confirms a correlation of maximum pyrite and organic carbon in sample C. The low sulphur content in the lowest ironstone J suggests that there is little pyrite at this level or immediately below, but at higher levels, such as sample O, where pyrite replaces fossil shells, the sulphur content is higher, i.e. 0.22.%

Phosphorus.

This element occurs in both organic and inorganic phosphate. The organic phosphate consists of fish remains, calco-phosphate fossil shells and plants, while the inorganic phosphate may be precipitated chemically in the form of collophane or phosphorite, or detrital as apatite. The precipitation of sedimentary phosphate is dependent on Eh-pH conditions (Krumbein and Garrels, 1952).

The P_2O_5 content of these rocks varies from 0.074% in the grey mudstone to 0.36% in the mudstone conglomerate. The very high values 0.31-0.36% P_2O_5 in the mudstone conglomerate is due to the presence of fish remains, recorded in the Faunal Phase analysis Chapter V, and a little collophane, recorded in Chapter VI. In the black shale the lower phosphate content, 0.17 and 0.19%, is probably due to detrital apatite and scattered fish remains. On Fig. 7.3. the correlation of the higher phosphate content of the Geisina Band with the high CO_2 suggests the presence of organic phosphate associated with fossil remains. The collophane that is a prominent mineral in the Geisina rich shales of Cumberland, Chapter VI, has not been identified in the Geisina Band at Bearpark.

The variations in the phosphate content of the mudstones and siltstones do not correlate with either total iron and CO_2 i.e. siderite, or detrital content (compare Fig. 6.1, and 7.3.). This variation is due to variations in the amount of detrital apatite.

Correlation and interpretation of total iron, CO_2, sulphur and phosphate contents.

The presence of these elements and compounds is important as regards the formation of authigenic pyrite, siderite and phosphate, under particular Eh-pH conditions in the depositional environment (Krumbein and Garrels, 1952, Garrels, 1960, and Nicholls and Loring, 1962). Nicholls and Loring (1962) showed that existence of a zone of sulphide enrichment in the basal black shales of the Bersham cyclothem, and a siderite enrichment in the upper grey mudstones, that they believe indicated a rise in oxidation potential under conditions of fairly constant pH. They further suggest that siderite could not be formed at a pH below 6.7 under natural aqueous conditions, and that pyrite and siderite can co-exist at such a pH providing that the Eh is between -0.2 and -0.3 volts. These deductions were made by consideration of the stability diagram of Garrels (1960), reproduced here as Figure 7.4.

The association of primary calcite and authigenic pyrite, probably formed in the sediments immediately after deposition, in the mudstone conglomerate and black shale, suggests an Eh of about -0.3 volts and a pH between 7.0 and 8.0, position A on Fig. 7.4. Such an Eh-pH position, shown on the diagram of Krumbein and Garrels (1952), here reproduced as Figure 7.5., is below the sulphate-sulphide Eh "fence" and near the "limestone" pH "fence" and is characterised by the association of calcite, pyrite and organic matter. In the grey mudstone above the Geisina Band, where there is no pyrite or siderite, the physico-chemical conditions are believed to have changed by a rise in the oxidation potential, through the $FeCO_3$ field to position B on Fig. 7.4. There may have been a slight fall in pH at this level, indicated by the replacement of lamellibranch shells, but probably it was the major rise in the Eh that enabled the benthonic mussel fauna to become established.

The appearance of ironstone in the mudstones above sample J would suggest a fall in the Eh value to point C on Fig. 7.4., in the siderite field. There was probably no great change in the pH at this level. This fall in the Eh value may have occurred in the sediment below the sediment water interface after deposition (Chapter VI), and so such a change would have no great effect on the environment above. In some samples from Bearpark, sample Θ for instance, the association of pyrite and siderite would suggest that the Eh may have fallen even lower locally, to near the siderite-pyrite join on Fig. 7.4., position D.

A change in pH may be reflected by a change in the phosphate content (Krumbein and Garrels, 1952 and Nicholls and Loring, 1962). On Figure 7.5. precipitated Phosphorite is shown in association with siderite but a rise in pH at constant Eh would indicate a fall in the phosphate content (Nicholls and Loring, 1962). However, in these sediments no change in the phosphate content has been observed that is attributable to a change in pH.

The chemical and mineralogical evidence from these sediments indicates that the major change in the physico-chemical conditions in the environment of deposition was one of oxidation potential rather than pH, hydrogen ion concentration.

Organic carbon.

The content of this element varies between 0.25% and 8.4% and is indicative of the plant content of the sediment. This plant content is partly macroscopic as described in Chapter IV and partly microscopic, detrital in origin, of clay mineral grain size or contributed from algae or phytoplankton from the overlying water.

The maximum carbon content is immediately above the Harvey Seam in sample A1, and is largely autochthonous or derived from the very local erosion of the coal seam or swamp and thus correlates with the high detrital content on Fig. 6.1. The carbon falls from A1 to B, Fig. 7.3. as do the detrital constituents on Fig. 6.1. and thus suggests a decrease in turbulence, the rate of sedimentation and the amount of local erosion. The high organic carbon content of sample C again correlated with high detritals indicating a fresh influx of sediment.

Although the carbon content of the black shale varies from 4 - 8%, this cannot be detected by colour difference as found by Broadhurst (1959, p.535). However, the Geisina Band with 2.5% carbon, when powdered is distinctly paler than the shale below. The Geisina Band has a lower content of organic carbon than would be expected probably due to the high proportion of fossil material and the inclusion of some of the overlying carbon poor shale.

In the sediments above sample E there is less than 1% of organic matter and this is mostly very finely divided being contributed either as clay mineral grade detrital sediment or from the phytoplankton. There is a very slight increase in the content to nearly 1% in both samples H and J, that might correlate with the higher $Na^+ : K^+$ ratio in these sediments and be suggestive of increased sedimentation. On Fig. 7.3. further correlation between the $Na^+ : K^+$ ratio and a carbon content of 1% is seen in sample S and in this rock macroscopic detrital plant fragments have been seen in the hand specimen, further suggesting rapid sedimentation.

The major fall in the carbon content at the top of the Geisina Band, affects the fossil distribution, Chapter V, and the presence of pyrite and sulphur.

Indirectly the major change in the organic carbon content of the sediment would seem to be the primary cause for the sudden rise in Eh at the top of the Geisina Band.

Boron.

Until a very late stage in this study it was hoped to be able to present the content of the trace element Boron in these rocks, as an indicator of palaeosalinity. Due however to toxic Beryllium poisoning from the spectrographic apparatus at Manchester University, the determination of the boron contents of these sediments has had to be delayed. The comparison with similar Coal Measure sediments, however, does give a very broad idea of possible palaesalinity.

Boron occurs in sediments in detrital tourmaline and replacing the Al^{+++} ion in the lattice of the "illite" clay minerals (Harder, 1959). Lindergren (1945) suggested that the concentration of this replacement cation in the clay mineral will depend on the concentration of Boron in the water of deposition, which varies with salinity. Thus the Boron content of a sediment might be expected to reflect the salinity of the water in which it was deposited. There are two main objections to this suggestion. Firstly, the Boron content of the clay may depend on the amount of time available for cation exchange, thus be dependent on the rate of sedimentation, and secondly the content may also depend on the proportion of detrital illite, previously saturated with Boron, in the sediment. Harder (1961) has shown that the initial adsorption of Boron by illite is rapid until the saturation level is reached, but once adsorbed the element is not easily removed from the clay mineral lattice. Thus although the rate of sedimentation will not greatly affect the Boron content, the source of the detrital illite will. A sediment composed of degraded illite, derived from a pre-existing marine sediment high in Boron, if deposited in fresh water with a low Boron content will give an entirely anomalous idea of palaeosalinity. The Boron content of such a sediment reflects the nature of the source sediment and not the salinity in the basin of deposition. This very situation is recorded by Hurst (1958), where in recent sediments deposited under known conditions of salinity there is no correlation between Boron and salinity.

Nicholls and Loring (1960) conclude that a relationship may exist between Boron content and salinity and a closely related group of sediments from the same source area, such as those in a Coal Measure cyclothem. Walker (1962) has presented further evidence for this relationship in the rocks of a Namurian cyclothem in the Pennines. The present position seems to have returned to that suggested by Degens, Williams and Keith (1957), that Boron is only a reliable indicator of palaeosalinity when considered together with other trace elements, such as Gallium and Germanium .

In the coalfields of Germany, Ernst, Krejci-Graf and Werner (1958) and Ernst, Michalau and Tasch (1961) have used Boron contents as indicators of palaeosalinity. In the latter paper the authors have gone so far as to establish a series of detailed "salinity facies", where common Coal Measure fossils are related to Boron content. This diagram is reproduced in Chapter VIII as Fig. 8.2. and its implications further discussed there. Eagar (1961) and Nicholls and Loring (1960 and 1962) have recorded and discussed the Boron content of British Coal Measure sediments, while Degens, Williams and Keith (1958) have used similar methods on Pennsylvanian sediments of North America.

The close lithological and chemical similarity of the sediments of the Hopkins Band to those of the Bersham Cyclothem, studied by Nicholls and Loring, permits only a very dubious correlation of salinity to be made in the absence of the absolute Boron contents. Probably as with the Bersham sediments those at Bearpark accumulated under broadly "brackish" conditions, but as described previously the major environmental factor is believed to have been the Eh-pH relationships and not the salinity.

3. Conclusion.

The geochemical evidence therefore confirms the relative rate of deposition of the sediments and indicates that the major physico-chemical factor of the environment is the Eh-pH relationship. Further evidence as to the organic factors in the environment are considered in the next chapter and all lines of evidence drawn together in the palaeoecological synthesis of section C.

CHAPTER VIII

THE FAUNAL EVIDENCE

The evidence presented in this chapter is derived partly from a study of the fossils in the Hopkins' Band, and partly from a review of the published work on the palaeoecology of such fossils or closely related forms. There is also a large amount of relevant information on the ecology of living organisms closely related to the fossils of the Hopkins' Band, that sheds further light on their palaeoecology. Only the ecology of the mussels and ostracods is considered here as that of the serpulids, fish and plants, has already been discussed in Chapter IV.

1. The non-marine lamellibranchs.

a) Mussel assemblages in the Hopkins' Band.

In the sediments of the Hopkins' Band non-marine lamellibranchs have been found in both life and death positions. Specimens of Carbonicola and Anthracosia have been found in life positions in the laminated and siliceous mudstones at Whitworth Opencast (7), Pelton (5) and Eppleton (19). The Eppleton example is a specimen of Carbonicola cf. oslancis, inclined at an angle of about 50 degrees to the bedding with the anterior end downwards, suggesting that it was buried while in the life position of a typical bottom crawling lamellibranchs with the foot extended into the mud below. A similar orientation has also been seen in the Pelton specimens in the laminated mudstones, and in a group of specimens of Anthracosia cf. regularis in the lower part of the siliceous mudstones at Whitworth Opencast. In none of these specimens was there evidence of burrowing or of pyrite replacing a decomposed foot or sinus in the shales above or below the lamellibranchs, as was found for Lingula in the L. Carboniferous, Top Hosie Shale, by Craig (1952). The interpreted life position seen here agrees with that suggested for Carbonicola pseudorobusta by Maclennan (1945).

The preservation of mussels in life position suggests rapid burial before death and thus preumably rapid sedimentation at this period . In all cases the original shell material of the lamellibranch has been replaced by pyrite, possibly due to local reduction in the sediments around the decaying animal.

Broadhurst (1959) and Eagar (1961) have shown that the orientation and preservation of lamellibranch shells after death provide direct evidence for the conditions of sedimentation. Figure 8.1. is a hypothetical reconstruction of the various possibilities of detachment and burial of lamellibranch shells under different conditions of sedimentation.

The orientations of the lamellibranchs found at each locality studied have been recorded and presented on the faunal phase diagrams in chapter V (Figs. 5.1. - 5.8.) Naiadites is mostly preserved as flat shells parallel to the bedding (Plate IV, figs. 2,4, & 6), but occasionally in the siliceous mudstones the two valves are preserved in relief (Plate IV fig.3.). The commonest orientation of the Anthracosidae is either with both valves attached and the shells closed on their side, in relief or crushed, or as single disarticulated valves, convex upwards. It is often difficult to determine whether what appears to be a single disarticulated valve convex upwards, is really disarticulated, or the upper valve of a closed shell on its side. By consideration of Fig.8.1. these shell orientations suggest that either the closed shells were buried rapidly, or else the shells were disarticulated by turbulence and then buried. However, the overall implication is of rapid turbulent sedimentation.

At East Holywell (3), a fairly dense mussel band, three inches thick, has been found (chapter II) and the orientation and preservation of 255 specimens of Carbonicola and Anthracosia has been studied. These details are represented overleaf ; -

	Articulated valves							Dis-articulated	
Orientation									

Number	17	21	162	1	2	4	1	30	15

Articulation Ratio : Articulated / disarticulated valves = 4.7 : 1 (255 valves)

Closure Ratio : Closed / open valves = 4.5 : 1 (208 valves)

Orientation Ratio : Concave up / convex up-

Articulated	= 0.81 : 1	(38 valves)
Disarticulated	= 0.5 : 1	(45 valves)

The commonest orientation, as in the other localities is with both valves closed on their sides, 64% of the specimens studied. The articulation ratio, 4.7 : 1 is low and similar to that recorded by Broadhurst (1959) for the more turbulent phases of the pulchella Band, 4.5 : 1 a nd 4.9 : 1 respectively, as distinct from a ratio of about 7 : 1 for the stagnant phases. This ratio is also fairly close to that of Band II of Eagar (1961), 3 : 1 , said to be a life assemblage living under turbulent conditions. The closure ratio, however, is high for an assemblage deposited under turbulent conditions, 4.5 : 1, compared with 1 : 1, of Eagar, but this discrepancy may be explained by very rapid burial after death, some specimens being preserved in life position. The orientation ratios for both articulated and disarticulated valves indicate the predominance of the convex upwards position, thus indicating burial following turbulence, as on Fig.8.1. The actual ratios are very close to those of both Broadhurst and Eagar for both articulated and disarticulated shells.

This shell band appears to be a life assemblage of non-marine lamellibranchs that lived and were buried under turbulent conditions. Such turbulent conditions suggest that the environment was well aerated and that periodically the sedimentation was fairly rapid causing the shells to be buried before disarticulation. The similarity in the orientation of the non-marine lamellibranchs at many localities suggests that such environmental conditions as those above existed widely throughout the coalfield at the time of the formation of divisions (2) and (3), or Phases 4 and 5, of the Hopkins' Band.

b) Palaeoecology of Coal measure non-marine lamellibranchs.

By means of a careful study of much of the literature on Upper Carboniferous non-marine lamellibranchs and their living relatives, it has been possible to reconstruct some of the ecological factors that may have limited mussel distribution in both a vertical and lateral sense within the Hopkins' Band lagoon.

The deduced ecology of each genus is first discussed and then the limiting factors considered.

i) Carbonicola and Anthracosia. Both these genera appear to have been active benthonic lamellibranchs with an erect life position (Maclennan, 1945), and a tolerance of fresh or slightly brackish water (Weir, 1945). Carbonicola may have prefered a carbonaceous bottom substrata and have been tolerant of a relatively low Eh and stagnancy, while Anthracosia prefered a carbon poor substrate, a higher Eh and turbulent conditions (Eagar, 1961). The slight differences in the habitat of these genera may have been related to slightly different feeding preferences, Carbonicola feeding on benthonic algae and Anthracosia on epilimnion plankton.

Such postulated differences of ecology would explain the vertical restriction of Carbonicola to dominance in the lower darker grey shales of the Hopkins' Band, and the vertical survival of Anthracosia above Carbonicola as the conditions in the environment became increasingly turbulent.

ii) Anthraconaia. This genus may have been an active bottom dweller, not a burrower (Broadhurst, 1959) and had habitat and salinity preferences similar to Carbonicola (Eagar 1961 and Weir, 1945). The cause for the lateral replacement of the thick shelled Carbonicola fauna by a thin shelled Anthraconaia fauna to the north-east of Blyth, is difficult to explain in terms of palaeoecology. However as suggested by Broadhurst (1959), to account for a similar change at the base of the *pulchella* Band, availability of calcium and hardness of the water may have been a contributary factor.

iii) *Naiadites*. Maclennan (1945) suggests that this genus was byssally attached to plants and other objects, analogous to the living *Dreissensia*. Frequently it appears to have been attached to floating vegetation and then had a pseudoplanktonic mode of life (Eagar , 1961), and may thus appear in a wide range of bottom environments. *Naiadites* probably had a wider salinity tolerance than the members of the Anthracosidae, being "euryhaline" or truly adapted to live in brackish water (Weir, 1945 and Eagar, 1961). A pseudoplanktonic mode of life accounts for its ubiquitous occurrence in the Phases of the Hopkins' Band.

iv) *Cirvirimula*. The habit of this genus seems to have been generally similar to that of *Naiadites*, pseudoplanktonic and byssally fixed. It may, however, have had a more restricted salinity tolerence nearer the marine end of the brackish range, brackish to "quasi-marine" or "*Lingula* facies". The occurrence of the rather dubious fragments of this genus immediately on top of the Harvey Seam provide the only evidence for the possible existence of "saline-brackish" conditions at this time, as indicated in the reconstruction of Figure 9.1.

c) Environmental factors affecting mussel distribution.

According to Eagar (1948) three main factors affect mussel distribution, nature of the bottom substrate, sedimentation and water velocity.

The nature of the bottom substrate may affect the food supply and the Eh-pH conditions of the environment. Such a factor may have prohibited the establishment of a benthonic mussel fauna above the Harvey Seam until the change in the conditions at the top of the Geisina Band.

Sedimentation depends on the depth of water and the nature and rate of supply of sediment. The depth of water in which modern fresh-water mussels flourish is between 0 - 25 ft. (Eagar, 1948), while Maclennan (1945) suggests that

10 ft. was the maximum depth of the lagoon in which Carbonicola pseudorobusta lived in the Fifeshire Coal Measures. The silt content affects the light and temperature relations of an environment and the amount of decaying organic matter that can be retained (Ellis, 1936). Probably the high silt content and the large amount of entrapped decaying carbonaceous matter together made the substrate of the black shale environment unsuitable for colonization by filter feeding benthonic lamellibranchs.

An increase in the silt content and sedimentation appears to have been a limiting factor in the distribution of the Anthracosidae, causing first a restriction in the size range of the shells (Broadhurst, 1960) and then a marked stunting of the fauna (Eagar, 1952) and finally elimination of the fauna. An increase in the sedimentation and silt content was probably the factor causing the "stunting" or arresting of Anthracosia to the "Carbonicola carissima" form, and the fading of the mussel fauna at the top of the Hopkins' Band.

The third limiting factor, water velocity, is related to depth of water and position of the environment in relation to the sediment source and is probably synonomous with sedimentation control in Coal Measure palaeoecology.

2. The Ostracods.

a) Evidence from the Hopkins Band.

The ostracod Geisina arcuata shows an association with Naiadites and "Spirorbis" and a vertical restriction to the carbonaceous shale. (Chapter V). Its vertical distribution can also be related directly to the organic carbon content as seen in Chapter VI. These facts suggest that this ostracod is associated in its ecology with plant matter and a pseudoplanktonic fauna. The carapaces of G.arcuata in the Geisina Band are generally not orientated (Figs. 5.2 - 5.8. and Plate XVII, Figs. 1 and 2)., and frequently fragmented and consist of only one moult, the adult (Chapter III). These characters suggest that the Geisina Band is a "local death assemblage", the carapaces coming together after the death of the ostracod that lived in the water above.

The fauna of Geisina subarcuata in the Claxheugh Shell Bed with six moults preserved, suggests that this is a true "life assemblage" (Boucott, 1953). Such a life assemblage has been preserved in very fine sediment by very quiet conditions of sedimentation.

The genus Carbonita, however, does not show any vertical restriction (Chapter V), or geochemical correlation, and is associated with both the pseudo-planktonic and benthonic fauna (Chapter V). At all levels except the Geisina Band, most species of Carbonita are present as at least two moults (Chapter III) further suggesting that a true life assemblage is preserved. The association with pseudoplanktonic and benthonic faunas and independence of lithology or carbon content suggest that it was a ubiquitous bottom dwelling form.

Further evidence of differences in the ecology of these two ostracod genera emerges from a consideration of their palaeoecology in the literature and the comparative ecology of living ostracods.

b) A review of the palaeoecology of Geisina and Carbonita, in the literature.

Krempe and Grebe (1955), describing species of ostracods from the Coal Measures of the Rhur district, record distinct palaeosalinity differences between Geisina and Carbonita. They describe Geisina as brackish-fresh water in habitat and Carbonita as distinctly fresh water. Subsequent interpretation of the Boron content of sediments in terms of palaeosalinity further reflects this difference between these two genera. The "salinity facies" chart, drawn by Ernst, Michelau and Tasch (1960) and reproduced here as Figure 8.2, shows Geisina (Jonesina) to have a range of environment brackish to marine. The Boron values for shales containing Carbonita. given by Ernst, Krejci-Graf and Werner (1958) falls well within the "limnic or freshwater facies" on Fig. 8.2.

The work of Eagar (1961) suggests that Geisina had a pseudoplanktonic mode of life being associated with floating plant matter, and living in warm brackish to marine water. This association of Geisina with plants is further recorded by Heath (1960), who found many shells of this ostracod clustered around plant remains in the shales of Pseudorobusta Band in the Lower Coal Measures of Lancashire.

The earliest review of the habitat of Carbonita was given by Jones and Kirkby (1896), who concluded that although this genus may have occupied rivers, lagoons and delta swamps, both brackish or marine, in the Lower Carboniferous, in Upper Carboniferous times it did not range out of fresh water. The most complete reconstruction of the environment of Geisina and Carbonita has been given by Scott and Summerson (1943) for the Middle Pennsylvanian of Tennessee. They consider that these ostracods flourished in permanent freshwater lakes, less than 10 feet in depth which has a luxuriant aquatic flora. Scott (1944) further suggests that "The floors of these lakes were certainly covered in part with mud, decayed vegatable matter and algae. The temperature of the water was similar to that found in lakes in the vernal period in the eastern United States today".

The evidence of comparative palaeoecology therefore suggests that these genera flourished in shallow, fresh or brackish water lakes or lagoons, which had a rich organic bottom sediment and an aquatic or floating vegetation.

c) Evidence from the comparative ecology of living ostracods.

As has already been done for the non-marine lamellibranchs in the earlier part of this chapter, by a careful study of the literature it has been possible to evaluate some of the ecological factors that affect ostracods and may have influenced the distribution of genera and species in the Hopkins' Band.

i) Ecological factors. The major factors that control the ecology of ostracods are; food supply, salinity, temperature, bottom substrate and physico-chemical conditions in the environment.

According to Hoff (1942) the food of fresh water ostracods consists of bacteria, diatoms, algae, protozoans and the faeces of larger animals. Swain (1955) reviews the food requirements of brackish water species of ostracod in the Gulf Coast region of Texas and concludes that it is mainly blue-green algae. The living fresh-water genus Cypridopsis, which has been likened to Carbonita by Scott and Summerson (1943), has been shown by Kesling (1951) to feed on desmids, diatoms and flagellates. Such food requirements as these suggested above would certainly have been available to the Coal Measure ostracods in the unpreserved micro-flora and microfauna of the waters of the Hopkins' Band "lagoon".

The experimental work of Kornicker and Wise (1960) on the environmental limitations of a living marine ostracod showed that it had a very wide salinity tolerance from 6 - 60 parts of salt per thousand. Benson (1961) reviews the salinity tolerance of brackish water ostracods and expresses it as, oligohaline 0.2 - 2‰, mesohaline 2 - 10‰, truely brackish 2 - 17‰. Genera such as Cyprideis, some species of which can have a superficial resemblance to Geisina, are truly euryhaline and can be found in all salinities from freshwater to marine and even hypersaline environments where the salinity may rise to 55‰.

Fresh and brackish water ostracods are generally tolerant of fairly wide temperature changes (Kesling 1951). Kornicker and Wise (1960) found that a marine species could live and breed happily within a 30°C temperature range. However, the seasonal temperature changes and seasonal death periods in such a shallow water environment as the Hopkins' Band lagoon may have been the cause of patches of Carbonita pungens coquina in the black shale. Scott and Summerson (1943) suggested such a temperature control for Carbonita coquinas they described from Pennsylvanian shales.

According to Benson (1961) the nature of the bottom substrate is of prime importance to benthonic ostracods as it determines their mode of life. Most species are crawlers, browsers, burrowers or swimmers on or near the substrate surface. Kornicker and Wise (1960) found that their marine species showed a distinct preference for a silty bottom substrate rather than an unstable oolitic sand. Burrowing forms such as Candona, are typical of organic muds (Benson 1961). The nature of the bottom substrate may have been the factor controlling the vertical distribution of the species _Carbonita cf. rankiniana_ and _C.cf.evelinae_ in the sediments of the Hopkins' Band. _C.cf rankiniana_ preferred the richly carbonaceous substrate below the _Geisina_ Band while _C.cf.evelinae_ preferred the carbon poor sediment above this Band.

The major physico-chemical factors affecting ostracods are the Eh and pH of the environment. Generally ostracods occur most abundantly in slightly alkaline waters and the form of the shell may vary according to the pH. _Cyprideis_, the common brackish water genus, increases the thickness and ornamentation of its shell, with increasing salinity and thus pH, due to the increasing availability of calcium carbonate (Benson 1961). In certain swamp environments of the Mississippi delta, where the pH is less than 6.0 and the Eh is also low, there are no benthonic ostracods but only pelagic forms with a chitinous carapace (Curtis 1960). Generally ostracods do not live on the surface of organic oozes where the Eh is very low. The presence of life assemblages of species of _Carbonita_ in the black shale below the Geisina Band, would suggest that the Eh was not all that low at the surface of this carbonaceous mud, although reducing conditions prevailed below the sediment-water interface.

ii) _Modern biofacies comparable to the "Hopkins' Band lagoon"_. Several ecological studies and observations on living ostracods faunas suggest the type of biofacies that may have existed in the Northumberland and Durham area at the time of formation of the Hopkins' Band.

In the Gulf Coast region of the United States, Swain (1955) describes a "prodelta biofacies" characterized by the genera _Darwinula_, _Limnocythere_ and rarely _Cyprideis_. This facies exists where a river enters an extensive shallow brackish lagoon, and it has a low but variable salinity. Curtis (1960) describes an "interdistributary bay sub-facies" of the Missippi delta, a sedimentary environment to which the later sediments of the Hopkins' Band are likened in Chapter IX, Section C. This sub-facies has a depth of less than 6 ft., variable and local current action, a low salinity 0 - 16 ‰, and a wide temperature range. The bottom sediments are sandy and clayey silts of the delta front and have a rapid rate of deposition. The ostracod fauna is limited to Candona and the two genera of cythereids.

Probably the earliest comment on the possible environment of these ostracods was that of Brady (1867), "My belief is, therefore that these strata that exhibit such very abundant and closely packed remains of the smaller Cypridae and Cytheridae have most likely been formed in shallow brackish lagoons or at the mouths of deltas of rivers". Indeed such is believed to have been the biofacies of the ostracoda of the Hopkins' Band.

d) Conclusions on the detailed palaeoecology of Geisina and Carbonita in the Hopkins' Band.

The evidence presented and discussed in the two preceeding sections b) and c) has enabled the palaeoecological reconstruction of the mode of life of the two ostracod genera in the Hopkins ' Band to be extended.

Both these genera were predonimantly benthonic forms living in a shallow lagoonal environment.

Geisina appears to have been a browser on floating or deposited plant remains and thus may have been pseudoplanktonic or benthonic. It probably fed on algae or bacteria associated with the destruction of the plant material. The genus appears to have had a wide salinity tolerance, probably being euryhaline like Cyprideis, dominently brackish water form but capable of living successfully in conditions from near freshwater to quasi-marine.

Carbonita may have been a bottom crawler on an organic or mineral substrate, rather like the living genus Cypridopsis, and as with this latter genus it may have become a plant crawler if the Eh of the bottom conditions became too low (Kesling 1951). Other features of its ecology may also have been similar to Cypridopsis, namely, feeding on diatoms, desmids and flagellate that abounded near the bottom sediment, a tolerance of a wide temperature range and a pH of about 6 - 7. The genus appears to have been oligohaline, tolerant of fresh to slightly brackish water but it was dominantly fresh-water in Coal Measure times.

The detailed ecology of these two genera together with that of the non-marine lamellibranchs in the earlier part of this Chapter indicate some of the ecological factors that must have been operative in the Hopkins' Band lagoon, as reconstructed in Section C.

SECTION C

"A Reconstruction of the depositional and ecological history of the ostracod-mussel bands".

CHAPTER IX

RECONSTRUCTION OF PALAEOECOLOGY

This section is a synthesis of all the facts and palaeoecological evidence presented in the previous sections. A very detailed reconstruction of the conditions of formation of the Hopkins' Band is attempted and these conditions compared with those deduced for the Three Quarter Band and Claxheugh Shell Bed.

1. The Hopkins' Band.

a) <u>Depositional and ecological history of Bearpark</u>

Armstrong and Price (1953, p.977) describe the deposition of the sediments above the Harvey Seam as being typically cyclothemic. The full thickness of the post-Harvey cyclotherm to which they refer is 40-50 feet, all but the basal 6 ft, less at Bearpark, being made up of sandstone. The sediments examined at Bearpark, therefore, represent only the basal part of a cyclothem.

It is not proposed here to review or discuss the various mechanisms that have been advanced to explain cyclothemic sedimentation, but only to describe the actual conditions of such sedimentation as occurred above the Harvey Seam. Fig. 9.1 is a pictorial reconstruction of these conditions.

The swamp deposits that formed the Harvey Seam were rapidly inundated by water bearing fine lithic fragments which were spread out as a thin carpet over much of the pre-existing swamp. The upper part of the "coal peat" does not appear to have been very much compacted or indurated as it undoubtedly contributed much of the carbonaceous matrix of this rock type.

3 This initial flood must have been fairly rapid and with sufficient force of water to carry in pre-existing rock fragments up to 2 cm in length, which appear to have been spread out probably from a South-Westerly direction to fill in irregularities in the original swamp surface.

Following this initial inundation the sedimentation conditions become more settled. The water may have deepened slightly, the currents weakened in strength bringing only fine detritus into a lagoonal enrironment. This lagoon was probably fairly shallow, distinctly brackish or saline brackish, with a rich carbonaceous floor, and a sparse pelagic and benthonic fauna. The fauna is that typical of Phase 1 of Chapter V, (Fig. 5.2) a pseudopelagic fauna of scattered Curvirimula, Geisina and fish and an equally sparse benthonic fauna of Carbonita pungens and humilis. A period of extremely quiet deposition of pure carbonaceous material from nearby erosion of the underlying "coal peat" or swamp, may have formed the 1/4 inch coal at the top of the mudstone conglomerate.

Such a lull in sedimentation may have been accompanied by penecontemporaneous solution and later recrystallization of the carbonate of the mudstone conglomerate. The Eh of the mudstone conglomerate appears to have been low by the presence of pyrite, but the solution of carbonate and recrystallization postulated a lowering and then rising of pH which most probably occurred at a much later stage.

A fresh influx of carbonaceous and fine detrital sediment began the deposition of the black shale. This sediment may have been derived from contemporaneous erosion of a marsh or swamp facies to the west or southwest, and spread widely throughout the lagoon by weak surface currents. The actual deposition of the sediment of fine silt and coarser plant fragments with associated eroded quartz (Chapters VI and VII), appears to have been below the wave base. The presence of a richly carbonaceous floor to the lagoon with a low Eh, and the abundant detrital silt, would seem to have been the ecological factors that prohibited the establishment of a benthonic mussel fauna. Dense swarms of Carbonita pungens appear to have covered the bottom with more scattered specimens of C. humilis and C. rankiniana. Geisina acruata appear largely present on the floating plant remains but it may have also occurred in groups on the bottom congregated around decaying plant matter. Naiadites and Spirorbid worms had a pseudoplanktonic mode of life, attached to floating plant matter and completed the faunal assemblage typical of Phase 2 (Fig. 5.2).

Towards the end of the period of black shale deposition a fresh influx of sediment was accompanied by a general increase in turbulence and weak current action at the sediment surface produced grouping of ostracod carapaces and winnowing out of fine clay material. This slight turbulence and winnowing action continued throughout the formation of the Geisina Band, Phase 3, but gradually descreased towards the top of this Band as the supply of detrital sediment was reduced. Much of the upper part of the Geisina Band suggests that it formed a "local death assemblage" of microfauna with little or no detrital sediment being supplied. The oxidation potential was very low about -0.3 volts below the sediment water interface, due to the decaying plant matter, but the pH was probably between 7 and 8. (Fig. 9.1.)

The abrupt change in lithology at the top of the Geisina Band indicates a change in sedimentation shown on Fig. 9.1. There may have been a slight deepening or increase in lateral spread of the lagoon so that the Bearpark area became more offshore in relation to the sediment source. Only fine clay mineral sediment was supplied to the area, perhaps from a north-westerly source, so that the bottom substrate became a fine poorly carbonaceous mud. The reduction in the amount of decaying carbon caused the Eh to rise sharply although a slight decrease in salinity may have occurred causing the pH to fall slightly (Fig. 9.1.)

This oxidizing environment was soon colonized by benthonic lamellibranchs, Carbonicola, Anthraconaia and Anthracosia while the benthonic ostracods C. pungens and humilis continued to flourish as below but were joined by the species C. cf. evelinae. This latter species of bottom crawler appears to prefer a poorly carbonaceous substrate. Scattered specimens of Geisina arcuata, surviving from the Geisina Band below soon died out but scattered Naiadites continued to flourish, Thus the typical Phase 4 fauna flourished and was preserved.

When more than 3 inches of compacted sediment had accumulated, bottom conditions became slightly more turbulent, the finely divided carbon settled out of suspension before the clay, which on being deposited with slight flocculation formed a laminated mudstone. In these conditions Anthracosia slowly took over dominance of the mussel fauna, Anthraconaia dies out and C.evelinae dominated the microfauna. This is the Phase 5 fauna.

The Eh = 0 boundary occurred below the sediment water interface in this laminated mudstone sediment, so that there was an oxidizing environment in water above and a mildly reducing one in the sediments below. Iron carbonate formed in this reducing environment, at first in isolated patches, then in more widespread bands, perhaps reflecting reduction related to carbonaceous bands in the sediment althouth the ironstone bands are many times thicker. Allowing for a compaction factor of 0.4 it is probable that about 6 inches of fine sediment had accumulated before ironstone formation began.

When about 1 foot of uncompacted mudstone had accumulated, the mudstone lost its laminated nature and Carbonicola occurred only sparsely, suggesting that these was a further increase in turbulence and rate of deposition. Pseudoplanktonic Naiadites, increased in importance in the fauna as Anthracosia dies out slowly. Anthracosia and the ostracods appear to have died out with the increase of fine silt that formed the siliceous mudstone. Perhaps this silt eliminated their source of food the epilimnion plankton or made bottom conditions too unstable or otherwise unsuitable for a benthonic fauna. At the highest levels of its occurrence Anthracosia shows slight stunting, characteristic of increased sedimentation The surviving Naiadites occurred in scattered groups, presumably clustered around rare plant fragments, but these shells lack the commersal attached spirorbid worms, perhaps a further evidence of silt inhibiting filter feeders (Chapter IV). This final survival of the pseudoplanktonic fauna is Phase 6.

The increase in sedimentation that eliminated the benthonic fauna suggests a general shallowing of the lagoon and advance of more litteral conditions from the north west. Such a change in facies indicates the beginning of the "Regrassion phase" of the cyclothem (Payton and Thomas, 1959), from lagoonal to more deltaic conditions. (Fig. 9.1.)

These sediments coarsen in grain size vertically and the presence of fine discontinuous silt laminae indicates the effect of eddies and currents that winnow out the fine clay material. Macroscopic plant fragments of a cordaitid or "swamp front" type of vegetation, reappear in these sediments and thus further indicate a closer approach to the margin of the depositional area. There appears to have been an increase in the rate of sedimentation in the siltstone sediments reaching a maximum when 3 feet of compacted sediment had accumulated above the coal seam. At this level the sediment shows distinct micro-crossbedding in the laminations, and quartz and carbon banding, but the presence of burrowing organisms (Plate XVI, Fig. 1) indicates shallow water conditions and intermittent periods of quieter sedimentation.

The sediments between 3 and 5 feet above the coal seam indicate that the sedimentation of siltstone with scattered plant remains continued. The Eh was still low in these sediments and thus ironstone continued to form but generally it was less dense than in the mudstone below, perhaps due to more mildly reducing conditions.

When perhaps 10-15 feet of uncompacted muddy sediment had accumulated, (c. 5 foot of compacted sediment.) there appears to have been a short period of slow and quiet sedimentation. A fine grey mudstone similar to that above the Geisina Band. was then laid down. A sparse benthonic fauna of <u>Anthracosia</u> and <u>Carbonita</u> and <u>Naiadites</u> flourished for a short time before more turbulent sedimentation returned. Further rapid sedimentation in shallow water fragmented the shale into shale pellets and it was bored through by worms.

Continued shallowing and a distinct change of the environment to fluviatile, caused a disconformable "flood plain" type of massive sandstone to be laid down. This sandstone probably persists vertically for the rest of cyclothem, becoming "earthy, argillaceous and rooty, finally culminating in a thin but persistent fireclay which is sometimes overlain by a thin coal about 40-50 feet above the Harvey Seam", to quote Armstrong and Price (1953, p.977).

The suggestion that the sediments above the Geisina Band were derived from a north to north-westerly source is derived from the work of Kellet (1927) and Jones (1955). Kellet suggested that the heavy minerals of the Coal Measure sandstone came from this direction, while Jones found that this was the predominant current direction in the 30 foot of sandstone that form the upper part of the post Harvey cyclothern in south east Northumberland.

The depositional and ecological history of these sediments at Bearpark would suggest that they formed in an environment comparable to the "prodelta" of a modern deltaic environment. The ostracod fauna of Chapter VIII, reveals a close similarity to the "interdistributary bay" of the Mississippi delta. The predominance of thick lamina of fine clay rich sediment even in the higher levels of succession reflects a closer affinity with the sediments of an "interdistributary Bay" (Shepard 1960) rather than modern tidal flats (Potter and Glass, 1958).

In terms of the Russian system of lithogenic facies, classification of Coal Measure sediments, (Bolvinkina, et.al. 1956) these sediments are of transitional and continental type. There is possibly a change from a "facies" of argillaceous sediments in lagoons and bays", at the level of the Hopkins' Band, through another transition "facies" of argillaceous - aleurolitric and arenaceous sediments of coastal lakes" to alluvial continental facies of "arenaceous-aleurolitic sediments on flood plains" (Jablokov, Botvinkina and Feofileva, 1962).

Fundamentally the sediments and fossils of the Hopkins Band represent the normal lagoonal phase of a Coal Measure cyclothern (Trueman, 1954) while the overlying sediments show the transition to the fluviodeltaic conditions that preceed the next coal forming period (Fig. 9.1.).

b) The Lithofacies and Sedimentary environments.

The lithofacies map (Fig. 1.8) and the lithological variation of the strata of the Hopkins' Band, Figs. 1.5 - 1.7, indicate, that while the sediments and ecology at Bearpark are typical, there was some lateral variation in conditions of sedimentation. The wide sampling of this study makes mapping of these sedimentary environments difficult but some general reconstruction is possible.

Fig. 9.2, is a reconstruction of the conditions at various levels, to the north-west and south east of Bearpark. Such a section runs approximately in the direction of Fig. 1.7, but includes other localities, namely (9), (10), (16), (17), (6), (20) and (22) (see Fig 1.4). This reconstruction is based on the faunal and lithological evidence for conditions of sedimentation seen at these localities and in intervening boreholes.

Reconstruction I shows the conditions soon after the inundation of the coal seam. A marsh or swamp facies with a cannel pool is developed in the north west, a lagoon facies in the central area, and a transitional facies with sandstone deposition in the south east. The presence of the swamp in the north west is based on the 1 foot seatearth seen at Lanchester (17), and the 9 inch coal at Leadgate (16), (Fig. 1.7.) that passes laterally into the cannel coals above the Harvey or Townley Seam at Chopwell (10) and Hedley Park (9) (Fig. 1.6.). The top two inches of the seatearth at Lanchester are black and shaley and contain a fauna of ostracods and rare Naiadites, similar to the top of the mudstone conglomerate at Bearpark. As at Bearpark this lithology is overlain by a 1/4 inch coal. The current arrow on Reconstruction I is to suggest that there was a transport of abundant plant matter and silt westwards from the swamp into the lagoon, to form the black shale of Reconstruction II.

In the extreme east of the Durham coalfield, Ryhope (15) and Harton (24), the basal mudstone conglomerate is replaced laterally on top of the Harvey Seam by a sandy seatearth. This may indicate the persistence of swamp and perhaps fluviodeltaic conditions to the east of the main lagoon under the North Sea. The recent offshore bores of the National Coal Board, suggest that to the east in general a "transition facies" similar to that in the south east existed contemporaneously with Hopkins' Band lagoon. Local development of shallow and temporary lagoons in this generally deltaic sequence would account for the presence of thin ostracod-mussel bands at intervals.

The second Reconstruction indicates the environment of deposition of the black shale at Bearpark, the black siltstone at Lanchester (17) and contemporaneous strata. Deposition of plant matter in the stagnant pool at Hedley Park continued, to form the thick cannel coal and cannel shale with ostracods, contemporaneous with the ostracod faunas of the black shale and Geisina Band. The eastward margin of this cannel pool, however, seems to have moved westward, as the thin band of cannel at Chopwell is succeeded by grey shale with rare mussels. In the south east area turbulent sandstone deposition continued, while in the extreme north east beyond Blyth the distinct silt enrichment in the black shale and Geisina Band may indicate a local influx of sediment, from the north.

The maximum extent of lagoonal depositioh is shown in Reconstruction III, grey laminated mudstone with benthonic mussels formed in the main Hopkins' Band lagoon, which had extended as far west as Lanchester. The cannel pool in the north west had been suppressed by a thick spread of laminated siltstones, indicating more marginal or litteral conditions and an influx of sediment from this direction. The replacement of <u>Carbonicola</u> by <u>Anthraconaia</u> in the mussel fauna and continued high silt content of the sediments in the extreme north east may indicate that there was a freshwater or fluviatile influence in the northern part of the main Hopkins' Band Lagoon. The siliceous mudstone and siltstone deposition of Reconstruction IV seem to have come at an earlier stage in the northern part of the Lagoon (Fig. 1.5b, locality 2), again reflecting a slight difference in sedimentation in this area.

In Reconstruction IV the main lagoon has been suppressed by the south-eastward advance of siltstone deposition to form a shallow littoral lake with widespread rapid sedimentation. Following the suppression of the main lagoonal phase by increased sedimentation, there appears to have been a local short lived recurrence of shallow lagoonal conditions in north east Durham, forming the 1/2 inch ostracod mussel Band seen at Harton (24), Follensby (4), Washington (12) and Hylton (13) (Fig. 1.5b and 1.6).

The deltaic or "flood plain" sandstone of the south eastern part of the coalfield may have been linked at this time with similar areas of deposition in West Northumberland (Fig. 1.8), by a series of washout channels, filled with characteristic multi-directional cross bedded "channel fill" sandstones. These channels probably ran in a braided pattern over much of the coal field at this period and subsequently, often cutting down through the underlying strata to the Harvey Seam. Frequently the direction of these channels was from north to south, for instance one ran for at least five miles through Gateshead. Alternatively a north west - south east trend is common as indicated by one running from Sunderland out under the sea north of Ryhope (15). Both these channels "wash out" the Harvey Seam. A lateral spread of "flood-plain type" sandstones and other alluvial sediments from this pattern of braided channels formed the thick sandstones of the upper part of the post Harvey cyclothem, throughout the coalfield.

c) Comparison with Midgeholme and Cumberland.

Certain general features of faunal (Chapter II and III) and lithological (Chapters I and VI) similarity between the Hopkins' Band and equivalent ostracod mussel bands in Midgeholme have already been described.

The Midgeholme Band is especially similar to the Hopkins Band both in species of fossils and succession of phases. The only feature of difference is the association of Carbonicola and Geisina in a dark carbon rich shale, there not being the vertical restriction seen in the Hopkins' Band. This association is similar to that recorded by Eagar (1962) from the Flockton Coals of Yorkshire, and suggest that at this level the Eh conditions at the substrate surface were higher than in the Hopkins' Band.

The ostracod-mussel band above the Eighteen Inch Seam of Cumberland suggest typical lagoonal formation. It is a thicker band than the Hopkins' Band, and its features suggest quieter conditions of formation. The actual Geisina Band lacks the laminae of the Hopkins' Band, the "life assemblage" of at least three moults of Geisina being preserved throughout the dark grey shale. This Band also has a lower quartz and carbon content than the Hopkins Band and precipitated collophane phosphate. These characters suggest quiet deposition, no turbulence and a low sedimentation rate, a higher Eh than Hopkins' Band as there is no pyrite but a distinctly lower pH as phosphate is precipitated. The presence of two types of detrital quartz in this band suggests a similar type of source for the carbon and detrital material, to the Hopkins' Band, but probably not the same source area as it lacks the detrital kaolin.

Various lateral facies changes above the Eighteen Inch Seam have already described in Chapter I. In general these changes are similar to those seen in Northumberland and Durham. To the north west of Maryport a "transition facies" of silts and sandstones replaces the ostracod mussel band while south of Maryport the lagoonal conditions pass into cannel or plant bearing silts.

In terms of regional palaeogeography, the environmental evidence from Midgeholme and Cumberland, suggests that a series of shallow, brackish water lagoons, rich in an ostracod and mussel fauna, existed within the Coal Measure swamps covering Northern England, contemporaneous with the Hopkins' Band. There may or there may not have been intercommunication between these lagoons. Over much of the area there seems to have been similar lateral facies changes related to these lagoons.

2. Three Quarter Ostracod-Mussel Band.

This Band occurs in similar position within the cyclothen to the Hopkins' Band. Both bands occur above coals or seatearth and have generally similar faunal sequence suggestives of lagoonal conditions.

The base of the Band differs at Bowburn and Fishburn (Chapter I). At Bowburn a shale sequence follows the coal (Fig. 1.11.) while at Fishburn local erosion removed the coal and deposited a thin mudstone conglomerate on top of the seatearth. The initial turbulent phase at Fishburn also grouped the ostracods into pockets towards the top of the mudstone conglomerate. Phases 1 and 2 of this Band probably formed in a brackish-saline lagoon with slow sedimentation. Although there was no macroscopic plant fragments entering the lagoon, hence no spirorbid remains, the bottom substrate in Phase 1 (Fig. 5.9) was probably a finely carbonaceous mud. A benthonic fauna of Carbonita and scattered Geisina flourished on this substrate while a pseudoplanktonic fauna Curvirimula, and fish flourished in the waters above. The fauna was much denser in phase 1 than phase 2 (Fig. 5.9) perhaps due to the more richly carbonaceous nature of the substrate. Conditions of sedimentation were quiet as a "life assemblage" of Carbonita is preserved and although the Eh was lower in Phase 1 than Phase 2, it was probably similar to that in the Hopkins' Band. The pH may have been higher than in the Hopkins' Band Lagoon on account of the higher salinity suggested by the presence of Curvirimula rather than Naiadites (Chapter VIII).

The appearance of benthonic Carbonicola at the base of Phase 3 and disappearance of Curvirimula suggest a change in conditions. Salinity may have decreased and more turbulent conditions produced a more oxidizing environment suitable for a benthonic macrofauna. As in the Hopkins' Band benthonic Carbonita continued to flourish with the mussels.

The rate of sedimentation appears to have increased vertically causing elimination of the mussel fauna and change in the lithology to a siliceous mudstone (Fig. 1.11, Fig. 5.9). The presence of ironstone in the mudstone and siliceous mudstone suggest the fall of Eh within the sediment after deposition as seen in the Hopkins' Band. With further regression of the lagoonal phase the siliceous mudstone passes vertically into the siltstone and then a sandstone in all three boreholes.

Thus the overall faunal phases of this Band can be explained by the changing environment and it would seem to differ from the Hopkins' Band purely in stratigraphical horizon and an initially more saline brackish environment.

3. The Claxheugh Shell Bed.

This fossil band is unique in type, because of its unusually rich Anthropod fauna of ostracods, Eustheria, insects and arachnids, and is of very local occurrence. It has only been found at the one surface locality shown on Plate VIII, fig 2. The fauna of this band although showing affinities with typical Upper Coal Measure faunas, also indicates a rather unusual environment. Evidence for the ecology of this environment is derived from both the lithology and the fauna of the Band.

The lithology of this Band is a finely cleaved and soft grey shale with thick ironstone bands (Fig. 1.12). This thin shale has an abrupt base on a pale argillaceous sandstone with rootlets and is overlain by a dark grey sandy micaceous shale that coarsens upwards. The nodular ironstones may be up to 1 - 3 inches thick and occur in irregular bands, and contain an uncrushed fauna suggesting that their formation was pre-compaction in date and may have been contemporaneous or precontemporaneous with the deposition of the shale.

The mussel fauna of Naiadites cf.elongata and cf. Anthraconauta phillipsi, is a true "life assemblage" as it contains both juvenile and adult forms. Such a wide size range in mussels is a typical "shale fauna" (Broadhurst, 1960), and indicates a life assemblage that lived under very calm conditions with slow sedimentation. Naiadites was probably a euryhaline genus, but dominantly brackish water in habitat while *Anthraconauta* (sensu stricto) "lived on or in the muddy bottoms of lagoons bordering on the Hinterland that was subject to progressive aridity" (Weir, 1960, p.274).

The ostracod *Geisina subarcuata* is the commonest anthrapod and a full "life assemblage" of six moults being present (Chapter III). The salinity range of this genus was probably fresh to brackish water (Chapter VIII). The specimens of *Euestheria* sp. present show a wide size range suggesting a "life assemblage" and probably a fresh or brackish water habitat (Jones, 1862). Trechman and Woollacott (1919) record the presence of the arachnid *Belinurus trechmanni* and two genera of insects, *Phylomylacius* and *Lithomylacius*, from this shale. *Belinurus* was probably a fresh water form, a swimmer or bottom crawler (Størmer, 1955). Bolton (1922, p.21) however suggests that insect remains were "laid down in quiet lagoons or swamp lakes, into which only the finer mud particles and floating pinnules and debris of coal plants could pass and accumulate. Such waters were probably fresh or brackish, shallow and limited in area".

The fish remains recorded by Armstrong and Price (1953) are typical of the "swamp facies fauna", of pools, lagoons and streams of the Coal Measure swamp (Chapter IV). Rare fragments of the plants, *Neuropteris*, *Calamites*, *Lepidodendron*, *Lepidophyllum* and *Sigillaria* are recorded by Trechmann and Woollacott (1919), and would seem to be a drifted flora of mixed swamp and terrestrial type.

All this palaeoecological evidence suggests that the Claxheugh Shell Bed formed in an unusual environment in a local pool or lagoon within the normal swamp area. This pool appears to have been shallow with a muddy substrate, a restricted water circulation and slow quiet sedimentation. The shale texture is very similar to a cannel shale and had there been a supply of fine carbonaceous material to this pool it might well have become a cannel pool similar to that seen at the level of the Hopkins' Band at Hedley Park (Chapter IV).

The lamellibranch and anthrapod faunas suggest that the pool was fresh or brackish and in close proximity to the Hinterland. The Eh was probably slightly reducing with ironstone forming at or just below the sediment water interface. The benthonic fauna of the pool was mainly lamellibranchs, Belinurus and Euestheria while Geisina was probably associated with floating or sunken plant remains. The insect remains probably fell into the pool after death as these genera were not aquatic forms (Bolton (1922). Occasionally the pool may have been open to other pools and channels of the swamp, as is evidenced by the presence of fish and drifting plant remains. The temporary nature of this pool is indicated as it was preceeded and succeeded by normal alluvial swamp sedimentation.

This environment of the Claxheugh Shell Bed differs from that of the other ostracod mussel bands by being a local lagoon within the main swamp and not marginal to the swamp as were the other two environments. Only rarely was this local lagoon in contact with other aquatic habitats of the Coal Measures and due to this it lacked the densely carbonaceous bottom substrate of the other lagoons and consequently had a higher Eh and predominantly benthonic fauna.

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APPENDIX I

RESEARCH TECHNIQUES

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RESEARCH TECHNIQUES

a) Palaeontological

1. Extraction and preparation of ostracods.

The various techniques that can be used for the extraction and preparation of ostracods have recently been summarized by Sohn (1961b) in the ostracod Treatise. Although all these techniques were tried only prolonged soaking in hydrogen peroxide released the ostracods from the fresh indurated shale of the Hopkins' Band.

Method used.

Clips of shale 1/4 - 1 inch in size were soaked for periods varying from 1 day to 2 weeks in 20 vols. Hydrogen peroxide. The resulting sludge was washed through a series of sieves 10, 30, 60, 90, 120, 150 and 200 meshes to the inch then dried and the ostracods separated by hand picking under a binocular microscope. Resistant shale fragments were further broken down by mechanical crushing and boiling in Hydrogen peroxide. The individual ostracod specimens were cleaned of matrix with a fine needle under water in a watch glass.

The majority of ostracods were found in the 30, 60 and 90 mesh sieves and were hand picked from a cardboard tray with a background grid under a binocular microscope. Heavy liquid separation of the ostracods was attempted but was not successful due to similarity of specific gravity of the fossils and shale fragments. The specimens were mounted on cardboard microslides.

2. Photography.

i) Ostracods. The ostracods were whitened with magnesium oxide and placed in various orientations on a wire above the cavity of a microslide. The specimens so mounted were photographyed using a Leica 35 mm. camera, slide copier, 5 cm. lens and long extension tube, mounted vertically over the fossils. A magnification of 10× was obtained with this set up, but the results were not very good due to a very small depth of focus. Equal intensity background lighting and one oblique spot light were used for illumination. Due to use of the long extension tube for high magnification, an exposure of many seconds was necessary and so great care had to be taken to avoid vibration of the apparatus.

ii) Non-marine lamellibranchs. These fossils were whitened with ammonium chloride and placed in plasticene in correct horizontal position, and photographed with a Leica 35 mm. camera, 5 cm. lens and very short extension tube. The image was about natural size and has been enlarged in printing as indicated on the plate.

3. Illustration.

The figured ostracods and spirorbid worms were drawn using a camera lucida with binocular microscope or graticule eyepiece and drawing on tracing paper over squared paper.

b) Petrological

1. Cutting. Due to the friable and fissile nature of these shales they could not be cut with a normal water cooled cutting machine. Thin chips of rock were cut by using a 3/4 inch diameter diamond impregnated cutting wheel on a small hand dental drill. Rock chips about 1/8-1/4 inch in thickness but restricted to 3/4 inch in width could be cut by this method, parallel, normal or oblique to the bedding as required.

2. Preparation of Thin sections.

The rock chips had to be impregnated and ground down using an adapted technique of Legette (1928), to prevent fragmentation. The shale fragments were impregnated with the resin "Lakeside 70", by soaking overnight in the resin in a desiccator under reduced pressure and then the resin allowed to set using a "hardener". The impregnated rock chip was then mounted on a glass slide and ground down under glycerine, as water would have caused fragmentation.

3. Examination and Photomicrography.

The volume percentage of quartz was measured micrometrically from the thin sections using a Swift integrating stage and point counter.

The photomicrographs, shown in Plates XI to XVII, were taken using a Seitz Panphot microscope with 1/4 plate camera attachment.

c) Geochemical.

1. Preparation of Samples.

The rock specimens for analysis were broken down to small chips using a hammer and then these chips crushed to a fine powder, passing through a sieve of 300 meshes to the inch, in a vibrating ball crusher. The finest residue of the shale passing through the 200 mesh sieve in the microfossil extractions was recovered by filtration and also examined by X-ray defraction.

2. X-ray diffraction.

Normal untreated mounts of the powdered rock samples were scanned with a Cu K beam of a standard Phillips X-ray defractometer.

3. Geochemical Analysis.

The samples were analysed for alkalis, total iron and phosphate by "Rapid analysis of Silicate rocks" techniques given by Shapiro and Brannock (1956) and Riley (1958).

Total carbon content was determined by the technique of Groves (1928) and carbon dioxide content by the method of Shapiro and Brannock (1955).

The organic carbon was found by subtraction of carbon dioxide, carbon, from total carbon.

Fine shale samples were analysed for carbon dioxide, total carbon and total sulphur by the Coal Survey Laboratory, Newcastle using methods given in B.S.1016. The carbon dioxide content was determined gravimetrically and the total sulphur content by the High Temperature method.

Rapid Silicate Technique.

The rock samples were digested in hydroflouric and perchloric acids and the resulting solutions B analysed for Na_2O , K_2O , total Fe and P_2O_5 .

Alkalis Na_2O and K_2O were determined on the flame photometer using aliquots of solution B.

Total Fe This was determined spectrophotometrically. Iron was reduced with hydroxylamine at pH 4.8-5.0 and complexed as the red ferrous dipyridyl complex.

P_2O_5 Phosphorus was determined in solution B by a single solution molybdenum blue method, using abscorbic acid as the reducing agent. The intensity of molybdenum blue was measured on the spectrophotometer.

Total Carbon. In Groves (1928) method all the carbon in the rock, whether originally organic or carbonate carbon, is oxidized to carbon dioxide by a mixture of phosphoric and chromic acids. The evolved carbon dioxide is absorbed in soda asbestos and this can be weighed directly.

Carbon Dioxide. The method of Shapiro and Brannock (1955) releases carbon dioxide from carbonates in the rock by heating with dilute hydrochloric acid. The reaction is carried out in a specially designed tube under oil so that the evolved gas bubbles through the oil to collect in a graduated size tube. This side tube had first to be calibrated.

Four of the samples analysed very accurately gravimetrically by the Coal Survey were used as standards. By varying the weight of these samples of known CO_2 content it was possible to calibrate the CO_2 tube as on the accompanying graph and table. The percentage equivalent of carbon dioxide per gram could then be quickly found for unknown samples, simply by finding the length of tube filled by the evolved gas and extrapolating on the curve.

CALIBRATION OF SHAPIRO AND BRANNOCK CO_2 TUBE.

Sample	Weight	Equiv. per gram.	Height of CO_2
A_2 (11.82 CO_2)	0.10 gm.	1.182	9.25 cm.
C	1.0 gm.	2.2	20 cm+ - off scale
(2.20 CO_2)	0.75 gm	1.605	14.2 cm.
	0.50 gm	1.10	7.6 cm
	0.25 gm	0.505	3.3 cm
	0.125 gm	0.253	1.4 cm
J	0.40 gm	1.84	16.4 cm
(4.63 CO_2)	0.20 gm	0.92	6.6 cm
	0.1 gm	0.46	3.2 cm
E	0.1 gm	(1.41) observed	11.9 cm
(13.9 CO_2)		1.39	

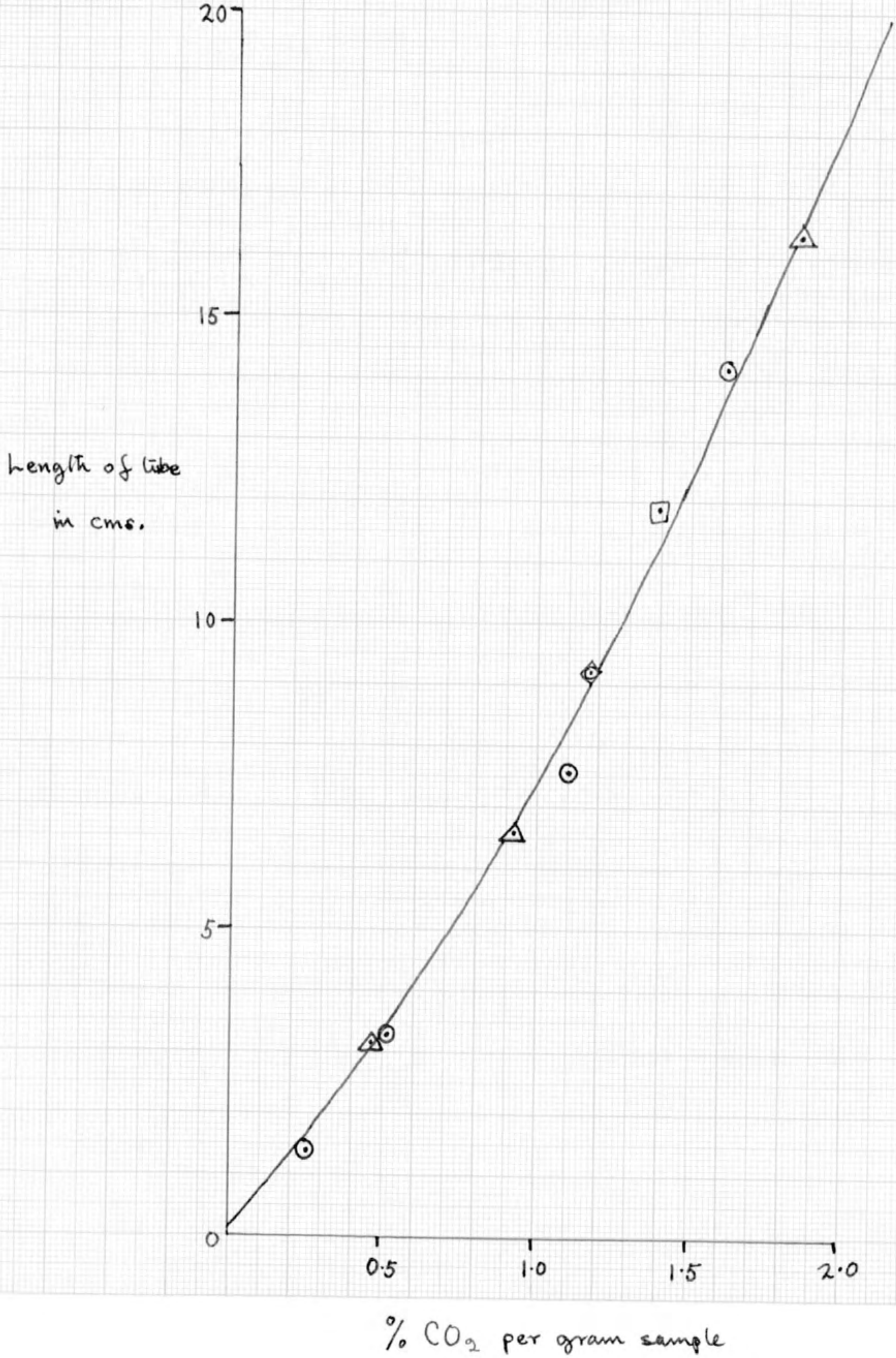
Points on the graph overleaf plotted from the standards;-

◇ Sample A2 - 11.82% CO_2

⊙ Sample C - 2.20% CO_2

⊡ Sample E - 13.93% CO_2

△ Sample J - 4.63% CO_2



Length of tube in cms.
20
15
10
5
0
0·5
1·0
1·5
2·0
% CO_2 per gram sample

APPENDIX II

DIMENSIONS OF OSTRACODS

DIMENSIONS OF 180 SPECIMENS OF <u>GEISINA ARCUATA</u> FROM

"GEISINA BAND" AT EPPLETON COLLIERY, DURHAM (in mm.)

Sq.No.	Ex. or M.	L	H	Tp
1.	M	1.20	0.78	0.44
	M	1.16	0.74	0.56
	M	1.10	0.72	0.54
	M	1.18	0.68	0.60
	M	1.28	0.74	0.52
2.	M	1.08	0.64	0.46
	M	1.14	0.64	0.46
	M	1.18	0.70	0.56
	M	1.20	0.74	0.54
	M	1.18	0.70	0.54
	M	1.10	0.76	0.54
	M	1.06	0.76	0.44
	M	1.20	0.68	0.60
	M	1.12	0.74	0.56
3.	M	1.14	0.66	0.46
	M	1.08	0.68	0.44
	M	1.16	0.76	0.40
	M	1.26	0.74	0.50
	M	1.32	0.74	0.66
	M	1.12	0.70	0.44
	M.17	1.18	0.74	0.50
	M	1.14	0.74	0.58
	M	1.30	0.82	0.60
	M	1.26	0.78	0.46
4.	M	1.10	0.68	0.56
	M	1.26	0.80	0.44
	M	1.12	0.66	0.48
	M	1.16	0.62	0.56
	M	1.20	0.76	0.50
	M	1.20	0.78	0.50
	M	1.28	0.76	0.64
	M	1.20	0.74	0.58
5.	M	1.08	0.66	0.44
	M	1.20	0.70	0.52
	Ex	1.40	0.84	0.66
	M	1.10	0.66	0.42
	M	1.08	0.62	0.50
	M	1.18	0.70	0.50
	Ex	1.26	0.74	0.54
	M	1.18	0.78	0.52
6.	M	1.04	0.72	0.52
	M	1.22	0.66	0.60
	M	1.22	0.66	0.56
	M	1.26	0.74	0.50
	M	1.18	0.76	0.60
	M	1.30	0.82	0.58
	M	1.28	0.78	0.58
7.	M	1.20	0.70	0.62
	M	1.12	0.72	0.48
	M	1.18	0.70	0.52
	M	1.32	0.74	0.50
	M	1.12	0.66	0.52

Square No.	Ex. or M.	L	H	Tp
8.	Ex	1.14	0.66	0.52
	M	1.24	0.82	0.66
	M	1.10	0.66	0.56
	M	1.18	0.70	0.56
	M	1.18	0.68	0.62
	M	1.14	0.78	0.52
	M	1.16	0.70	0.48
	M	1.18	0.74	0.52
9.	M	1.18	0.76	0.50
	M	1.22	0.68	0.62
	M	1.30	0.82	0.58
	M	1.14	0.72	0.56
	M	1.20	0.66	0.62
	M	1.20	0.72	0.54
	M	1.22	0.76	0.58
	M	1.16	0.76	0.46
	M	1.24	0.78	0.46
	M	1.16	0.70	0.48
	M	1.10	0.64	0.46
	M	1.14	0.64	0.56
10.	M	1.20	0.64	0.60
	M	1.16	0.64	0.60
	M	1.24	0.76	0.54
	M	1.12	0.74	0.54
	M	1.28	0.72	0.64
	M	1.14	0.68	0.58
	M	1.24	0.86	0.62
	M	1.14	0.78	0.54
11.	M	1.22	0.80	0.52
	M	1.12	0.70	0.46
	M	1.32	0.90	0.46
	M	1.26	0.72	0.68
	M	1.26	0.70	0.66
	M	1.72	0.78	0.64
	M	1.22	0.76	0.58
	M	1.18	0.70	0.56
	M	1.22	0.78	0.56
	M	1.24	0.72	0.62
	M	1.12	0.62	0.56
	M	1.18	0.78	0.56
12.	M	1.20	0.76	0.52
	M	1.18	0.74	0.60
	M	1.14	0.70	0.50
	M	1.62	0.70	0.60
	M	1.20	0.76	0.44
	M	1.10	0.70	0.50
	M	1.18	0.64	0.58
13.	M	1.18	0.76	0.46
	Ex	1.04	0.74	0.60
	M	1.12	0.70	0.58
	Ex	1.22	0.70	0.60
14.	M	1.00	0.72	0.46
	Ex	1.28	0.68	0.60
	M	1.10	0.66	0.48
	M	1.18	0.74	0.46
	M	1.18	0.70	0.52
	M	1.26	0.84	0.42

Square No.	Ex. or M.	L	H	Tp
15.	M	1.12	0.66	0.58
	Ex	1.14	0.76	0.50
	E	1.28	0.74	0.54
	E	1.14	0.74	0.50
	M	1.18	0.68	0.48
	E	1.20	0.74	0.54
	M	1.16	0.74	0.56
	E	1.08	0.72	0.48
1 16.	Ex	1.36	0.72	0.66
	M	1.14	0.72	0.46
	M	1.22	0.66	0.48
	M	1.24	0.84	0.54
17.	Ex	1.20	0.80	0.48
	M	1.16	0.76	0.48
	M	1.14	0.75	0.48
	M	1.14	0.74	0.44
	M	1.18	0.72	0.54
18.	M	1.12	0.64	0.54
	Ex	1.24	0.78	0.60
	Ex	1.22	0.76	0.60
	Ex	1.14	0.70	0.54
19.	M	1.24	0.72	0.50
	Ex	1.24	0.80	0.48
	M	1.04	0.70	0.52
	M	0.28	0.78	0.58
	M	1.04	0.70	0.60

Square No.	Ex.or M.	L	H	Tp
20.	E	1.26	0.76	0.60
	E	1.20	0.76	0.52
	NQ	1.18	0.74	0.52
	Ex	1.04	0.62	0.44
	M	1.10	0.68	0.46
	Ex	1.28	0.84	0.54
	M	1.14	0.66	0.48
	M	1.18	0.68	0.52
	M	1.20	0.60	0.50
21.	M	1.24	0.80	0.58
	Ex	1.12	0.60	0.52
	M	1.12	0.64	0.56
	M	1.20	0.70	0.54
	Ex	1.14	0.72	0.42
22.	M	1.24	0.72	0.58
	M	1.16	0.72	0.54
	Ex	1.20	0.72	0.50
	M	1.20	0.72	0.48
	Ex	1.18	0.74	0.54
	M	1.24	0.74	0.54
	M	1.12	0.72	0.48
	Ex	1.12	0.62	0.54
23.	M	1.28	0.70	0.68
	M	1.24	0.78	0.64
	M	1.04	0.60	0.50
	M	1.08	0.62	0.48
	M	1.14	0.60	0.56
	M	1.10	0.70	0.48
	Ex	1.10	0.70	0.48
	M	1.24	0.80	0.56
	M	1.18	0.76	0.34
	M	1.04	0.64	0.50
	M	1.26	0.82	0.56
	M	1.16	0.80	0.50
	M	1.24	0.76	0.52
	M	1.16	0.66	0.46
	M	1.18	0.68	0.50

DIMENSIONS OF GEISINA SUBARCUATA FROM CLAXHEUGH

Square No.	Ex or M.	L	H	Tp
8.	Ex	1.60	0.86	0.80
	M	1.20	0.72	0.60
10.	Ex	1.34	0.72	0.60
	Ex	0.82	0.52	0.40
	M	0.76	0.46	0.34
11.	M	1.00	0.58	0.
	M	1.36	0.74	
	M	1.00	0.56	0.56
14.	M	0.46	0.26	0.22
	M	0.56	0.56	0.16
	M	1.38	0.70	
	M	1.38	0.90	
	M	1.68	1.26	
	M	1.60	0.06	
	M	1.56	0.84	
	M	1.54	0.90	
	M	1.54	1.06	
	M	0.86	0.60	
		1.74	0.96	
		1.32	0.86	
		1.24	0.74	
		1.20	0.68	

Square No.	Ex or M.	L	H
	M	1.44	0.84
	Ex	1.26	0.90
	M	1.10	0.64
	M	1.44	0.88
	M	1.32	0.74
	M	1.28	0.86
	M	1.42	0.82
	M	1.46	0.88
	M	1.60	0.96
	M	1.30	0.92
	M	1.20	0.88
	Ex	1.40	0.84
	M	1.10	0.76
	M	1.56	0.98
	M	1.30	1.00
	M	1.40	0.92
	M	1.20	0.80
	M	1.52	0.98
	M	1.46	0.86
	M	1.76	1.08
	M	1.60	0.94
	M	1.36	0.78
	M	0.96	0.60
	M	0.80	0.46
	M	1.24	0.64
	M	1.58	0.94
	M	1.56	0.92
	M	1.50	0.88

DIMENSIONS OF SPECIES OF CARBONITA FROM THE HOPKINS' BAND AT VARIOUS LOCALITIES. (MEAN SPECIFIC DIMENSIONS ON Fig.3.24).

Species	L	H	Tm	Species	L	H	Tm
1. Carbonita cf. evelinae				2. Carbonita cf. rankiniana.			
	0.84	0.38	0.22		0.82	0.42	0.34
	0.86	0.38	0.28		0.88	0.46	0.40
	0.80	0.36	0.26		0.96	0.52	0.40
	0.90	0.38	0.18		0.96	0.52	0.40
	0.88	0.36	0.26		0.96	0.48	0.30
	0.84	0.34	0.24		1.08	0.60	0.30
	0.92	0.42	0.28		0.98	0.50	0.40
	0.98	0.42	0.28		0.92	0.40	0.34
	0.94	0.46	0.28		1.00	0.52	0.38
	0.94	0.42	0.30		1.00	0.56	0.42
	0.98	0.36	0.28		1.01	0.60	0.40
	0.94	0.40	0.26		1.00	0.47	0.33
	0.96	0.44	0.28		1.03	0.54	0.42
	0.98	0.42	0.32		0.90	0.53	
	0.96	0.40	0.30		0.88	0.46	0.30
	0.92	0.40	0.30		1.02	0.56	0.43
	0.96	0.38	0.30		1.04	0.61	0.42
	0.98	0.40	0.30		1.03	0.53	0.40
Mean :	0·88	0·40	0·27	Mean :	0·97	0·51	0·38

Species	L	H	Tm
4. Carbonita pungens.			
	0.56	0.28	0.22
	0.48	0.26	0.20
	0.54	0.24	0.22
	0.46	0.18	0.18
	0.40	0.15	0.14
	0.40	0.22	0.18
	0.60	0.28	0.20
Mean :	0·49	0·23	0·19

3. Carbonita humilis from Silksworth.

Female		Male	
L	H	L	H
0.65	0.47	0.67	0.42
0.68	0.48	0.76	0.48
0.66	0.48	0.74	0.49
0.63	0.45	0.68	0.44
0.70	0.50	0.65	0.42
0.71	0.61	0.73	0.42
0.64	0.43	0.72	0.44
0.66	0.50	0.72	0.40
0.65	0.45	0.74	0.45
0.67	0.45	0.71	0.42
0.63	0.44	0.74	0.44
0.66	0.44	0.72	0.44
0.61	0.49	0.76	0.50
0.66	0.44	0.66	0.38
0.68	0.45	0.69	0.40
0.74	0.46	0.65	0.42
0.62	0.45	0.68	0.39
0.72	0.50	0.76	0.43
0.67	0.48	0.68	0.45
0.69	0.45	0.75	0.45
0.70	0.47	0.71	0.45
0.71	0.48	0.71	0.44
0.68	0.44	0.74	0.47
0.67	0.46	0.75	0.47
0.69	0.47	0.80	0.47
0.57	0.45		
Mean of : 0·67	0·46	0·71	0·44

Percentage H/L 68·7% 61·9%

APPENDIX III

PETROLOGICAL NOTES AND GEOCHEMICAL DATA.

PETROLOGICAL NOTES.

BEARPARK TYPE SECTION.

Locality: old roadway 100 yards east of the shaft.

Slide: 800

½-1 inch above the seam, equivalent to geochemical sample A2 in part.

Hand specimen: Black earthy mudstone with a subconchiodal fracture not the true mudstone conglomerate. Plants and Carbonita pungens below dense band of Spirirbis

Thin section: Pale mudstone below ostracods and rare Naiadites fragments. A carbon rich argillaceous carbonate matrix with scattered detrital quartz, and ostracods.

The carbonate occurs in cloudy lumps and patches and rarely as included fragments of quartz-carbonate rock, up to 0.3 mm. in size. Detrital minerals are quartz and large scattered kaolinite flakes.

Large and strained quartz grains occur rarely.

Max. grain size of quartz. 78 mu. Vol : 6% approx. (2043 points).

Kaolinite flakes up to 120 mu. in length.

Fossil remains are separated but complete valves of thin shelled ostracods probably C.pungens, locally grouped into pockets, and plants preserved as carbon streaks parallel to the poorly developed bedding.

Slide: 801

1-1½ inches above Seam, equivalent to samples A2 and B in part.

HAND specimen: Dark grey-black earthy mudstone.

Spirorbis and Curvirimula ? fragments below, C.pungens abundant and very rare G.arcuata.

Thin section: Three fold division recognisable.

Lower: Pale argillaceous rock; clay mineral matrix appears to have been replaced by a carbonate cement. There are rare included fragments of carbonate rock, ostracods, sub-angular detrital quartz and large "book" kaolinite flakes. Complete carapaces of C.humilis and G.arcuata can be recognised as well as Spirorbis and ?Naiadites

Middle: Paler mudstone than below richer in detritals.

Large eroded quartz grains common up to 103 mu. in diameter.

Many included dark carbon rich patches.

A few lenticular lithic fragments parallel to the bedding.

Upper: Dark very carbon rich matrix with ostracods and Spirorbids.

Max. quartz grain size: 96 mu. Vol : 4% approx. (3179 points).

Slide 802.

1 -2½ inches above Seam. No equivalent geochemical sample.

Hand Specimen: Top of mudstone conglomerate, dense black rock rich in plant matter below approaching a coal above. The top surface is a layer of Cordaites and Calamites remains.

Thin section: A rock composed mostly of black isotropic carbon with cleat cracks filled with white crystalline calcite.

There is a thin layer of ostracods, spirorbids and Naiadites at the base.

The opaque coal like material appears to have shrinkage cracks filled with secondary calcite, but locally lenticular patches of crystalline pyrite replace the carbon. This pyrite is also of secondary origin. There are no detrital minerals within the coalfield material but very small rare quartz grains occur with the Cordaitid remains in the upper part,

Slide 803.

2 -2½ inches above the Seam. Equivalent to slide 171 and geochemical sample C in part.

Hand specimen: Black carbonaceous shale. Rich in fusainous plant matter and spirorbids at the base, poorer in fossils above but with an even scatter of Carbonita pungens, rarer leaf fragments and fish teeth.

<u>Thin section</u>: Black shale with strong "cryptophylite" texture, i.e. parallel orientation of clay minerals and fine "illite" flakes.

Large detrital flakes of kaolinite rounded, up to 105 mu.

sub-angular grains of detrital quartz, mean grain size: 30 mu.

Ny pyrite seen.

Fossil remains are a few ostracod carapaces and spirorbid shells.

The density of carbonaceous matter decreases upwards.

Max. quartz grain size: 72 mu. Vol : 6 % Approx. (2209 points).

<u>Slide 804</u>.

2 -3" above the Seam. Equivalent to slide 171 and geochemical sample C in part.

<u>Hand specimen</u>: Black carbonaceous shale. Layers of <u>C.pungens</u> and <u>Naiadites</u> shell fragments.

<u>Thin section</u>: Dark "cryptophyllite" shale with very little fossil material.

Small "illitic" flakes present in clay mineral matrix.

Large "lozenge" shaped kaolinites up to 100 mu.

Quartz grains small, sub-angular, mean grain size c. 30 mu.

As the slide is rather thin there is no fossil material sectioned and the volume of quartz os very low as most grains have been lost.

Max. quartz grain size: 65 mu. Vol : 3.4% (658 points).

<u>Slide 805</u>.

3 -4 inches above Seam. Equivalent to slide 181 and geochemical sample D.

<u>Hand specimen</u>: Black "cryptophyllite" shale with distinct laminae of ostracod-spirorbid <u>Naiadites</u>.remains. The shale weathers with a fine "cross-bedded" appearance, and the upper bedding surface is slightly undulating suggestive of ripples. Ostracods frequently occur in pockets.

<u>Thin section</u>: Similar shale to below but thin slice so the larger quartz may have been lost.

Fine "illite" or hydromuscovite flakes up to 50 mu. in length occur in the clay mineral matrix.

Large kaolinite flakes more abundant near the top of the section.

Quartz grains sub-angular.

Naiadites shells parallel to bedding, ostracods and spirorbis appear to disturb the clay maneral orientation slightly.

Max. quartz grain size: c.75 mu. Vol : c. 5% (1054 points).

Slide 806.

4-4½ inches above Seam. Equivalent to slide 182 and geochemical sample E.

Hand specimen: "Geisina Band". This specimen has 1/8 inch of black shale at the base, 1/4 inch of "Geisina Band", and 1/4 inch of dark gray shale above. The Geisina Band consists of undulating laminae of shale interlaminated with thicker laminae of a dense Geisina-Spirorbis-Naiadites coquina. The top of the Geisina Band is irregular and it is overlain with a brittle well-jointed grey shaley mudstone with scattered ostracods, spirorbids and Carbonicola cf. bipennis.

Thin section: Black shale; "cryptophyllite" shale densely carbonaceous, and rich in detrital quartz, with a mean grain size of about 30 mu.

Large crackes and eroded, sub-rounded, quartz grains up to 125 mu., "lozenge" kaolinites common.

Max grain size quartz: 62 mu. Vol : 7% (2329 points)

"Geisina Band"; The lower shell laminae are rich in spirorbids and Naiadites, while the upper ones are rich in spirorbids and Geisina. The shell laminae contain detrital mineral and carbon among the crushed shell material fragmentation mut no clay mineral matrix. (Some of the shell fragmentation may have occurred during grinding). In the higher laminae there are many complete ostracod carapaces seen in transverse and longitudinal section, but much of the coquina consists of crushed or separated valves. In the uppermost laminae there is a matrix of grey shale, and shell and plant fragments are replaced by pyrite.

Grey shale; A rock composed largely of pure clay minerals. The carbon and detrital mineral content falls abruptly at the top of the Geisina Band and a little pyrite appears.

The matrix of this rock is pure clay mineral in an apparently crystalline state with a slight dis-orientation around fossil fragments.

Large cracked sub-rounded quartz up to 108 mu. rare.

Very scattered sub-angular quartz, 20-65 mu.

Slide 807.

4½-5 inches above Seam. Equivalent to slide 191 and to geochemical sample F.

Hand specimen: Pale grey shaley mudstone. There is a layer of dark grey shale with crushed immediately above the Geisina Band. Within this pale grey rock there are thin but persistent darker laminae probably containing very finely divided carbon, but this cannot be seen in this section. Naiadites, Carbonicola, and Spirorbis common ostracods Carbonita rare.

Thin section: Very thin and fragmentary.

Homogenous clay mineral rock, virtually carbon free and with very scattered detrital minerals. Clay mineral matrix less than 5 mu. grain size, poorly cryptopyllite texture, extinction rosettes around fossils.

Rare detritals - subangular quartz, "lozenge" kaolinite, and illite.

Large quartz 140 mu. seen.

Max. quartz grain size: 86 mu. Vol : less than 1% (0.8% 1153 points).

Slide 808.

5-6 inches above Seam. Equivalent to slide 192 and geochemical sample G.

Hand specimen: Grey shaley mudstone with scattered Naiadites and Carbonicola, and rare ostracods.

Thin section: Very thin virtually all detrital mineral lost.

Clay minerals similar to 807.

Transverse sections of spirorbid and Naiadites shells.

A few scattered grains of sub-angular quartz much less than 1.

Slide 809.

$7-7\frac{1}{2}$ inches above the Seam, Equivalent to geochemical sample H and part of J.

Hand specimen: Grey shaley mudstone with scattered ostracods below, 1/4 inch ironstone band above.

Thin section: Homogenous clay mineral rock, no detritals.

Very small granules of carbon and scattered Pyrite and Siderite.

The clay mineral matrix is very slightly coarser than below being greater than 5 mu. There is probably ground mass quartz but no detrital quartz.

The ironstone band has an abrupt base where proportion of sphaerosiderite suddenly increases. Some of the fossil fragments within the ironstone are partly replaced by pyrite. A good transverse section of Spirorbis from this ironstone is shown in Fig. 4.3b.

Quartz volume must be very much less than 1% .

Slide 810.

$8\frac{1}{2}-9\frac{1}{2}$ inches above the Seam. Equivalent to geochemical samples J and K.

Hand specimen: Grey siderite mudstone with ironstone nodules and bands, poorly fissile.

Naiadites, both juvenile and adult occur with shell replaced by pyrite. Rare Anthracosia cf. regularis, 1/4 inch ironstone band.

Thin section: small section of siderite shale and ironstone band. Fine clay mineral matrix c. 5mu., no detritals but fine granules of sphaerosiderite.

Patches of Framboidal pyrite, up to 100 mu. within the ironstone.

Slide 811.

$9\frac{1}{2}-10$ inches above Seam. Equivalent to geochemical sample K.

Hand specimen: Pale grey mudstone, poor fissility and sub-conchoidal fracture.

Scattered pyritized Naiadites and Spirorbis. Ironstone in small indistinct patches.

Thin section: Fine even textured mudstone free from detrital minerals.

Homogenous texture of clay minerals, less than 5 mu. grain size.

No siderite seen, rare carbonaceous streaks.

Paler patches of shale, probably richer in clay size quartz.

Pyrite replacing plants parallel to the bedding, small areas of framboidal pyrite.

Very rare Naiadites replaced by pyrite.

Slide 812.

11-12 inches above Seam. Equivalent to geochemical sample L.

Hand specimen: Pale grey sideritic mudstone, poorly fissile. Lenticular ironstone nodule linch in length. Pyritized Naiadites.

Thin section: Mudstone distinctly coarser texture than that below.

Micaceous texture of clay minerals, grain size > 10 mu., random orientation.

Fine interstitial sub-angular quartz up to 20 mu.

Some larger micaceous flakes around 20 mu.

Streaks of carbon parallel to the bedding and some distinct plant fragments replaced by pyrite.

Ironstone nodule of dense granular siderite with paler patches.

Shell fragments within the nodule are pseudomorphed by pyrite.

Slide 813.

1'2"-1'2½" above Seam. Equivalent to geochemical sample N in part.

Hand specimen: Pale grey siliceous mudstone, poor fissility but flinty and sharp fracture. Slightly soapy feel. A little siderite in pale brown bands. No visible fauna.

Thin section: Coarse clay mineral matrix grain size about 10 mu., random orientation or faint parallelism. Ground mass quartz c. 10 mu.

Finely divided carbon and pyrite. Dendritic groups of pyrite seen, one 70 mu. in length and with crystalline lamellae in reflected light.

Slide 814.

1'3"-1'3½" above Seam. Equivalent to geochemical sample N in part.

Hand specimen: Pale grey siliceous mudstone as 813.

Poor in siderite, weathered surface has a coarse "cryptophyllite" appearance.

Thin section: Coarsely crystalline clay mineral rock. Faint parallel orientation of the clay minerals, except for the coarser ones c. 10 mu. Coarser flakes of kaolinite more than 10 mu.

Groundmass quartz c. 10 mu. Finely divided carbon and pyrite.

Elongate areas of dendritic and framboidal pyrite up to 50 mu., suggesting local areas of reduction, decaying organism?

Slide 815.

1'5"-1'6" above Seam. No equivalent geochemical sample.

Hand specimen: Grey siliceous mudstone similar to 813 and 814.

Thin section: Coarse clay mineral matrix with scattered Naiadites. Very rare grains of sub-angular detrital quartz associated with the Naiadites, 40, 113 and 25 mu. respectively. One large piece of "book" kaolinite attached to a Naiadites shell. 79 × 89 mu.

Naiadites shells up to 3 mm. in length, either replaced by pyrite or pyrite developed on their surface. Areas of siderite associated with Naiadites frequently contain patches up to 40 mu. in diameter and rarely granules up to 20 mu. in diameter. Finely divided pyrite granule in the patches of siderite. Some of the Naiadites have both valves still attached.

Slide 816.

1'6"-1'7" above Seam. Equivalent to geochemical sample O in part.

Hand specimen: Grey siliceous mudstone as 815.

Thin section: Clay mineral rock about 10 mu. grain size with Naiadites. Naiadites shell replaced by pyrite. Plant or shell fragment, now replaced by pyrite.seen with an attached sub-angular quartz grain 50 mu. diameter.

Siderite in small not very dense patches.

Pyrite present as scattered granules and as a mass 0.55 mm. by 0.23 mm. surrounded by siderite. Such patches do not disturb the clay minerals.

Slide 817.

1'9"-1'10" above Seam. Equivalent to geochemical sample O in part.

Hand specimen: Pale grey siliceous mudstone as 813-816.

Thin section: Similae to previous sections, but slightly richer in siderite.

Irregular crystalline patches of pyrite.

Rare crystals of quartz apparently in interstitial habit, 46, 17, 17, 26 and 86 mu.

Slide 818.

1'11"-2'0" above Seam. Equivalent to geochemical sample P in part.

Hand specimen: Grey siliceous mudstone as 817 etc. with rare plant fragments.

Thin section: Coarse clay mineral matrix 10-15 mu.

Whispy micaceous flakes up to 20 mu.

Detrital or interstitial quartz more common, 17, 20, 31, 13, 32, and 50 mu. recorded, the largest one being strained.

Plant matter as fine linear streaks or replaced by pyrite.

Rare and scattered pyrite granules.

Slide 819.

2'2"-2'3" above the Seam. Equivalent to geochemical sample Q in part.

Hand specimen; Pale grey siliceous and silty mudstone.

Irregular fracture, with a fine sparkle of small quartz grains on the fracture surface. Coarse granular cryptophyllic weathering.

Fine quartz laminae in the central part, $\frac{1}{2}$ inch ironstone above, itself overlain by a fine siltstone with mica flakes as well as quartz.

Thin section: Silty mudstone below, quartz laminae in the middle and a coarse ironstone above.

Silty mudstone; coarse micaceous clay minerals, grain size c.15-20 mu. Detrital quartz, sub-angular to sub-rounded grains scattered, 31, 24, 26, 45, 65 add 86 mu. respectively. One large patch of apparently interstitial quartz 220mu. Finely divided pyrite and carbonaceous matter.

Quartz laminae; Very fine discontinuous laminae, up to 0.4 mm. thick and 3 cm. in length. The laminae are composed of fine equigranular quartz, muscovite and cloudy and carbonaceous material. Quartz appears to have a detrital and interstitial habit.

Max. detrital grain size c.50-60 mu.

Muscovite in fresh flakes up to 85 mu. in length and may form 5-10 of the laminae. Some snall graine of quarts show indentation suggestive of pressure solution or authigenic recrystallization, perhaps during compaction of the laminae.

Ironstone; Siderite granules first appear in the darker carbonaceous patches between the pale laminae, and then appears as scattered granules in the laminae, then increase in density until the silty mudstone texture is no longer visible. There is a high proportion of sub-angular quartz granules among the siderite granules, perhaps suggesting a coarsening of the rock upwards.

Slide 820

2'7"-2'8" above the Seam. Equivalent to geochemical sample R in part.

Hand specimen: Pale grey silty mudstone approaching a muddy siltstone. Patches of pale siderite.

Thin section: Coarse clay mineral rock with a large detrital quartz content and this discontinuous quartz laminae.

Micaceous clay mineral grain size c.15-20 mu. with a large proportion of muscovite flakes c.20 mu. in the matrix.

Mean grain size detrital quartz c. 45mu., Max. c.60 mu.

Siderite present as finely scattered small granules less than 5 mu.

Small dark granules of iron ore up to 40 mu.

Vol. detrital quartz; 3% approx. (1371 points).

Slide 821.

3'0"-3'1½" above Seam.   Equivalent to geochemical sample S in part.

Hand specimen: Pale grey muddy siltstone.

Scattered carbonaceous matter at base, Cordaited probably.

Laminated with distinct paler and darker laminae up to 1/8 inch thick.

Laminae parallel not cross-bedded, may show irregular top.

Thin section: Muddy siltstone fairly homogenous but with thin discontinuous or lenticular laminae.

Dark streaks of plant material up to 0.5 mm. in length.

Detrital quartz in the siltstone up to 50 mu., larger grains in the laminae.

Laminated siltstone; thicker laminar present showing some grading.

top; Fine carbon and clay mineral rich.

Fine quarts c.30-35 mu.k mica and cloudy material.

bottom; Coarser quartz c. 60 mu., and muscovite

In the darker laminae there may be cloudy masses of siderite up to 95 mu. in diameter, with associated iron ore and pyrite.

The uppermost part of this slide is a coarse quartz-muscovite siltstone with fine sandstone laminae.   Quartz grain size c.80 mu.

These laminae are very fine and curved, indicating cross-bedding and seven alternate dark and light laminae are seen in 3mm. of rock.

Slide 822.

3'3"-3'5" above Seam.   Equivalent to geochemical sample T in part.

Hand specimen: Pale grey finely laminated muddy siltstone.

Pale laminae mostly hair-like, thickest 1 mm.

Thin section: Poorly sorted siltstone, finer laminae with quartz.

Muscovite and clay minerals, may pass laterally into coarse quartz-muscovite laminae.   Micaceous minerals only show sub-parallel orientation in the darker layers rich in carbon and clay minerals.

Small pockets of coarse quartz and muscovite may occur in the siltstone.
Quartz grain size c.30-40 mu. in the siltstone, and c.60-70 mu. in the coarser parts of the laminae.
Iron ore and siderite occur in small scattered patches.
The whole rock suggests turbulent deposition or flocculation.

Slide 823.

4'4"-4'5" above Seam. Equivalent to geochemical sample U in part.
Hand specimen; Dark grey micaceous siltstone rich in plants.
Impressions of *Calamites* and *Cordaites* and small *Calamites* with attached spirorbids.
Thin section: Poorly sorted muddy siltstone that becomes coarser upwards to form a fine carbonaceous and micaceous sandstone. The basal siltstone is faintly laminated with scattered sub-angular quartz 50, 34, 36, 73, and 80 mu. Possible decayed felspar c.25 mu. In the arenaceous laminae within the siltstone the quartz grain size may be rarely 125 mu., but 80-90 mu. is more common.
There is a mixed layer of densely carbonaceous siltstone and sandstone, 3 mm. in thickness, with sub-rounded and cracked quartz 103,140 mu., muscovites more than 100 mu. in length and siderite up to 150 mu. in diameter.
Arenaceous layer; 1 mm. sandstone layer - large sub-angular quartz, muscovite and biotite and patches of siderite.
Mean quartz grain size c.90 mu., Max c.120 mu.
No carbon in this band.
Biotite in fresh, whispy flakes, pale brown, strongly pleochroic up to 180 mu. in length, less abundant than the muscovite.
Some of the large quartzes in this band are strained.
Plant rich layer; 1 mm. layer above arenaceous biotite layer contains the plant seen in the hand specimen. Abundant plant matter and coarse mica, muscovite up to 1.75 mm. measured.
Scattered biotite also occurs at this level.

Slide 824.

4'11"-5'0" above Seam. Equivalent to geochemical sample V in part.

Hand specimen: Dark grey muddy siltstone below and a shaley mudstone above. The basal siltstone is rich in plant matter and muscovite, and thin shale laminae or pellets.

The uppermost shaley mudstone contains fossil remains, of Naiadites, Anthracosia and ostracods Carbonita pungens and humilis.

Thin section: Mixture of shale, mudstone and siltstone.

Layer if fine "cryptophyllite" shale at the base, overlain by a laminated silty mudstone, a poorly sorted siltstone and a shale. The lowest two lithologies are penetrated by a transcurrent worm burrow.

Basal shale: Presumably a shale pellet as seen in the hand specimen.

"Cryptophyllite" shale, homogeneous clay minerals, with a grain size of less than 5 mu. Scattered detrital quartz and mica.

Max. quartz grain size 58 mu.

Silty mudstone: Mudstone with a finely crystalline matrix of clay mineralsy c. 10 mu. grain size. Detrital quartz up to 80 mu., small patches of ironstone and carbonstreaks.

There is an impersistant layer of quartz-muscovite-biotite sandstone at the base of the mudstone.

Muddy siltstone: This layer is 1 cm. in thickness and from it the worm burrow descends through the underlying layers.

1 mm. arenaceous layer at the base. Poorly sorted siltstone rich in clay material, carbon streaks and small ironstone patches.

Detrital quartz and muscovite, included fragments of shale up to 1 mm. in size.

Mudstone: Abrupt base above siltstone, fine homogeneous mudstone with included coarse muscovite flakes as in the rocks below. Detrital quartz, carbon streaks and iron stone as below.

Other slides from Bearpark type section.

Slide 171.

$2\frac{1}{2}$-3 inches above the Seam.

Hand specimen: similar to slide 803.

Thin section: As 803. Fine lamination present due to differences in the content of carbonaceous material. Rare sub-angular Zircon grains. A little pyrite seen. Kaolinite up to 140 mu. present, quartz mean grain size c. 25 mu.

Max. quartz grain size, 55 mu. Vol : 9% approx. (1789 points).

Slide 172;

3-$3\frac{1}{2}$ inches above Seam, equivalent to slide 804.

Hand specimen: Similar to slide 804.

Thin section: Rather thin, larger quartz lost. Kaolinites up to 62 mu.

Max. quartz grain size: c.40 mu. Vol : 7% approx (6.8, 486 points)

Slide 181.

$3\frac{1}{2}$-4 inches above Seam. Equivalent to slide 805.

Hand specimen: As slide 805 but with *Lepidostrobus* cone.

Thin section: Fragmentary, quartz lost.

Kaolinite c. 112 mu. seen.

Slide 182:

4-$4\frac{1}{2}$ inches above Seam. equivalent to 806.

Hand specimen: "Geisina Band".

Thin section: Thick slide. As slide 806.

Mean grain size of quartz; c.40 mu.

Max. quartz Grain size; c.75 mu. Vol : 5% (4.8) all constituents (5127 points)
7% (7.25) minus calcite

Slide 191.

$4\frac{1}{2}$-5 inches above the Seam. Equivalent to slide 807.

Hand specimen: Similar to 807, but with fine colour laminae.

Thin section: As 807.

Quartz rare or lost c.10 mu. only seen, eroded grains c.50 mu.

"book" kaolinite present but rare.

Framboidal pyrite up to 30 mu. rare.

Vol. quarts;	c.0.5%	(3550 points)		
191a	0.4%	(2000 points)	Max. grain size;	55 mu.
191b	0.8%	(4000 points)	" " "	62 mu.

Slide 192.

5-6 inches above Seam. Equivalent to slide 808.

Hand specimens: As slide 808.

Thin section; " " " Kaolinite flakes up to 120 mu.

Two types of quartz. Large sub-rounded up to 125 mu.

Small sub-angular c. 30 mu.

Max. grain size: 77 mu. Vol quartz less than 1% .

Slide 201.

6½-7 inches above seam. No equivalents.

Hand specimen: Grey shaley mudstone with ironstone nodule.

Thin section: Very thin slide, mainly all siderite granules. c.7-20 mu. in diameter.

Very rare quartz, only one seen c.19 mu. Vol far less than 1% .

Slide 211.

8 -8 inches above the Seam. Equivalent to slide 810.

Hand specimen: As 810 but without ironstone.

Thin section : Clay mineral matrix less than 8 mu.

Quartz rare but mean grain size; c.26 mu., Max. c.65 mu.

Pyrite replacing plant fragments.

Vol quartz far less than 1% .

Slide 921.

0-2 inches above the Seam. Equivalent to 800 in part.

Hand specimen: Full succession of mudstone conglomerate.

Upper 1 inch comparable with slide 800, lower 1 inch equivalent to geochemical sample A1.

Basal 1 inch: Pale grey mudstone conglomerate with carbonaceous partings and veinlets.

Thin section: A very thin fragment of the lowest ½ inch only.

Lenticular mudstone pellets in a matrix of fairly coarse clay minerals.

Detrital minerals have been lost from the matrix except for quartz c.53 mu.

Lithic fragments are a pre-existing mudstone with detrital quartz and perhaps felspar. These fragments are often outlined with carbonaceous matter, and there are distinct carbon streaks.

Pyrite occurs in framboidal and spongy patches up to 2 mm. in diameter no distinction carbonate cement of the matrix can be seen as in slide 800.

Slide 990.

4-4½ inches above the Seam. Equivalent to slides 806 and 182.

Hand specimen: "Geisina Band". As 806.

Thin section: Threefold division discernable as in slide 806.

Black shale: Vol detrital quartz; 10% (10.1 , 1291 points).

Max. grain size; 75 mu.

Geisina Band: Many complete ostracod carapaces well preserved.

Grey shale: Vol detrital quartz: 1.4% (1.37 , 1023 points)

Max. grain size 84 mu.

Slide 970.

1'9" above the Seam. Equivalent to slide 817.

Hand specimen: Pale grey siliceous mudstone, as slide 817.

Thin section: Similar to slide 817. Quartz very rare, one grain c.12 mu. only seen. Small patches and bands of a pale brown material, perhaps Collophane phosphate.?

WHITWORTH OPENCAST Locality 7.

(See photographs on Plate IX + X)

Slide 700.

0-1 inch above Harvey Seam.

Hand specimen: Mudstone conglomerate, containing lenticular fragments of mudstone up to 1 cm. in length in a matrix rich in carbonaceous matter.

Thin section: Matrix: Mostly clay miheral material with abundant quartz, Carbon streaks and pyrite.

Quartz in sub-angular and subrounded grains, largest showing strain and up to 310 mu. in size.

Pyrite in large irregular spongy patches, replacing plant matter and often associated with brown patches suggestive of the mineral Collophane.

Included fragments; mudstone fragments, lenticular and with well defined edges, often outlined by carbon streaks.

These fragments are of a pale grey mudstone, composed of clay minerals and a little detrital quartz but no carbonaceous matter.

Quartz grains within the mudstone are distinctly strained and up to 112 mu. in size.

Specimen 701.

1-1½ inches above Seam.

Hand specimen only; Pale grey mudstone conglomerate with pyritized Lepidodendron fragment.

Specimen 702.

2-2½ inches above Seam.

Hand specimen only. Fine mudstone conglomerate with black matrix below, an earthy black mudstone above.

Slide 703.

$2\frac{1}{2}$-3 inches above Seam.

Hand specimen: Base of black carbonaceous shale.

Thin carbon partings at the base. Sigilaria bark and Lepidostrobus cone,

C.pungens, rare G.arcuata and spirorbids.

Thin section: Carbon rich "cryptophyllite" shale, similar to slides 803 and 171 at Bearpark Type Section.

Twotypes of quartz grains grains and detrital kaolinite common.

Quartz mean grain size; c.50 mu., Max. c. 82 mu.

Kaolinite up to 103 mu.

Slide 704.

5-$5\frac{1}{2}$ inches above Seam.

Hand specimen only: Top of black shale, rich in ostracods, spirorbid, Naiadites and plant fragments.

Slide 705

$5\frac{1}{2}$-6 inches above Seam.

Hand specimen: Thin "Geisina Band", 1/4 inch dense Geisina Band, 1/4 inch of grey shale above.

Thin section: Very good slide, three fold division as Bearpark 806, 182 and 990.

Detrital quartz and kaolinite common in lower part of the slide.

Max. quartz grain size; 96 mu. Vol : 6% (6.25, 721 points).

Max. grain size in the grey shale 86 mu., large grains c.130 mu.

Slide 707.

About 1'4" above the Seam.

Hand specimen: Pale grey sideritic mudstone, scattered Anthracosia and Naiadites.

Thin section: Coarse clay mineral rock without detrital minerals but with small spheres of framboidal pyrite.

Fine carbon streaks.

Slide 709.

About 2' 3" above the Seam.

Hand specimen: pale grey siliceous mudstone.

Thin section: Coarse textured clay mineral and mica rock.

Quartz and clay grain size about 10 mu.

Rare scattered larger quartz grains and muscovite up to c.90 mu.

Carbon streaks parallel to the bedding.

Slide 711

About 3'3" above the Seam.

Hand specimen: Pale grey micaceous siltstone passing into a fine micaceous sandstone above.

Thin section: Micaceous siltstone with fine arenaceous bands.

Composition similar to slide 822 from a similar level above the Seam at Bearpark.

There is a slight lineation of carbonaceous matter and small angular pyrite grains.

Slide 710.

About 3'4" above the Seam.

Hand specimen: A fine buff coloured quartz mica sandstone with laminae of coarser muscovite and plant fragments, current bedded.

Calamitid, Cordaitid and Neuropterid plant fragments are discernable.

Thin section: Fine equigranular sandstone, fresh sub-angular quartz and unorientated muscovite.

Cross bedding outlined by clay mineral material and plant remains.

One fresh fragment of Plagioclase felspar seed, c.112 mu. in length, well twinned and with an extinction angle of about 30 degrees, thus perhaps Andesine-Labradorite in composition.

Max. grain size of quartz: 173 mu.

EPPLETON Locality 19.

Slide 722.

0-1 inch above Seam.

Hand specimen: Fine mudstone conglomerate. Pale buff mudstone fragments in a pale grey matrix. Sub-parallel orientation of the fragments.

Thin section: A pale matrix of carbonate mud, containing carbon, detritals and fragments of a carbonate rock.

There are patches of fine crystalline carbonate in the argillaceous matrix.

The matrix includes two forms of detrital quartz, sub-rounded grains being up to 130 mu. in size, detrital kaolinite, streaks of carbon, patches of pyrite and ostracod shells.

Some of the lithic fragments are lenticular in shape of a black quartz rich shale.

Carbonate: This occurs both as primary lithic fragments, of a cloudy appearance, and as clear recrystalline carbonate.

The recrystalline carbonate has a high relief, two good cleavages, high order polarisation colours, and a refractive Index of

There is no acid reaction of this carbonate, but it is sometimes rimmed with iron.

The above characters would suggest that this carbonate is Ankerite.

Slide 723.

3½-4 inches above the Seam.

Hand specimen: Dark grey carbonaceous flinty mudstone.

Thin section: Argillaceous matrix rich in carbonate and carbon.

Detrital quartz, and kaolinite and pyrite replacing plant matter common.

Patches of an ostracod spirorbis coquina.

Slide 725.

5½-6 inches above the Seam.

Hand speciman: "Geisina Band", dark and pale grey shale.

Irregular undulating bedding visible.

Thin section: "Cryptophyllite shale throughout.

Ostracod-Naiadites coquina concentrated more into pockets than into a dense layer.

Max. grain size detrital quartz: 55 mu. Vol : 3% (2.65, 1035 points).

Abrupt base to the pale grey shale above, rarer detrital minerals plants replaced by pyrite locally.

Slide 720:

8-10 inches above the Seam at Eppleton.

Hand specimens: Grey laminated shaley mudstone. Distinct paler and darker laminae with very faint current texture seen.

Thin section: Fine laminae due to variation in iron distribution and content of very finely divided carbonaceous matter.

Medium coarse clay minerals c. 15 mu., rare scattered Quartz c. 38 mu.

There may be some grading in the laminae, with the coarser and darker material at the base, finer and paler at the top.

FOLLONSBY Locality 4

Slide 726.

5½-6 inches above the Harvey Seam.

Hand specimen: Dense "Geisina Band" 1 inch thick.

Thin section: Succession of thin shale laminae between coquina layers.

Many complete ostracod carapaces.

Plant fragment seen enclosing a subrounded quartz grain c.108 mu.

Max. grain size: 65 mu. Vol : 7% (6.9 887 points).

Slide 728.

About 2 feet above the Seam.

Hand specimen: Pale grey siliceous mudstone, similar to slides 818 and 819 from Bearpark.

Thin section: As Bearpark 818, with rare quartz about 35 mu. A layer of granular but cubically crystalline pyrite, with granules about 50-70 mu. in diameter.

Slide 727.

About 2'2" above the Seam.

Hand specimen: Pale grey silty mudstone similar to slide 819.

Thin section: Mudstone rich in silt and with this quartz laminae.

Fine even bedding outlined by carbon streaks.

Quartz max. grains size; 70 mu. one sub-angular felspar crystal seen

Plagioclase ? c. 56 mu.

Granulae and streaks of pyrite after plants.

BATES, BLYTH. Locality 2.

Slide 730

-1 inch above the Beaumont Seam.

Hand specimen: Basal 1 inch of mudstone conglomerate.

Pale lenticular rock fragnemts in a grey matrix. Pyrite nodules.

Thin section: A fine argillaceous matrix rich in carbonate and streaks of carbon.

Detrital quartz c. 60 mu. and kaolinite c. 130 mu. are common.

The included lithic fragments are sub-rounded and cloudy and some have recrystallized to form equigranular patches of carbonate with the original fragmental shape.

Frequent patches of framboidal pyrite.

Slide 732

$1\frac{1}{2}$-$2\frac{1}{2}$ inches above the Seam.

Hand specimen: Dark grey shightly silty shale, with Naiadites and ostracods.

Thin section: Cryptophyllite shale with finely divided carbon.

Rich in small elongate sub-rounded flakes of kaolinite about 100 mu. but rarely up to 140 mu.

Max. quartz grain size; c.85 mu., mean c. 60 mu.

Slide 732.

About $3\frac{1}{2}$ inches above the Seam.

Hand specimen: Grey silty shale with Geisina in laminae.

Thin section: Poorly bedded silty shale, rich in small grains of sub-angular quartz, poorer in kaolinite than the rocks below.

Bedding disturbed around shell fragments. Fish spines and ostracods.

Max. quartz grain size: 100 mu. (85-90 common)

Vol detrital quartz: 12% (4460 points).

Slide 733.

$3\frac{1}{2}$-4 inches above seam.

Hand specimen: "Geisina Band", dark grey silty shale

Thin section: Similar to 732.

Poorly sorted silty shale, undulating bedding.

Geisina carapaces not very dense restricted to pockets or discontinuous laminae.

Mean grain size detrital quarts: 45 mu. Max. 105 mu. (c. 90 common)

Volume detrital quartz: 13% (13.2, 2212 points).

Slide 734

$6\frac{1}{2}$-7 inches above Seam.

Hand specimen: Pale grey shaley mudstone with $\frac{1}{8}$ inch band of ironstone.

Bed of Naiadites and scattered ostracods.

Thin section: Cloudy mass of siderite, clay minerals replaced. No detritals seen.

Naiadites partially replaced by pyrite.

Slide 735

1'0"-1'1" above Seam.

Hand specimen: Grey muddy and micaceous siltstone, plant fragments and Anthracosia. Surface texture suggestive of fine current deposition.

Thin section: Coarse texture of unorientated clay minerals detrital sub-angular quartz c. 80 mu. and fresh muscovite c. 50 mu.

Muscovite grains in the matrix are less than 40 mu.

Slide 736

About 3'6" above Seam.

Hand specimen: Grey macaceous laminated siltstone.

Thin section: Similar to slide 822 from Bearpark Type Section.

Linear orientation of coarse muscovites.

LANCHESTER locality 17

Slide 942

About 1'2" above the Harvey Seam.

Hand specimen: Dark grey micaceous siltstone, with fine muscovite grains up to 0.25 mm. in length, and scattered plant fragments.

Thin section: Fine micaceous and carbonaceous siltstone.

Equigranular texture of sub-angular quartz grains up to 110 mu.

Interstitial muscovite and kaolinite flakes. Pale bands and lenticles of coarse quartz -mica mosaic.

Large "book" kaolinites, sub-angular, i.e. without the rounded ends usually seen in these flakes, up to 151 mu. in length.

Muscovite flakes up to 250 mu. in length.

Large angular grains of black iron ore.

Carbonaceous matter similar grain size to the micas.

Matrix of coarse clay minerals.

Vol.% quartz: 15% (14.8, 9 49 points)

Slide 943

As for slide 942.

Hand specimen and thin section similar to slide 942.

Vol% quartz: 14% (13.6, 323 points).

The quartz content for both these slides may be low due to loss of quartz during grinding.

TANFIELD LEA   Locality 11.

Slide 960

6-12 inches above the Harvey Seam.

Hand specimen: A 6 inch succession of laminated muddy soltatone and fine sand stone. Horizontal persistance of laminae without change in thickness.

Dark laminae of plant rich micaceous siltstone up to ½ inch thick.

Paler laminae of fine grey-buff sandstone or siltstone that increase in thickness vertically. These laminae may show a slight lateral thickening but this may be due to compaction differences.

Thin section: Banded nature very well see.

Darker bands: Mainly composed of fine lineated muscovite flakes with streaks of carbonaceous matter, very little distinct clay mineral material is visible. Small sub-angular quartz c. 30 mu., probably in a similar propoetion to slide 942 and 943.

Dark iron ore grains occur, but no kaolinites.

Lighter siltstone bands: Some times as in the darker bands but without carbonaceous matter.

Generally a rock composed of fine muscovite and clay minerals with very little detrital quartz or carbonaceous matter.

Where there are thin dark laminae within the paler ones there is an increase in the grain size and proportion of the detrital quartz.

Arenaceous bands: Fine grained clear quartz-muscovite sandstone

Equigranulae texture of sub-angular quartz grains 70-140 mu. in the largest dimension, mean c. 86 mu.

Quartz forms 54 approx. of the rock.

Fresh flexible flakes of muscovite up to 250 mu. in length and not orientated with respect to quartz. Vol . 18% Approx.

Patches of decayed and cloudy material, not identifiable, 28 or rock.

There are very scattered patches of framboidal pyrite up to 100 mu. in diameter.

Slide 961

About 10 inches above the Harvey Seam.

Hand specimen: Dark grey muddy and plant rich siltstone and sandstone. Recognisable Neuropterid and Cordaitid plant remains.

Thin section: Largely an arenaceous band, similar to the coarser band of slide 960. Layer with many small spheres of framboidal pyrite in association. Spheres between 20 and 60 mu. in diameter, some associated with plant remains or cloudy material.

CUMBERLAND.

NELSON PARK PIT, BROUGHTON MOOR, nr. MARYPORT.

Slide 940.

About 6½-7 inches above the Eighteen Inch Seam.

Hand specimen: Dark grey shale with dense ostracod coquina and crushed mussels, *Anthracosia* and *Naiadites*.

Thin section: Dark carbonaceous shale with dense coquina. Poor "cryptophyllite" texture, very little detrital muscovite.

Detrital quartz - sub-angular grains, c. 55 mu. max.

sub-rounded grains, c. 125 mu. max.

Large irregular crystals, cracked, moderate relief, pale brown colour and isotropic. Probably Collophane.

Also in patches up to 0.5 mm. diameter.

Ostracod carapaces mostly separate often crushed, few complete carapaces in various orientations.

Volume % of detrital quartz; 2 % approx. (1.96, 1325 points).

X-RAY DIFFRACTION RESULTS

Mineral	Lattice index	d-spacing Å-units	2θ angle degrees	Intensity
Chlorite	001	6.2	14.3	70
Mixed-lattice Illite	001	10.0	8.5 - 9.0	100
Kaolinite	001	8.15	12.2 - 12.4	100
Chlorite	002	7.15	c.12.4	100
Illite	002	4.48	19.7 - 19.9	90
Quartz	100	4.26	20.7 - 20.9	35
Siderite		3.59	24.7	60
Kaolinite	002	3.57	24.8 - 24.9	100
Quartz	101	3.34	26.7	100
Illite	003	3.33	26.7	90
Albite		3.20	27.8 - 27.9	100
Calcite		3.04	29.4	100
Ankerite	211	2.899	30.7	500
Siderite		2.79	c.31.7	100
Pyrite		2.71	33.0	84
Illite	004	2.57	34.8 - 34.0	54
Kaolinite	003	2.33	38.4 - 38.6	90

CuK radiation

Conclusions on the nature of the Carbonate mineral in samples A2 and B .

On the defractometer chart of sample A2 a peak is present at $30.7^\circ 2\theta$ and at $30.75^\circ 2\theta$ on chart of sample B. The position and cell size, 2.90°A, suggest that the mineral present is a carbonate, either Dolomite or Ankerite. The exact position of the peak is closer to the maximum intensity of Ankerite (211), 2.899 A, $30.76^\circ 2\theta$. than of Dolomite (211), 2.886 A, $30.9^\circ 2\theta$. (Howie and Broadhurst, 1959). Chart A2 a higher peak about $41.0^\circ 2\theta$, which although diffuse when compared in intensity with the peak at $30.7^\circ 2\theta$ is suggestive of Dolomite.

A series of peaks at 41.0°, 50.5° and $51.0^\circ 2\theta$, show an approximately equal intensity being suggestive of the 30 I, of Ankerite, (210), (332), and (333), rather than the intensities, 150. 100 and 150 I, typical of the similar lattice spacings of Dolomite. A comparison of the size of the respective peaks described above from the two X-ray charts, indicate that there is between two and three times as much of the carbonate mineral in sample B than in sample A2. If this carbonate mineral is Ankerite, as the X-ray evidence suggests then the increase in the amount of this mineral accounts for the 2 % increase in the content of total Fe_2O_3 seen in sample B. (See chart of geochemical data that follows.) Although sample A2 contains the carbonate mineral it does not have an appreciably higher total Fe content than sample A1.

It is concluded, therefore, that the carbonate mineral present in these samples is probably Ankerite, although Dolomite, low in total Fe, may be present in sample A2.

GEOCHEMICAL RESULTS OF SHALES BP. 105 SERIES.

	A_1	A_2	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	T	U	V	HMB
Na_2O	0.22	0.22	0.26	0.27	0.29	0.32	0.36	0.31	0.35	0.28	0.29	0.29	0.31	0.35	0.30	0.31	0.38	0.42	0.47	0.41	0.47	0.40	0.60
K_2O	1.90	1.90	1.90	2.15	2.27	1.37	2.55	2.52	2.40	2.13	2.64	2.06	2.37	2.35	2.08	2.18	2.05	2.08	1.98	2.11	2.06	2.28	3.74
Total Fe	2.72	2.70	4.79	2.72	2.70	2.90	2.24	2.90	3.30	9.52	3.24	9.21	6.75	4.10	10.30	5.66	6.02	7.25	9.30	17.75	8.84	4.82	4.35
P_2O_5	0.34	0.31	0.35	0.17	0.19	0.27	0.14	0.084	0.088	0.17	0.074	0.084	0.18	0.11	0.09	0.092	0.097	0.082	0.11	0.14	0.15	0.11	0.22
CO_2	3.2	11.82*s	14.8	2.20*s	2.2	13.92*s	2.0	1.4	1.1	4.63*s		4.6		1.4	5.70*		4.75		5.65	11.3	4.9	2.45	1.0
Organic carbon	8.4	5.3*	4.9	8.0*	4.6	2.5*	0.75	0.69	0.75	0.6*		0.89		0.64	0.5*		0.39		1.0	0.26	0.83	0.71	2.76
Sulphur	0.46*		0.67*			0.94*				0.10*					0.22*								
Na/K ratio	0.17	0.17	0.20	0.19	0.19	0.34	0.21	0.18	0.22	0.19	0.16	0.21	0.20	0.22	0.22	0.21	0.28	0.31	0.36	0.29	0.31	0.26	0.24
Total alkalis	2.12	2.12	2.16	2.42	2.56	1.69	2.91	2.83	2.75	2.41	2.93	2.35	2.68	2.70	2.38	2.49	2.43	2.51	2.45	2.55	2.49	2.68	4.34
Total carbon	8.5	9.4*	9.2	8.5*(8.2)	5.2	6.3*(6.2)	1.3	1.1	1.1	1.9*		2.1		1.0	2.1*		1.7		2.5	3.34	2.2	1.4	3.03

* Analysis made by Coal Survey Laboratory, Newcastle.

s - Sample used as a standard to calibrate CO_2 tube.

HMB - ?*Lingula* shale from the Harvey Marine Band, Harton Colliery County Durham. For comparison.