The faunel content, the variation and distribution of the shell beds of the limestone coal group of Ayrshire considered in relation to the cyclic sedimentation

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The work presented in this thesis has been performed by me, except where mentioned in the text and in such cases a full acknowledgement of the sources is given.

20th April, 1953.

G.M. Bennison.

THE FAUNAL CONTENT, THE VARIATION AND DISTRIBUTION OF THE SHELL BEDS OF THE LIMESTONE COAL GROUP OF AYRSHIRE CONSIDERED IN RELATION TO THE CYCLIC SEDIMENTATION.

by

George Mills Bennison.

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CONTENTS

I. Introduction.

It has long been known that lamellibranchs, probably of non-marine type, occur at two horizons in the Limestone Coal Group of the Lower Carboniferous of North Ayrshire. Craig (1883) described the marine fauna of the group but failed to distinguish between the marine and non-marine lamellibranchs. Subsequent workers on the Scottish Lower Carboniferous rocks have made but passing reference to these fossils.

The general stratigraphy has been described by Macgregor (1930) and the main variations in thickness of the groups of Carboniferous strata were discussed by Richey (1935).

The purpose of this thesis is twofold: to describe in more detail than has hitherto been attempted the fossils from the Limestone Coal Group, with particular reference to the lamellibranchs, and to give an account of the stratigraphy. The range, geographical extent and affinities of the fossils are here considered and statistical and graphical representation of the communities has been employed, both to give a clearer conception of the great variability of the forms dealt with, and to clarify their position in relation to other Carboniferous non-marine/

marine lamellibranchs. The stratigraphy is discussed in the light of present knowledge of sedimentation, relating this to the occurrence or non-occurrence of the faunas, thus contributing to our knowledge of their palaeoecology.

Ayrshire falls naturally into four areas separated by major faults. Richey (1935) in a comprehensive paper on Carboniferous Sedimentation has shown that these faults were, at least in part, contemporaneous for they separate areas in which the rocks differ considerably in thickness. The Limestone Coal Group for example, which immediately to the north of the Dusk Water Fault attains a thickness of six hundred feet, is found to be greatly attenuated south of the fault where it is no more than half this thickness.

Changes in the faunal content of the principal fossiliferous horizon of the group, the Johnstone Shell Bed, have been observed and related to the changes in thickness of the group. A detailed study of the rhythmic units, or cyclothems, has shown the nature of this relationship.

The four areas as given by Richey (op. cit.) are as follows:-

(A) North of the Dusk Water Fault.

(B) Between the Dusk Water and Inchgotrick Faults.

(C) Between the Inchgotrick and Kerse Loch Faults.

(D) Between the Kerse Loch Fault and the Southern Upland Boundary Fault.

This work, which has been extended to cover all these areas, shows that the lamellibranchs of non-marine type are confined to the northern area (Area 'A'), which is therefore dealt with in detail. A general consideration of the remaining areas is given and the implications which may be drawn from the absence of the non-marine lamellibranchs are discussed.

The succession of rocks dealt with, the Limestone Coal Group, is defined as the strata from above the Top Hosie Limestone to immediately below the Index Limestone. In addition the fauna of the shales below the former have been examined to determine the relationship to faunas of the overlying strata.

<u>Collection of material</u>.

All localities throughout Ayrshire where the Limestone Coal Group has been shown to outcrop were examined and collections made from all the fossiliferous localities. In addition, material collected by members of H. M. Geological/

Geological Survey was examined for comparison with the material which I had collected, and further, the records of the Geological Survey were consulted to find all localities from which material had been recorded.

The mudstone of the lower shell bed, the Johnstone Shell Bed weathers to a depth of several feet at any outcrop. This makes the collecting of good material a long and difficult task as the shells tend to crumble.

The shells of the higher important fossiliferous horizon, the Maich Shell Bed, occur in a hard, calcite-cemented shale or in ironstone. No shells have been obtained from the latter although sections cut show the form of the shells. With perseverance fossils can be obtained from the shale, though rarely complete since the matrix is considerably harder than the calcite shells. A number of the diagrams are therefore restorations.

II. The General Lithology of the Limestone Coal Group.

North of the Dusk Water Fault the Limestone Coal Group consists of six to seven hundred feet of dominantly shaly beds. The shales and mudstones ('blaes') are of blueish grey colour but they become brown and 'irony' on weathering. Sandier shales ('fakes') are common and sandstones of lenticular form occur. Coals accompanied by seat-earths are present in the upper part of the group. No true limestones occur and the marine horizons are calcareous shales, so that the name of the group is perhaps less suitable than that by which it was formerly known, 'The Coal and Ironstone Group'. Several ironstones are present; the two chief ones, which were formerly worked, serve as useful index horizons.

The group as a whole is typical of shallow coastal water and brackish swamp sedimentation - the latter may have been estuarine - and there is a general lithological similarity to the Coal Measures of Upper Carboniferous (Westphalian) age.

The shales and mudstones are of remarkable uniformity throughout the area, and such lithological variations as do occur are of little help in placing a bed in the succession.

Maich Water, lying one mile north of Kilbirnie, may be considered to be the 'type succession'. Here the whole of the Limestone Coal Group, except for perhaps a hundred feet of strata cut out by faulting, is exposed in the stream valley above Kerse Bridge for about one mile. The shales and sandstones not far below the Index Limestone are encountered at the bridge; immediately upstream the coals of the upper part of the group outcrop. The general dip is to the south so that proceeding upstream successively lower beds are found. Detailed mapping on the scale of six inches to the mile was carried out but the map is not included: the information gained has been used to compile a succession and to construct a diagram showing the cyclothems.

As well as the principal ironstones all the fossiliferous horizons are well developed in the Maich Water section. The general succession is shown in figure 1.

Rhythmic Sedimentation.

Rhythmic sedimentation is characteristic of much of the Carboniferous system in Britain. Here in Scotland, where the Lower Carboniferous consists of inshore and estuarine deposits, the rhythm is well developed. The rhythmic nature of the sediments can be explained, as suggested/

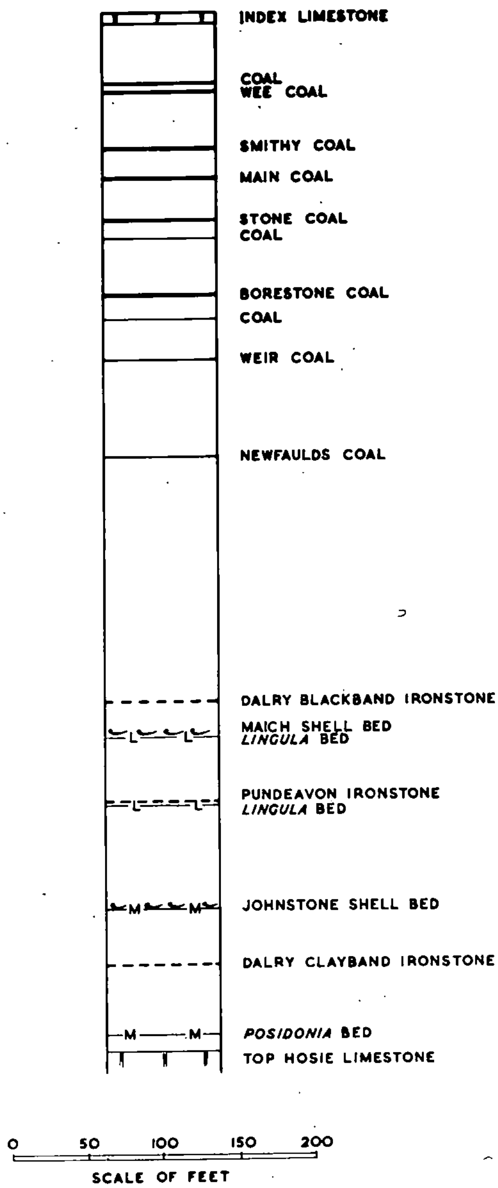


Figure 1.- General succession of the Limestone Coal Group of North Ayrshire to show the principal horizons.

suggested by Peach, by supposing that the beds were laid down over a gradually sinking area, but that subsidence was intermittent. Richey has shown that this subsidence was also differential, thus accounting for the lateral variations in thickness of the strata.

Short periods of relatively rapid depression alternated with longer periods of slow downward movement, during which silting up of the area of deposition took place. There is some evidence that actual uplift took place at times thus accelerating the process of silting up, although it was never sufficient to produce disconformity.

Richey (1935) recognised a rhythmic cycle of sedimentation in the Carboniferous Limestone Series as follows:

11. Coal.
10. Fireclay.
9. Shale.
8. Sandy shale.
7. Sandstone.
6. Sandy shale.
5. Shale, often bituminous, with b) Estuarine fish.
   a) <u>Lingula</u>.

4. Calcareous shale with b) Lamellibranchs.
   a) Brachiopods and a marine fauna.

3. Limestone with marine fossils.

2. Calcareous shale with b) Brachiopods and a marine fauna.
   a) Lamellibranchs.

1. Shale, often bituminous, with b) *Lingula*.
   a) Estuarine fish.

As Richey states "The lowest part of the sequence below the limestone is often absent". This is especially true of the Limestone Coal Group and, further, the limestone member of the cycle is always absent.

A detailed succession measured in Paduff Burn, Kilbirnie, illustrates the general lithology of the group and an attempt has been made to relate it to Richey's cycle (figures in parenthesis correspond).

(7)	20'-30'	Massive sandstone.
(6)	30'-40'	Shales.
(5) & (4b)	4' 6"	(Shales with *Lingula*. (Shales with lamellibranchs and *Lingula*.
(?)	2"	Hard shale.
	6"	Nodular shale.
	1' 6"	Shales (base not seen).

Beds (5) and (4) are not, in this case distinct, but lamellibranchs decrease numerically upwards whilst Lingula increases.

Where the Johnstone Shell Bed is well developed with a lower marine 'leaf' and an upper 'leaf' with a Carbonicola fauna, as for example in Kersland Glen, then it corresponds to bed (4) of the cycle.

There are, in the Limestone Coal Group, no less than thirteen rhythmic cycles but in no case is the cycle complete. In the lower part of the group the higher parts of each cycle, i.e. the coal and fireclay, are always absent, due to renewed sinking and the initiation of a new cycle before the previous one was complete. The cycles of the upper part of the group are less well defined and are also incomplete. The succession towards the top of the Limestone Coal Group consists essentially of sandy shales, sandstones and coals. The latter, though too thin to be worked in this northern area of Ayrshire, are numerous. Here then the lower units of each cycle are lacking, due to insufficient sinking of the area of deposition to permit the encroachment of the sea, and the beds are of a more deltaic character.

This is summarised in figure 2 which is a composite section/

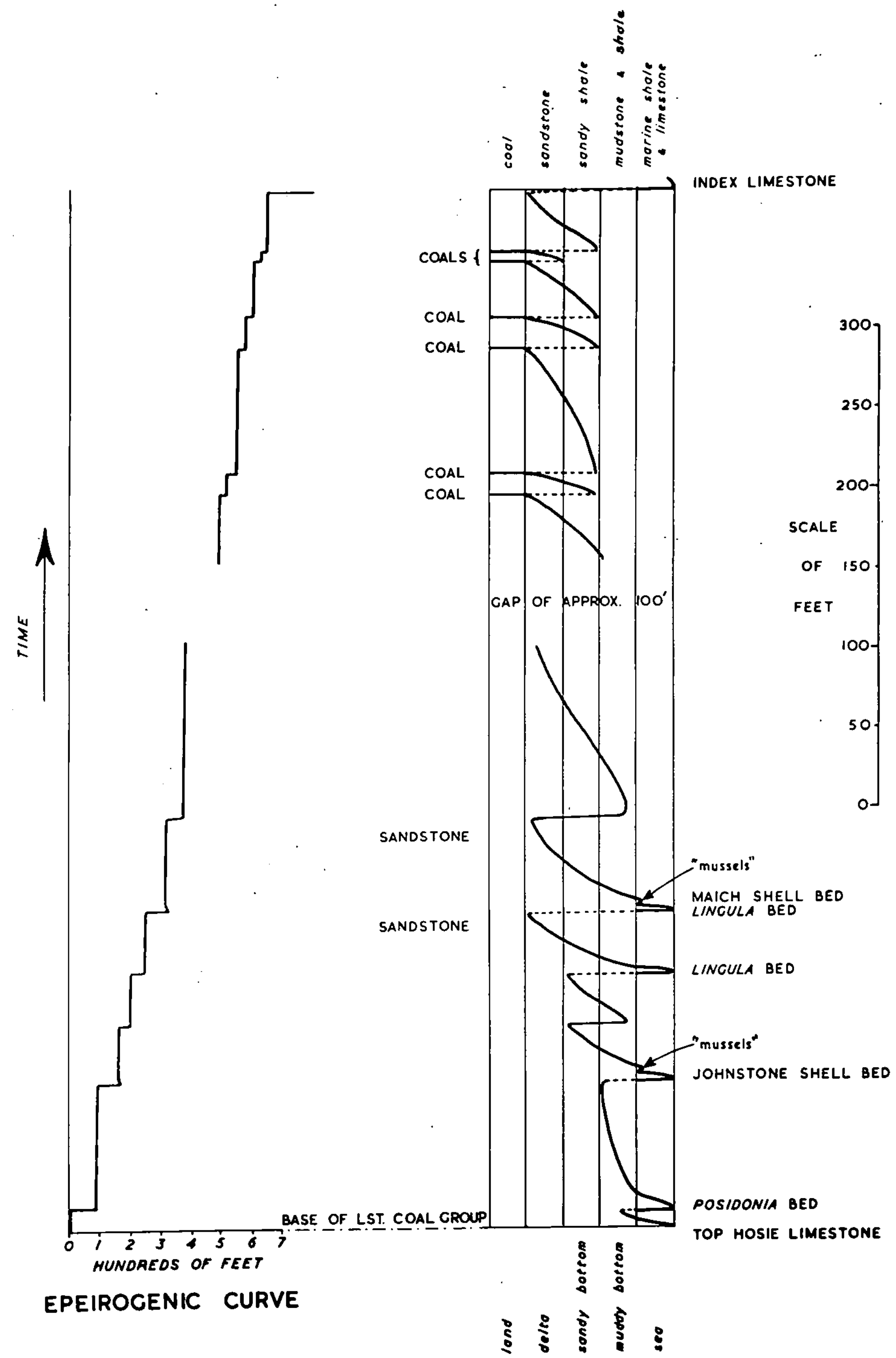


Figure 2. - Diagram to illustrate rhythmic sedimentation in the Limestone Coal Group of North Ayrshire.

section derived from detailed successions measured at several localities to the west of Beith and in the region of Kilbirnie. The cyclothem diagram is compared with an epeirogenic curve.

The shell beds are seen to occupy corresponding positions in the cycles.

III. The Main Fossiliferous Horizons of the Limestone Coal Group.

The lowest fossiliferous horizon within the Limestone Coal Group is at, or near to, the base of the group in the shales which occur above the Top Hosie Limestone. In blueish shales is found the marine lamellibranch *Posidonia corrugata.* Some are found pyritised but more rarely they retain the original shell material.

The next, and most important horizon in the whole group, is the Johnstone Shell Bed which occurs some seventy or eighty feet above the base of the group. The shales between this shell bed and the *Posidonia* bed are apparently barren. A detailed description is given later but essentially the Johnstone Shell Bed consists of a lower four to six feet of shale or shaly mudstone with a chiefly *Productus* fauna, but with other marine shells including some *Lingula*. Above this are from three to six feet of mudstones with *Lingula* and non-marine lamellibranchs.

An impoverished marine band containing only *Lingula* and what was tentatively identified as a fish was found just below the Pundeavon Ironstone in Maich Water and adjacent/

adjacent streams. Like the ironstone this *Lingula* bed is not persistent laterally.

Associated with the Dalry Blackband Ironstone, but below the chief ironstone band, is a *Lingula* bed, and a few feet above this the Maich Shell Bed consisting of limy shales and ironstone with naiaditiform lamellibranchs and *Lingula*. In addition it should be noted that marine fossils have been recorded, Macgregor (1929).

As has already been noted, in the higher cyclothems of the Limestone Coal Group the lower members of the unit cycles are absent, so that it is self evident that marine and non-marine fossils alike are absent from the upper part of the group. The only fossils found in the higher horizons were plant remains which are commonly to be found in the sandy shales.

IV. The Johnstone Shell Bed.

(i) Area 'A' - North of the Dusk Water Fault.

The Johnstone Shell Bed here consists of from six to ten feet of dark blueish grey shaly mudstones which tend to break irregularly and more or less cuboidally although they are laminated.

The fauna of the lower four to six feet is largely a brachiopod fauna, containing chiefly the genus *Productus* but with *Bellerophon* and marine lamellibranchs. Craig (1883) has recorded the following:-

Crinoid ossicles.
Productus (several species).
Lingula.
Aviculopecten.
Edmondia.
Nucula.
Bellerophon.
Nautilus.
Rhynchonella.
Ostracods.

Most of these were found at all the principal localities where the Johnstone Shell Bed outcrops. Although there are no fossils present of short stratig-raphical/

raphical range this is an important and easily recognisable index horizon throughout Ayrshire, for it is the only horizon within the group with an abundant marine fauna.

The upper part of the Johnstone Shell Bed in this area consists of mudstones, lithologically similar to those immediately beneath, in which Lingula squamiformis Phillips is found in abundance together with lamellibranchs of the non-marine genus Carbonicola. The latter are quite small, having an average length of a little over thirteen millimetres, but it must not be assumed that they are necessarily a dwarfed fauna before ascertaining whether this species elsewhere attains a larger size. It is possible that their environment was inimical to their growth.

The marine shells are not found in this upper part of the shell bed and the change from a marine to a 'non-marine' fauna is quite abrupt: the brachiopod fauna and the mussels are mutually exclusive of each other and, with the exception of Lingula, no marine forms are ever found in the musselband. The very presence of Lingula in the musselband in association with what is always taken to be a non-marine form, suggests an abnormal environment. The association is particularly close and intimate/

intimate and *Carbonicola* and *Lingula* have been observed lying on the same bedding plane, although it must be remembered that neither is in the position of growth. The evidence is conclusive, however, that they co-existed simultaneously and that they shared the same general habitat although not necessarily the same ecological station. For this reason the ecology is henceforth referred to as 'specialised marine' and a fuller discussion on the probable ecology of the mussels in the light of evidence provided by *Lingula* and by work on sedimentation is given in Chapter VIII. The essential factors are:-

a) The *Carbonicola* fauna was not truly marine since it is never found with the brachiopod fauna.

b) *Carbonicola*, since it shared the same habitat as *Lingula*, must have existed on a muddy bottom in shallow water, probably in an estuary or a semi-enclosed lagoon.

c) The only factor of which there can be no evidence is the salinity, and it is presumed that this was the controlling one.

d) *Carbonicola* probably existed in conditions too brackish for the brachiopod fauna to exist but sufficiently/

sufficiently saline for the continuation of *Lingula*, which occurs together with both the brachiopod fauna and the *Carbonicola* fauna.

e) *Lingula* becomes more numerous towards the top of the shell bed, except in the top six inches where it gradually declines, so that the top of the bed is ill-defined, whereas *Carbonicola* steadily decreases numerically upwards, and so is, to a slight degree, showing a tendency to be mutually exclusive of *Lingula*. This suggests that the two forms were not completely adjusted to the same environment but that they were able to tolerate it.

A rapid downward movement caused the marine incursion which introduced the marine fauna. The abrupt change to the specialised marine fauna (*Carbonicola* and *Lingula*) which ensued could not have been due solely to silting up of the area of deposition but must have been due to uplift, though probably very slight, which cut off any connection with the sea. Slightly increasing saline conditions could account for the gradual decline of *Carbonicola*. The final elimination of both forms could be due to silting up and the gradual introduction of more detrital/

detrital material into the area. While it cannot entirely be ruled out that the animals continued to exist but failed to be preserved, it does seem unlikely. More probably, they ceased to exist by dying out or by migration.

The Johnstone Shell Bed at different localities.

The Johnstone Shell Bed was found at eight localities in the area north of the Dusk Water Fault. The *Carbonicola* fauna is generally, but not always present and at some exposures the shells are considerably less numerous than at others.

The shell bed is particularly well developed in the region of Glengarnock and there are good exposures in Powgree Burn and Kersland Glen. Here both marine and specialised marine parts of the shell bed are found. To the north west, in Maich Water the upper part is not so well developed and an insufficient number of mussels was obtained from this locality to permit a statistical analysis. To the south west in Pitcon and Gowkhouse Burns mussels are apparently absent. Here only *Lingula* was found in the upper part of the shell bed and specimens collected by officers of H. M. Geological Survey confirm that *Carbonicola* is almost absent. In Maulside railway/

railway cutting, half a mile beyond the disused Bracken-hills Station, the Johnstone Shell Bed consists of three or four feet of blue shales with marine fossils; six feet above this Lingula was found but no mussels. The exposure is, however, now overgrown by vegetation.

At two other localities, Beith Station and in Paduff Burn, Kilbirnie, a shell bed containing only Carbonicola and Lingula outcrops; no lower marine bed is found. Although this shell bed is similar to the upper part of the Johnstone Shell Bed at other localities in every way this correlation was postulated with reserve since the marine Johnstone Shell Bed is of very wide extent, occurring not only throughout nearly all Ayrshire (north of the Southern Uplands) but elsewhere in the Midland Valley. Detailed mapping of the Paduff Burn locality failed to establish the precise horizon of the shell bed and at Beith Station there are few exposures. In both cases no more can be said than that the shell bed lies between the Dalry Clayband Ironstone and the Dalry Blackband Ironstone, probably nearer to the former. That is to say it lies at approximately the same horizon as the proved Johnstone Shell Bed... At one of these localities, Paduff Burn, the exposure is good and there is no doubt that/

that the marine brachiopod fauna is absent from below the *Carbonicola* bed. Despite the proved absence of such a marine bed at Paduff Burn, and its presumed absence at Beith Station, a statistical analysis of the assemblages from these localities confirms the original opinion that the shells are identical with those from the upper part of the Johnstone Shell Bed at Kersland Glen and in Powgree Burn. It seems very unlikely that there can be two such musselbands and they can be assumed to be one and the same horizon since all the evidence points to this conclusion. It must be admitted then, that here the musselband was not preceded by the usual marine bed, and that the incursion of the sea was of limited extent, downwarping being only sufficiant to permit the introduction of brackish water conditions.

(ii) The Johnstone Shell Bed South of the Dusk Water Fault.

In area 'B', between the Dusk Water and Inchgotrick Faults, there is a marked attenuation of the succession as shown by Richey (1935). This thinning, over 50%, as he pointed out, takes place at the Dusk Water Fault and its north easterly branch near Lugton.

The fauna of the Johnstone Shell Bed reflects this change, and nowhere south of the Dusk Water is the *Carbonicola* fauna found. The Johnstone Shell Bed is well exposed in the region of Stewarton, in East Burn and Annie Burn. It is also found near Dunlop and Newmilns. At all but the last of these localities the marine brachiopod fauna is followed by a few feet of mudstone containing only *Lingula*. Here then the shell bed, while retaining its two distinct 'leaves', (if the term may be extended to include two fossiliferous beds, one following immediately on the other), has lost the *Carbonicola* fauna, so characteristic a feature north of the Dusk Water Fault. It seems probable that the marine brachiopod fauna ceased to exist, or persist, due to conditions becoming less saline but that they never became sufficiently brackish to permit the establishment of/

of the <u>Carbonicola</u> fauna. This may be taken as further proof of the very specialised ecological conditions which the latter required to thrive.

There are three exposures of the Johnstone Shell Bed in the triangle between the main Dusk Water Fault and its north easterly branch near Lugton. These are west south west of Lugton in Dusk Water itself, Duniflat Burn and in the railway cutting near Lugton Station. The main variation in thickness of the group was shown by Richey to take place not at the Dusk Water Fault but at its branch. North of the main fault the Limestone Coal Group is upto 650 feet thick, in the immediate proximity of the fault at Barrmill and south of the fault in the Lugton area it is 450 - 480 feet thick, while south of the branch fault it is of the order of 200 feet only. By this criterion the exposures mentioned lie on the north side of the line of variation. However, the faunal content of the bed is similar to that found at localities south of the line of variation. At the Dusk Water exposure and in Duniflat Burn, (in the latter the exposure is particularly good and this was mapped on the scale of six inches to the mile), the marine brachiopod fauna is followed by a bed containing only/

only *Lingula*. In the railway cutting where the exposure was not so good only *Lingula* was found, belonging, it is believed, to the upper part of the Johnstone Shell Bed. Thus it is established that it was the main Dusk Water Fault, and not its branch, that was responsible for limiting the area of deposition in which the *Carbonicola* fauna flourished. There are insufficient exposures of the shell bed containing *Carbonicola* to enable a palaeogeographical map to be drawn, but the faunal content of the Johnstone Shell Bed at all the localities where it was found is given in figure 3.

One other exposure of the Johnstone Shell Bed in North Ayrshire is worthy of mention. It was found on the foreshore at Ardrossan which is at the south west extremity of, and in line with, the Dusk Water Fault. This exposure yielded only *Lingula*, badly fragmented, and a very few marine shells have been recorded. The shell bed belongs in faunal type to area B.

At approximately the line of the Inchgotrick Fault the upper part of the Johnstone Shell Bed (containing) *Lingula*) disappears and south of this line throughout the rest of Ayrshire, where the Johnstone Shell Bed is/

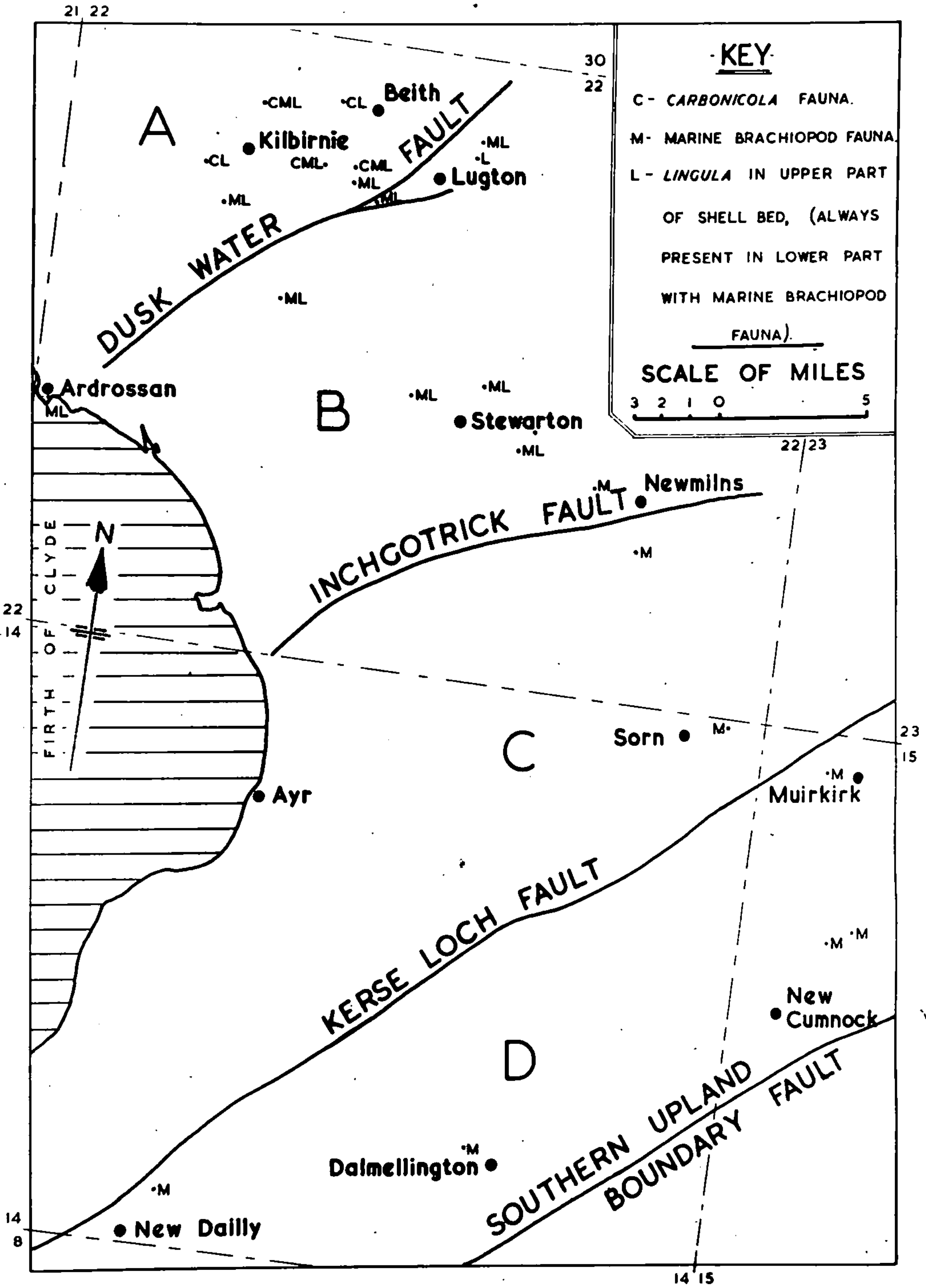


Figure 3.- Variations in faunal content of the Johnstone Shell Bed.

(FIGURES IN MARGINS REFER TO ONE INCH SHEETS) is found it consists only of a marine bed - a few feet of shales with still the characteristic brachiopod fauna. Admittedly, at only two localities was it found in mid-Ayrshire between the Inchgotrick and Kerse Loch Faults. These were south of Newmilns and near Sorn. In this area C the Limestone Coal Group is thinnest and seldom exceeds a hundred feet. The presence of the Johnstone Shell Bed however indicates that even here sinking was, on one occasion, sufficient to permit a marine incursion although this was a relatively little depressed area compared with those to the north and south.

South of the Kerse Loch Fault the Limestone Coal Group thickens to four hundred feet or more and is approaching the thickness found north of the Dusk Water Fault. Despite this the Johnstone Shell Bed shows no change in character and there is no reappearance, as might have been expected, of the upper part with either a Lingula or Carbonicola fauna. The shell bed is found at a number of localities in this area D, except in close proximity to the Southern Upland Fault, and particularly good exposures were seen in the opencast coal workings north east of New Cumnock (now no longer exposed). In the extreme south of this area, as the Southern Upland Fault/

Fault is approached, there is a rapid attenuation of the Limestone Coal Group accompanied by a facies change. The beds become dominantly sandy and the Johnstone Shell Bed is absent.

Ayrshire may thus be divided into three areas with regard to the fauna of the Johnstone Shell Bed. Throughout Ayrshire north of the Southern Upland Boundary Fault, except in close proximity to it, there exists a bed containing a marine, chiefly brachiopod fauna. This is followed, north of the Dusk Water Fault, and probably restricted to a basin centred on Kilbirnie and Glengarnock, by a bed with a *Carbonicola-Lingula* fauna. South of Dusk Water, but north of the Inchgotrick Fault, the marine bed is followed by an impoverished marine bed containing a solely *Lingula* fauna. South of the Inchgotrick Fault the marine bed is followed by unfossiliferous strata.

The other shell beds found in North Ayrshire, notably the Maich Shell Bed, but also the *Lingula* beds, are not found south of the Dusk Water Fault; i.e. they are restricted in geographical extent to area A. Thus the Johnstone Shell Bed is the only persistent and widespread fossiliferous horizon, and for this reason, it forms a very useful index.

We have evidence of the nature of the variations in thickness of the Limestone Coal Group at the lines of variation, the contemporaneous faults. It is known that the thinning took place by differential subsidence. The faunal changes give a more detailed picture of the subsidence.

At least one cycle, that in which the Johnstone Shell Bed occurs, is found throughout Ayrshire, although south of the Inchgotrick Fault the absence of the upper part, with its brackish water or 'specialised marine' fauna, shows that the marine conditions came to an end rather abruptly. Here, probably uplift took place. accelerating silting up of the area of seposition.

The absence of other fossiliferous horizons shows that, either the cycles containing them are missing completely, or that those cycles are incomplete through the absence of the lower members of the cyclothems. In other words, sinking was insufficient to permit marine incursions into the areas south of the Dusk Water Fault, and these must have been relatively less depressed than area A. In areas B and D it would appear that most of the cycles present in North Ayrshire are also present, but that they are less complete (or not so well developed). In/

In area C, where the attenuation of the strata is greatest, it is probable that, besides the poorer development of individual cycles, some cycles of sedimentation are completely absent.

The mechanism of thinning, whilst in both cases being due to differential subsidence, can operate in two ways: through the attenuation of individual cycles and through the absence of some cycles.

A closer examination of the strata of area D shows why, despite the thickening of the group, there is no reappearance of the *Lingula* or *Carbonicola* fauna of the Johnstone Shell Bed. In this area the thickening of the strata is due to a better development of the higher members of the rhythmic cycles, and so here coals are thicker, and in fact this is one of the more important Lower Carboniferous coalfields. There must have been greater differential subsidence in this area than in areas C and B to the north in order to accommodate the greater thickness of strata, but that subsidence was such that it kept pace with deposition and did not, with the exception of the one occasion marked by the Johnstone Shell Bed, ever exceed the rate of deposition sufficiently to permit a marine, or even a non-marine, incursion.

(iii) The Johnstone Shell Bed elsewhere in the Midland Valley.

The Johnstone Shell Bed has now been found almost throughout the Midland Valley where the Limestone Coal Group outcrops. It occurs round the periphery of the Central Coalfield (except perhaps on the north west flank and in the Kilsyth district), in the Lothians and in west and central Fife.

Over distances such as these the character of the shell bed changes considerably, though less abruptly, than it does in Ayrshire. The variation in thickness of the strata has also been shown to vary from east to west, but again the changes are more gradual and, while they may be related to differential subsidence and down-warping, they are not related to contemporaneous faulting as in Ayrshire. Further east, too, the 'lines of variation' found in Ayrshire, as described by Richey, are less marked in their effect, and in the east of the Midland Valley, the north-south variations in thickness take place more gradually. These features are again reflected by the character of the Johnstone Shell Bed, and further east the lines of variation do not seem to have been a prime factor in limiting the areas of sedimentary environment/

environment, as was found to be the case in Ayrshire.

North of Ayrshire in the region of Paisley there are no outcrops of the Johnstone Shell Bed, though it is known from borings and colliery sinkings. Here it is described as being full of Lingula, also as having a marine fauna, but there is no record of the Carbonicola fauna.

To the east of Ayrshire in the Strathaven area on the south side of the Central Coalfield, the Johnstone Shell Bed is similar in character to its occurrence north of the Dusk Water Fault in area A. At Black Linn in Calderwood Glen the shell bed is recorded as being about five feet thick, the lower half containing many Productids, the upper half containing Lingula and many small lamellibranchs. Again, further east but in the same area, lamellibranchs have been recorded in association with Lingula overlying a bed containing Productus and crinoids. The most surprising fact is that these localities are far to the south of the continuation of the Dusk Water Fault, or even of its north easterly branch (Richey's line of variation ab). They are more or less in line with his line of variation bc - the continuation of the Inchgotrick Fault. Obviously in this/

this region the line of the Dusk Water branch fault was not the limit of the basin of deposition in which *Carbonicola* flourished.

In the Bathgate area the Johnstone Shell Bed takes on a more limy character, and three feet of limestone are recorded followed by marine shales. The various estimates of the thickness of limestone vary and probably some of the older boring records are not reliable.

In west and central Fife the Johnstone Shell Bed consists of about twenty feet of fossiliferous 'blaes' with a marine fauna. Chiefly marine lamellibranchs are recorded together with brachiopods and crinoid fragments. Here the bed lies above the Sulphur Coal.

In Midlothian the Johnstone Shell Bed was examined at a number of localities, and material from this horizon in the collections of H. M. Geological Survey was also examined. The shell bed was found to consist of two distinct leaves separated by as much as twenty feet of unfossiliferous strata. Both leaves bear a very similar marine fauna, and there is no relation between this feature and the twofold division of the shell bed into a lower marine and an upper brackish-water bed typical of North Ayrshire and Strathaven. This is not surprising for/

for the Lothians lie approximately in line with the continuation of the Kerse Loch Fault. The variations in thickness of the strata of this area do not correlate with those of west and mid-Scotland and the Limestone Coal Group is thicker on the west flank of the Lothians anticline than the east.

Summarising the changes found in the Johnstone Shell Bed in the Midland Valley we see that it is typically and normally a bed of marine shales varying considerably in thickness but attaining the greatest thickness in Fife. In the south east of the Midland Valley, in the Lothians, it splits into two leaves, both with a marine fauna. On the east side of the Central Coalfield the Johnstone Shell Bed becomes locally, in part, a limestone. In two areas, north of the Dusk Water Fault in Ayrshire, and near to Strathaven, the marine bed is succeeded immediately by a bed containing Lingula and Carbonicola. Between the Dusk Water and Inchgotrick Faults in Ayrshire this upper part of the shell bed is found but it is impoverished and only Lingula is present. There is insufficient evidence to show whether the two areas in which the mussels are found in the higher part of the Johnstone Shell Bed were originally one continuous basin/

basin, or whether they were sub-basins connected in any way; it can merely be concluded that simultaneously in these two areas similar environmental conditions existed to permit Carbonicola to flourish.

V. The Maich Shell Bed.

(i) Its occurrence in North Ayrshire.

In Maich Water, one mile north of Kilbirnie, about thirty feet below the horizon of the Dalry Blackband Ironstone, there occurs a shell bed of local importance.

A two foot bed of shale with Lingula is followed some three feet higher by a shell bed one foot one and a half inches in thickness. The bed is crowded with calcite-shelled fossils which may be observed from a distance standing out against the dark background of the matrix. The shell bed consists of shale below followed by ironstone, and the shells are distributed throughout the whole thickness except for a thin band near the top which is quite barren. The detailed succession is as follows:

	4 ft. 0 ins.	Soft laminated shales.
Maich Shell Bed. 1 ft. 1½ ins. (	3 ins.	Ironstone with shells.
(	1½ ins.	Ironstone, barren.
(	9 ins.	Shale with shells.
	2 ins.	Sandy shale.
	2 ins.	Blue shale.
	4 ins.	Ironstone.
		Shales.

The position of this shell bed in the rhythmic cycle is difficult to place although the exposures in the banks of Maich Water are good. The succession is complicated by the presence of a number of bands of ironstone which do not appear to occupy any constant position in the rhythmic cycle. Setting aside the ironstones for the moment and considering the strata exposed in the cliff section, it is seen that the shell bed does follow an impoverished marine band (a Lingula band), and that above the shell bed follow shales, sandy shales and sandstone. The shell bed must then occupy a position near to the commencement of a cycle, following almost immediately the marine incursion proved by the presence of Lingula. The succession including the Maich Shell Bed is as follows:

	5 ft. 0 ins.	Shale.
	7 ft. 0 ins.	Laminated sandstone.
	6 ft. 0 ins.	Laminated sandy shale, softer at the base.
	1 ft. 0 ins.	Ironstone.
	4 ft. 0 ins.	Shale.
Maich Shell Bed.	$4\frac{1}{2}$ ins.	Ironstone with shells in upper three inches.
	9 ins.	Shale with shells.

	2 ins.	Sandy shale.
	2 ins.	Blue shale.
	4 ins.	Ironstone.
1 ft.	8 ins.	Shales.
1 ft.	0 ins.	Ironstone.
2 ft.	0 ins.	Shale with Lingula.
1 ft.	6 ins.	Ironstone.
Over 4 ft.		Shales (base not seen).

This information is incorporated in figure 2 showing the cyclic nature of the Limestone Coal Group sediments, and a position analogous to that of the Johnstone Shell Bed is adduced for the Maich Shell Bed.

The fauna of the Maich Shell Bed, in contrast with that of the Johnstone Shell Bed, is not very varied and consists only of naiaditiform lamellibranchs and Lingula. A few marine fossils have been recorded by Macgregor (1930) who lists, in addition to Lingula squamiformis, two species of Aviculopecten and Edmondia. No marine forms were found however.

It is probably chiefly because of this recorded association with marine shells that the naiaditiform shells have been referred to Myalina, by Macgregor (op. cit.) and in The Geology of North Ayrshire (1930). It is/

It is in the latter that the term Maich Shell bed is first ascribed to this bed previously known as the Musselband Ironstone. This memoir also assigns the shells to the genus Myalina: ".....a marine assemblage, and does not include Naiadites as formerly supposed. The prevalent shell is a thick-walled Myalina, specifically indeterminable om account of the distorted condition of the specimens."

The shells are indeed very badly distorted through crushing and are, in addition, partially dissolved so that the outer layer of shell material has been removed. Despite this a close study of their morphology, and in particular, their internal characters, has shown that Hind's original identification was correct. This is discussed more fully in the chapter on the palaeontology of Naiadites.

The calcite derived from the shells by solution has re-cemented the shale so that it is now hard and it is an arduous task to obtain the brittle-shelled specimens from the matrix.

The faunal assemblage is unusual, comprising Naiadites, Lingula and a very few marine lamellibranchs. The presence of the latter, although they were not found, is beyond/

beyond dispute and, together with the evidence provided by the presence also of Lingula, a more or less marine environment must be assumed. Certainly it must have been rather different from that in which the Coal Measure Naiadites flourished, but then these Lower Carboniferous forms are quite different in character with their thick calcite shells and large size. The shell thickness is no doubt a function of their ecological station about which so little is known. The absence of Carbonicola such as occurs in the upper part of the Johnstone Shell Bed requires an explanation, for the converse is found, and a small percentage of Naiadites does occur in the Johnstone Shell Bed. Carbonicola is quite absent from the Maich Shell Bed and it must be supposed that the very specialised ecological conditions which it required did not become established. Probably in view of the presence of marine forms here, it may be supposed that the environment was too saline to permit its establishment.

Other localities where the Maich Shell Bed is found.

The Maich Shell Bed is recorded as outcropping at two other localities; one mile south south east of Beith in the railway cutting north east of Ward Farm, and in the/

the railway cutting near the disused Brackenhills Station on the Beith Branch line.

The former is almost completely over-grown but *Lingula* was found. Near Brackenhills Station shells were obtained by digging. The total thickness of the shell bed could not be determined but the succession seen was as follows:

5 ft.	Massive sandstone.
7 - 8 ft.	Laminated sandy shale.
	Ironstone with naiaditiform shells.

This is sufficient to indicate that this is the Maich Shell Bed but only the upper ironstone member was reached. Few good specimens could be obtained but sufficient to establish their similarity to those from the Maich Water outcrop.

(ii) The absence of the Maich Shell Bed elsewhere in the Midland Valley of Scotland.

The three exposures of the Maich Shell Bed lie north of the Dusk Water Fault within a small radius of Glengarnock. It seems significant that this is precisely the centre of the area in which the Johnstone Shell Bed *Carbonicola* fauna is found. It is not, of course practicable to delimit the area of occurrence of the Maich Shell Bed with the limited evidence available, but it has not been found, nor is there any record of it, south of Dusk Water. Since the important index horizon, the Dalry Blackband Ironstone, is not found further south in Ayrshire it is impossible to say whether the rhythmic cycle which includes the shell bed is absent, or whether it is present but that the sinking which initiated that cycle was insufficient to permit the incursion of quasi-marine conditions.

Lingula beds and marine beds are known at higher horizons in the Limestone Coal Group. The Black Metals is perhaps the best known and most widespread. Though it does not outcrop in the area of North Ayrshire dealt with here it is known in borings just to the north in Renfrewshire. In the East Kilbride and Motherwell districts/

districts there occurs, between the Johnstone Shell Bed and the Black Metals Marine Band, a Lingula and mussel bed correlated by Weir and Leitch (1942) with the Maich Shell Bed. North east of Glasgow at Springburn and at Stepps this shell bed is recorded as containing chiefly Lingula but some marine lamellibranchs.

The Maich Shell Bed and its equivalents are not of very wide extent but occurrences are known in the Central Coalfield area from both north and south of the ab line of variation. In this respect its occurrence resembles that of the upper part of the Johnstone Shell Bed.

VI. Palaeontology - the *Carbonicola* fauna of the Johnstone Shell Bed.

The *Carbonicola* fauna was sufficiently abundant at four localities for enough material to be obtained to permit a statistical analysis. These were the exposures in Kersland Glen, in Powgree Burn, near Beith Station and in Paduff Burn. The first two of these are shown on Geological six-inch maps as the Johnstone Shell Bed; the last two are not but it has been established that they are at, or very near to, the horizon of the Johnstone Shell Bed. It was the intention to collect approximately a hundred specimens from each locality for the purposes of statistical analysis, though in two cases the number of shells sufficiently intact to give reliable measurements falls a little below this figure. In a very variable community it is essential to have of the order of one hundred specimens.

The conventional measurements were made, length (L) being measured as far as it is possible to decide, in the direction parallel to a line drawn through the muscle scars. The height (H) was measured (perpendicular to the length) and the length of the anterior end (A). No specimens could be extracted solid and in only a very few/

few cases could the tumidity be estimated, and then only approximately.

Other variable properties occur such as the incurving of the anterior-umbonal slope, the inclination of the growth-lines and the oblique truncation of the posterior end, but these are scarcely measurable properties. Such variations are portrayed graphically but are not subjected to statistical analysis.

Variation diagrams were drawn for the ratios of height to length (H/L) and length of the anterior end to length (A/L), expressed as percentages, for the assemblages taken from the four localities mentioned. These curves are shown in figures 4 and 5. The range of variation of these ratios is fairly great but is approximately the same in each case. Further, the modes of the assemblages are similar:

	Kersland Glen	Powgree Burn	Beith Station	Paduff Burn	All specimens
H/L x 100	57.5	57.5	62.5	57.5	57.5
A/L x 100	27.5	27.5	22.5	27.5	27.5

The apparently large discrepencies in the figures for Beith Station are entirely a function of the intervals chosen/

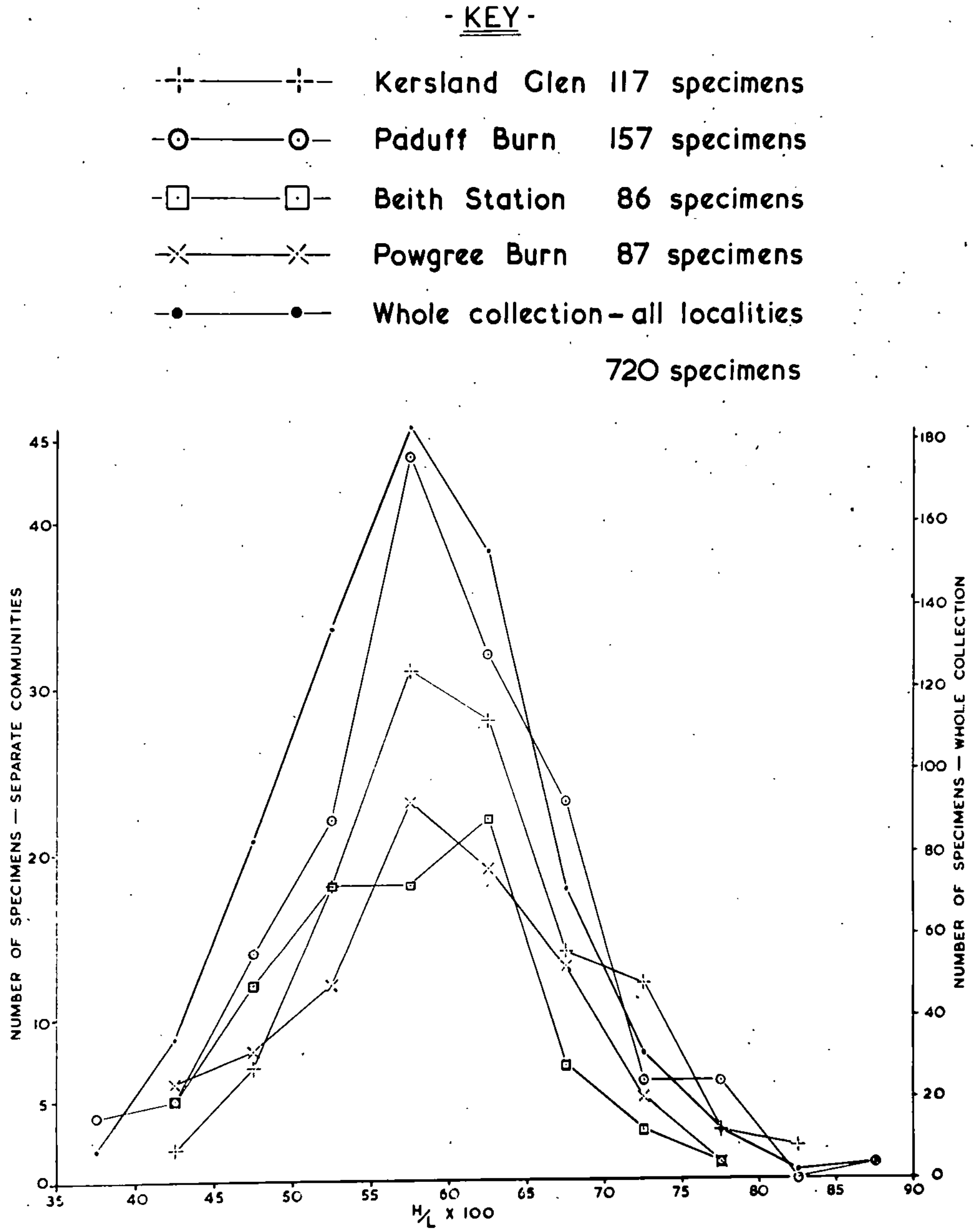


Figure 4 - Variation graphs to show the ratio of Length to Height in *Carbonicola* collections from the Johnstone Shell Bed.

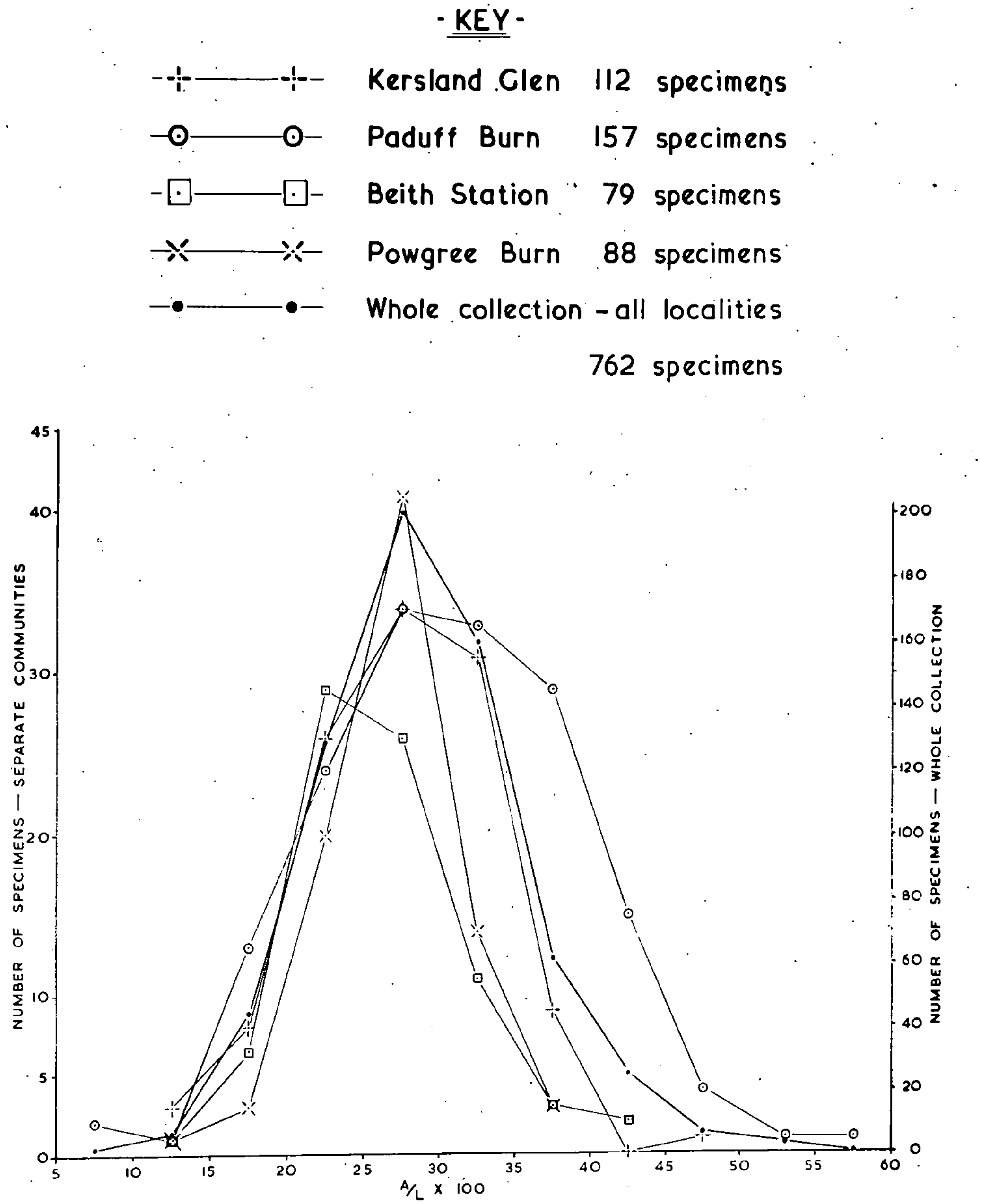


Figure 5 - Variation graphs to show the ratio of Length to Length of Anterior End in *Carbonicola* collections from the Johnstone Shell Bed.

chosen. As the range of variation is so great it was necessary to choose a wide interval between the values of H/L and A/L plotted as abscissae of the graphs. The curves were re-drawn choosing different ranges of variation and, though these graphs are not reproduced here, the modes so obtained were:

	Kersland Glen	Powgree Burn	Beith Station	Paduff Burn
H/L x 100	60	55	60	60
A/L x 100	25	25	30	25

In every case a continuous curve was obtained showing that a continuous variation exists between the mode and the extreme variants. This shows that all the members of the community belong to one species group.

The close similarity of the curves also shows that the assemblage from the four localities has the same range of variability.

The similarity of the assemblages is evidence that the shell bed found in Paduff Burn and at Beith Station is, in fact, the Johnstone Shell Bed.

In the Paduff Burn exposure the shell bed is so well developed and exposed that it was possible to make separate/

separate collections from the top, middle and base of the shell bed for comparison. A sample was taken from three six inch bands,(see figure 6), but it must be emphasised that the shells do contiue through the whole four feet six inches and that it was merely sampled thus for the purpose of statistical analysis. The mussels do decline numerically upwards and the number of measurable specimens obtained from the top was scarcely sufficient.

The curves for H/L x 100 and A/L x 100 were drawn and were compared with the curves obtained by the summation of all three samples, and also with curves obtained for a separate and representative collection, collected from the whole four feet six inches thickness of the shell bed, since it was feasible that this might not give exactly the same results as a mere summation. (Considerable care was excercised in making this collection in order to avoid the obvious pitfall of collecting a disproportionately large number of shells from the lower part of the shell bed.)

The variation diagrams, figures 7 and 8, show that the three samples give similar modes and exhibit in general a similar range of variation. Such discrepancies as/

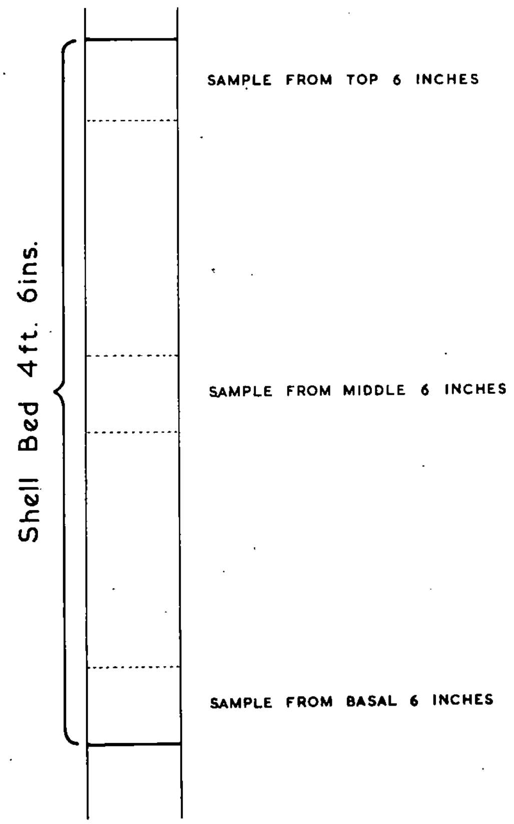


Figure 6.- Diagram to show sampling of the Johnstone Shell Bed, Paduff Burn.

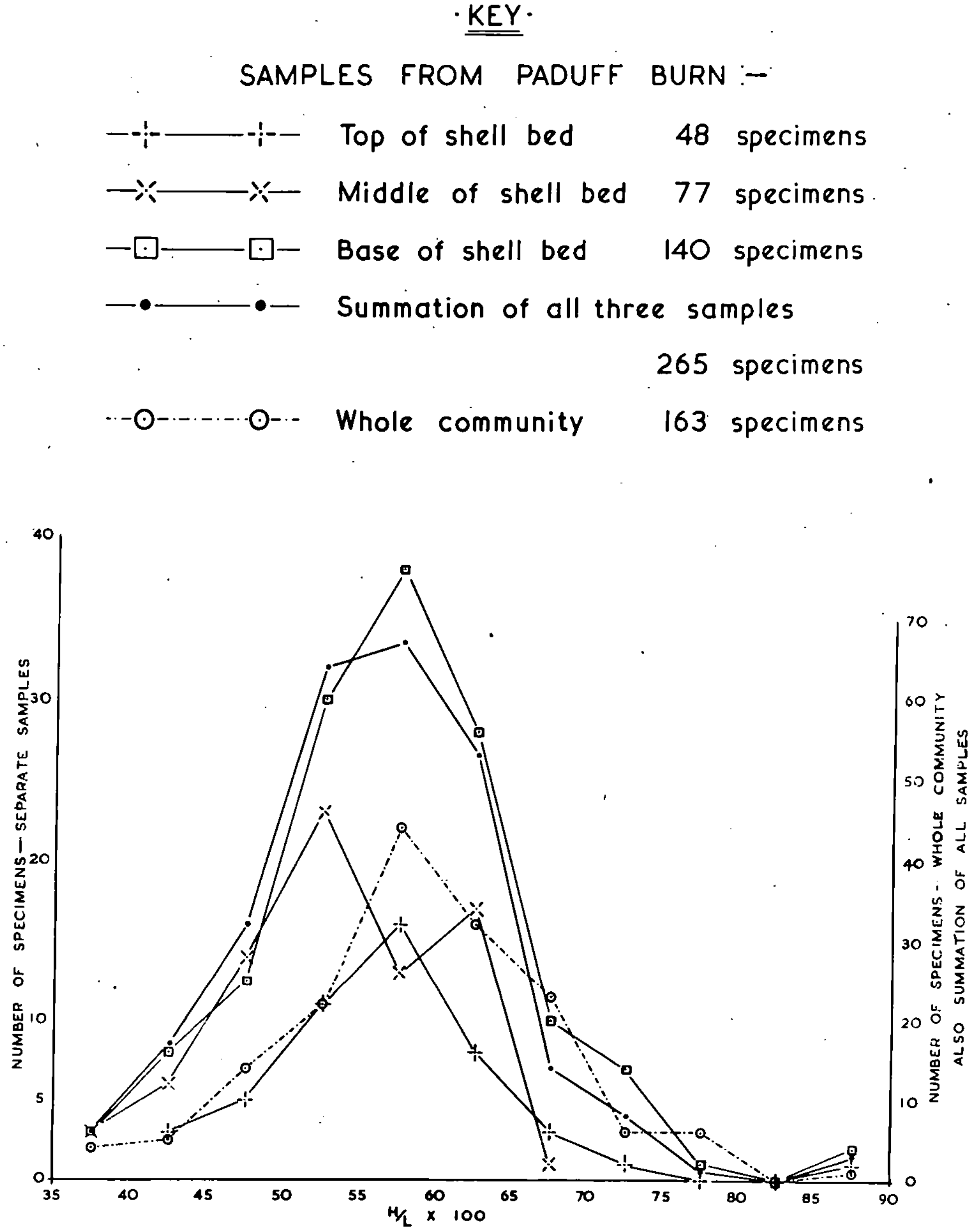


Figure 7.- Graphs illustrating variation in the *Carbonicola* community of the Johnstone Shell Bed.

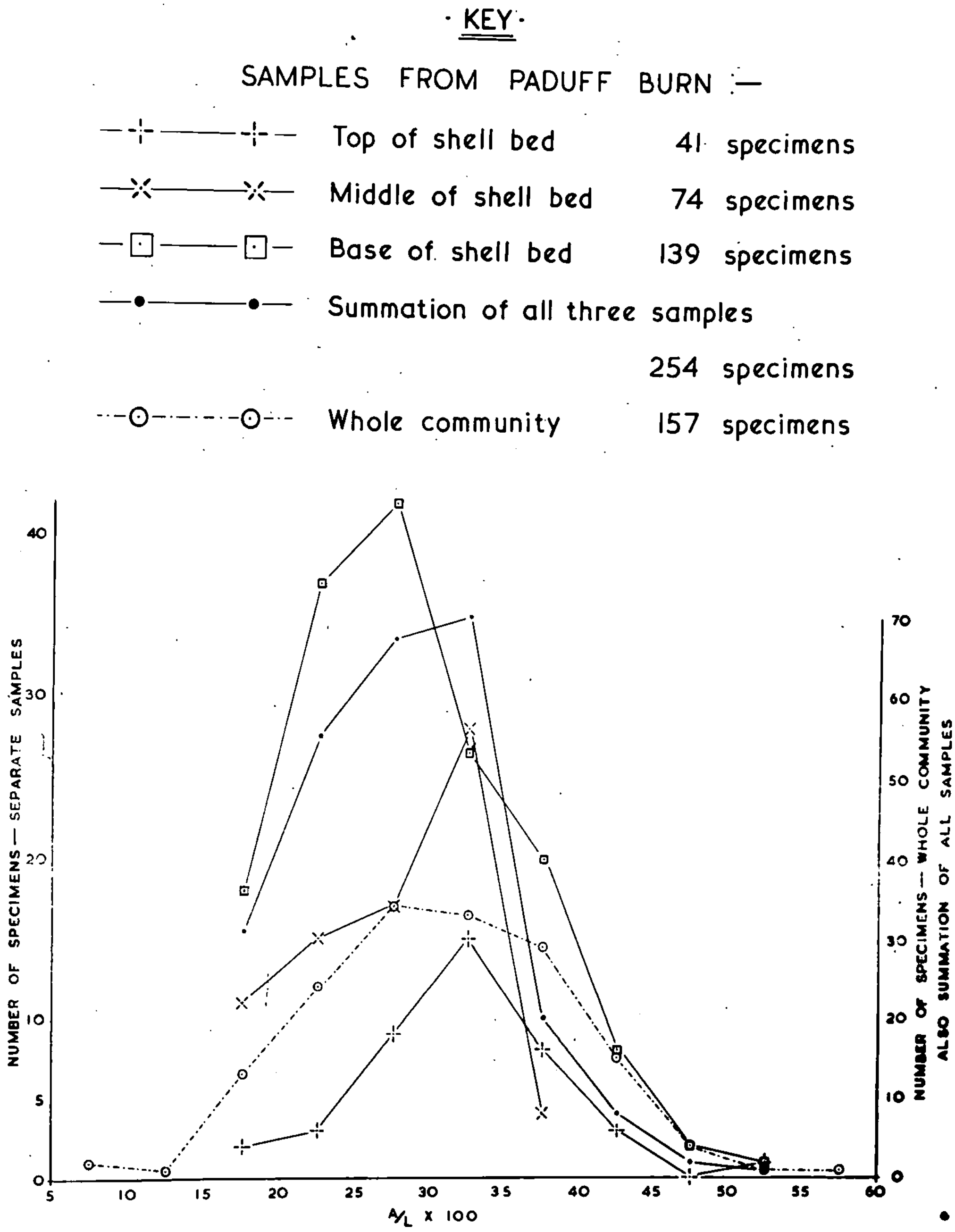


Figure 8.- Graphs illustrating variation in the *Carbonicola* community of the Johnstone Shell Bed.

as do occur, chiefly the tendency to contain fewer variants with a low value for A/L may not be significant but may be due to insufficient numbers of specimens in the samples to give a truly representative picture.

The figures for the modes of the variation diagrams are as follows:

	Samples from			Summation	Whole
	Base	Middle	Top		community
H/L x 100	57.5	52.5	57.5	57.5	57.5
A/L x 100	27.5	32.5	32.5	32.5	27.5

Here again the apparent discrepencies are due to the relatively large intervals chosen for the values of H/L and A/L. The graphs were redrawn (the curves are not included here) and the following figures were obtained:

	Samples from			Whole
	Base	Middle	Top	community
H/L x 100	60	50	60	60
A/L x 100	25	30	30	25

The similarity of the modes and the range of variation for the three samples shows that there is no detectable trend/

trend of variation with horizon in this, admittedly very limited example.

The carbonicolae of the Johnstone Shell Bed are assigned to a separate species Carbonicola beithensis sp. nov. of which a full description follows on page 47. This name is used throughout the following discussion.

The community is very variable and this has been indicated in some measure by the statistical analysis. The factors involved in the variation of shell shape are:

(a) Relative elongation (or decrease in height): the height varies between 35% and 90% of the length with a mode between 55% and 60% (approximately 57.5%).

(b) Variation in the position of the umbo so that the length of the anterior end varies between 5% and 60% of the length with a mode between 25% and 30% (approximately 27.5%).

(c) Changes in the degree of curvature of the ventral margin.

(d) Incurvature of the anterior-umbonal slope.

(e) Oblique truncation of the posterior end and a tendency for the dorsal margin to become arched near to the posterior end.

The variation in each character shows a continuous passage from one extreme to the other. Certain of the factors show some degree of correlation in that they vary in conjunction one with the other. Thus elongation is accompanied by a tendency for the ventral margin to become straighter. The incurvature of the anterior-umbonal slope is more pronounced in those shells which have a relatively long anterior end.

Thus the variants resulting from the combinations of such changes can be arranged in series illustrating their nature and degree of deviation from the norm of the community. Figure 9 is an arrangement on a morphological basis of the variants into series of transitional intergrades, and figure 10 shows the distribution of the community relative to the figured intergrades of figure 9. (Figured intergrades are represented by black circles. Each circle represents an individual and its position on the diagram is controlled by its resemblance to one or more of the figured intergrades.) Figure 11 summarises the main changes which take place.

Specimens B and C represent a trend of variation showing a progressive increase in the ratio of H/L, while specimens D and E represent a trend with decreasing values/

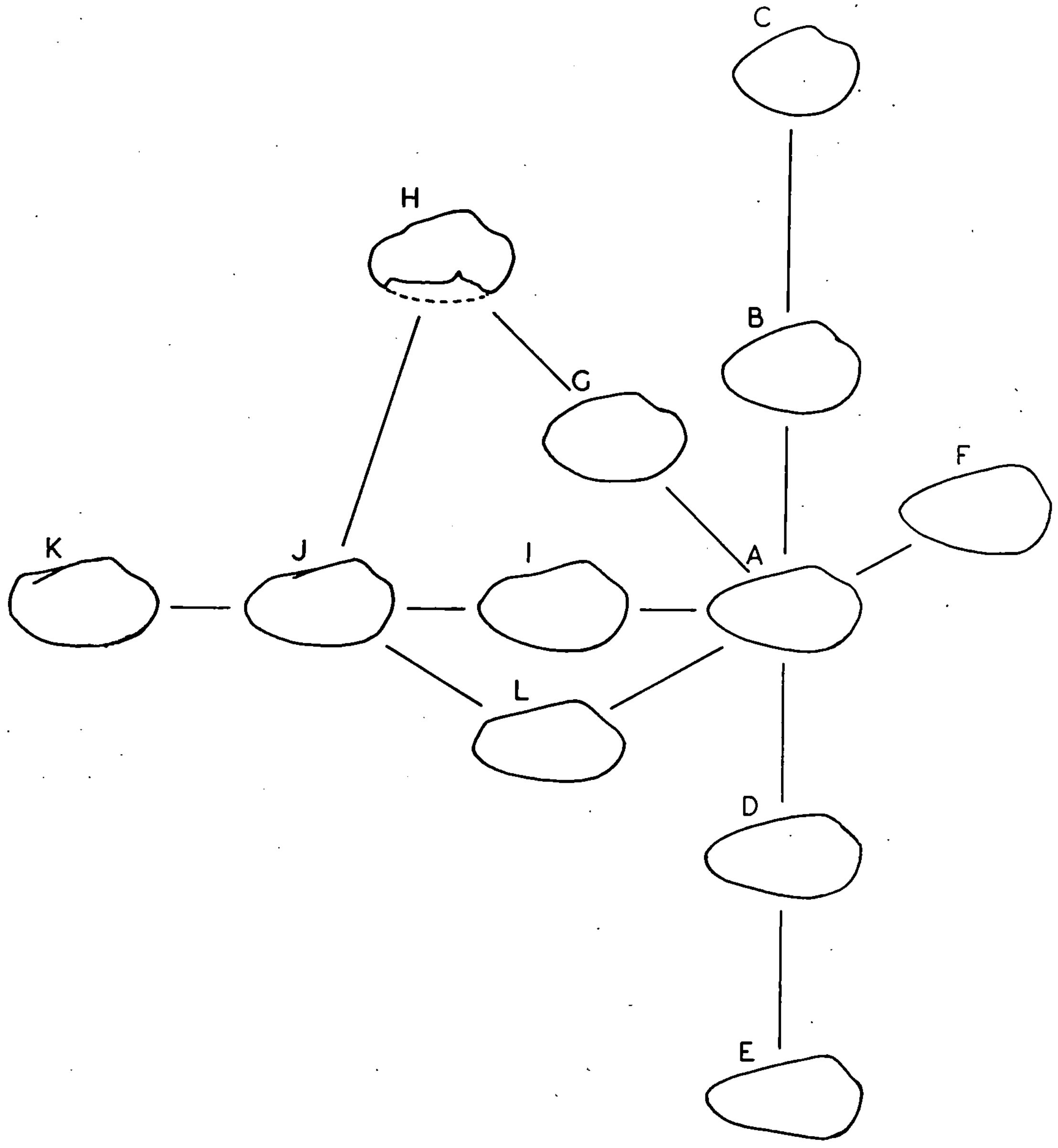


Figure 9.- Variation intergrades of *Carbonicola* arranged in series. Kersland Glen.

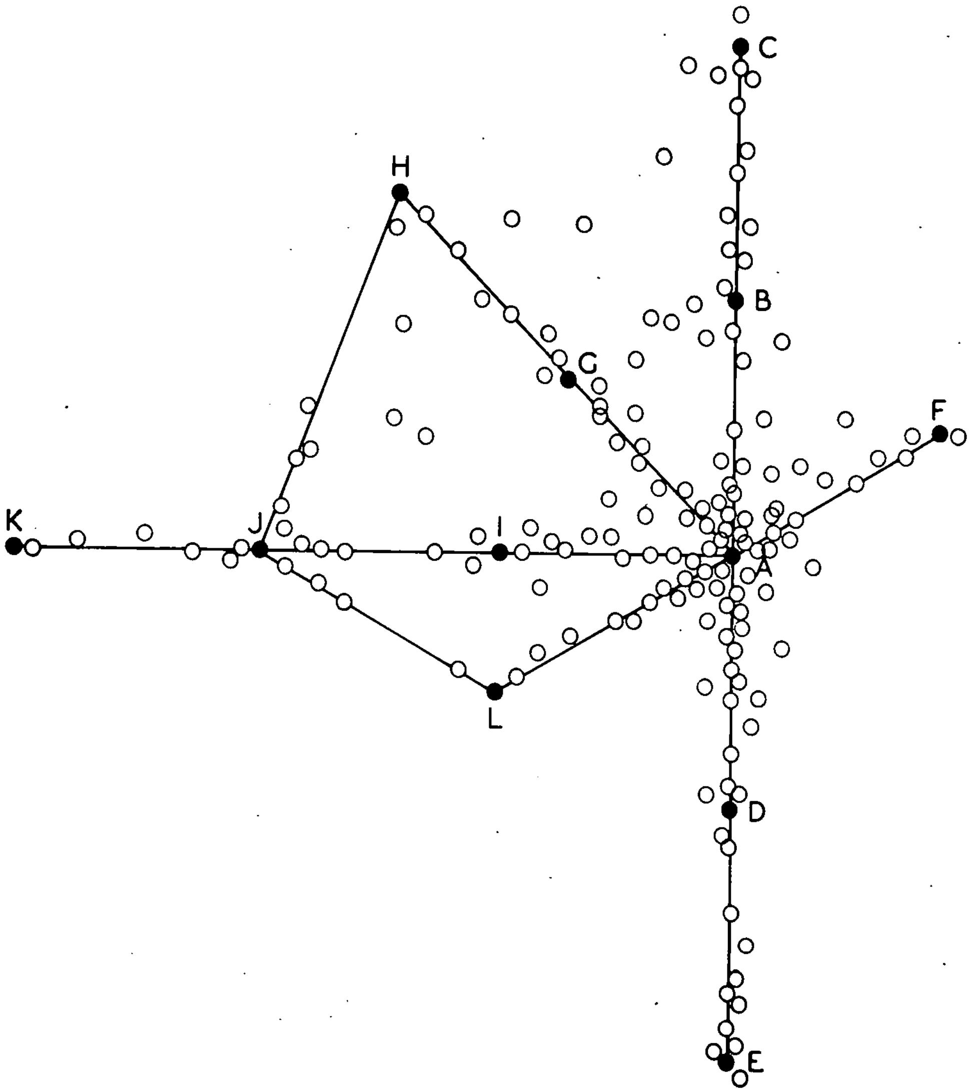


Figure 10.- Distribution scatter of variants of *Carbonicola.*
Lettered circles represent the figured intergrades of figure 9.

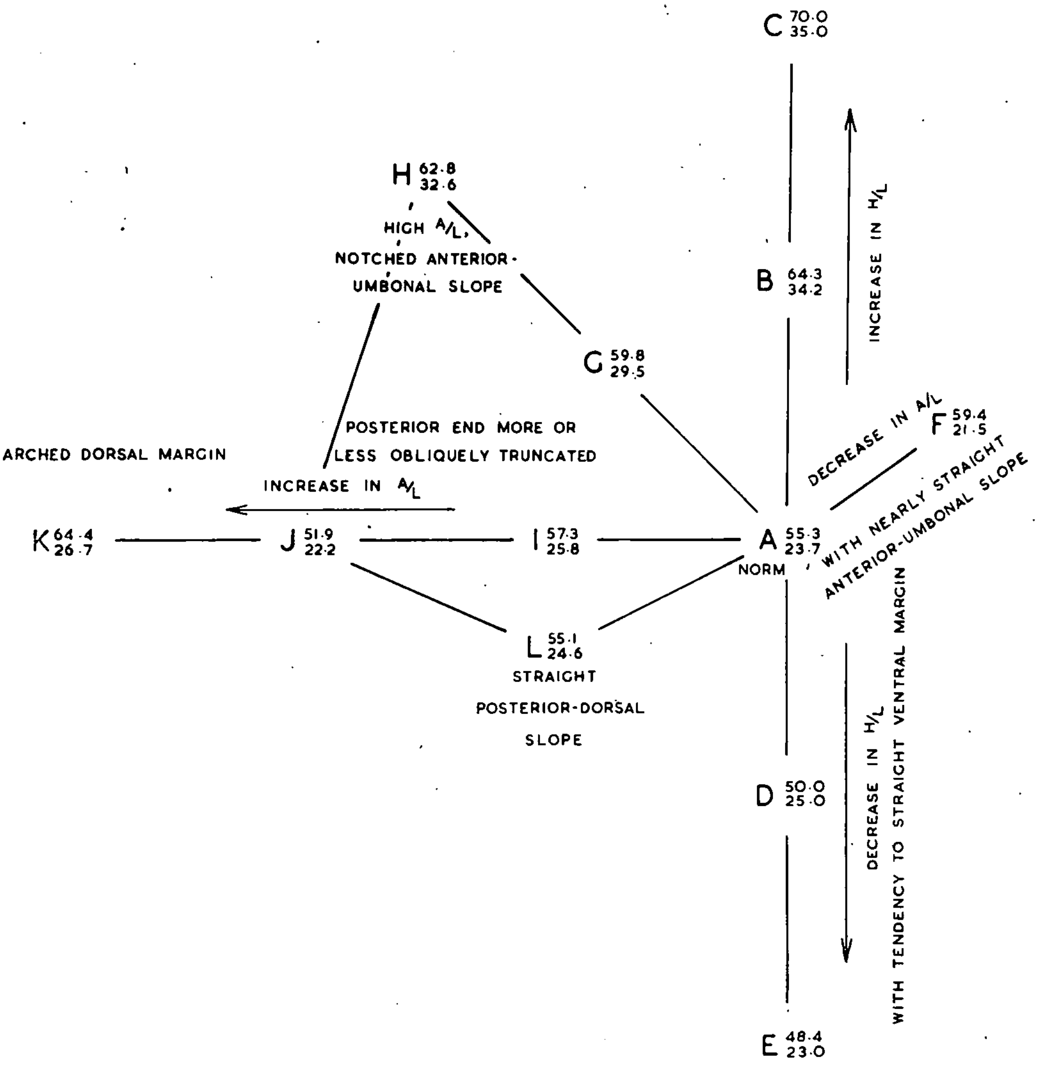


Figure 11.- Variation of characters shown by figured specimens of figure 9.

values for H/L, accompanied by a straightening of the ventral margin. F is a representative of those forms with a low value for A/L, i.e. with a relatively short anterior end and with a nearly straight anterior-umbonal slope. The specimens figured on the left side of the diagram have the posterior end more or less obliquely truncated. The posterior-dorsal slope of the series represented by specimens I, J and K is arched near to the posterior end. Specimen L lies off this trend and has a nearly straight dorsal margin. The trend of variation represented by specimens G and H shows a progressive increase in the value for A/L accompanied by a more markedly incurved anterior-umbonal slope.

The greatest concentration of specimens is, of course, centred about the norm for the norm is close to the mode. The distribution of the community above and below the norm is almost symmetrical but rather more specimens lie to the left of it than the right, since variants with a high value for A/L are more numerous.

Description of *Carbonicola beithensis* sp. nov.

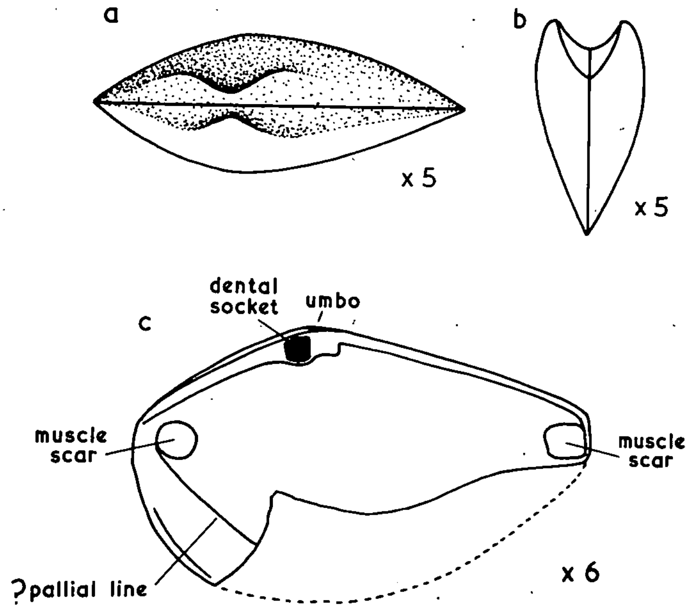
The shell is small and ovate, although there is considerable variation in shell shape. The anterior-umbonal/

umbonal slope is slightly concave and, rarely, arched near to the posterior end. The posterior end is bluntly rounded though sometimes obliquely truncated. The ventral margin is gently rounded and passes upwards in a continuous curve to the anterior end which is short. The tumidity is difficult to estimate from single valves, the only material available, but the maximum tumidity occurs at one third of the height below, and just posterior to, the umbones.

The growth lines, which are very indistinct, are parallel to the ventral margin on the lower part of the shell, but in the middle of the shell may be gently inclined.

Teeth are absent in nearly every case but not all specimens are edentulous as was originally believed. Plasticine casts of the umbonal region of more than twenty better preserved specimens failed to provide any evidence of teeth or dental sockets. In a single specimen, a right valve (figure 12, plate I), there is a cardinal dental socket. The umbones are smooth and rounded and are not contiguous.

The holotype (the norm of figure 9), plate IIa, is very close to the mode but has a slightly lower value for/



figures a and b are restorations of internal casts

Figure 12:- Internal characters of *Carbonicola*, Kersland Glen.

for A/L.

Two paratypes were chosen.

Paratype 1 (specimen G of figure 9), plate IIb, has a rather higher value for both H/L and A/L and has a more incurved anterior umbonal slope. It was chosen for its similarity to Carbonicola antiqua Hind.

Paratype 2 (specimen L of figure 9), plate IIc, lies very close to the mode but has a slight arching of the dorsal margin and was chosen for its similarity to Carbonicola elegans (Kirby).

Dimensions:

	L	H	A
Holotype	13.7	7.6	3.25
Paratype 1	11.2	6.7	3.3
Paratype 2	13.9	7.4	3.4
Means of the community	13.58	8.33	4.05

Ratios:

	H/L	A/L
Holotype	55.3	23.7
Paratype 1	59.8	29.5

	H/L	A/L
Paratype 2	57.3	25.8
Modes of the community	57.5	27.5

Localities:

The holotype and paratypes were collected from the Johnstone Shell Bed in Kersland Glen, one mile east of Glengarnock. Other measured specimens were collected from the same locality, from Powgree Burn, Paduff Burn and Beith Station.

Affinities:

Both *Carbonicola antiqua* Hind and *Carbonicola elegans* (Kirby), plate III, fall within the range of variation exhibited by *C. beithensis*.

	C. beithensis	*C. elegans*	*C. antiqua*
H/L x 100	Mode 57.5 Range of variation 35 - 90	50	64

Further more the type specimens of *C. antiqua* and *C. elegans* resemble some of the variants of *C. beithensis* and could be readily fitted into figure 9 as variation intergrades/

intergrades. It seems probable that this species from the Johnstone Shell Bed of the Limestone Coal Group may stand as a transitional form between the two Calciferous Sandstone species and the Coal Measure *carbonicolae*. However in view of its restricted geographical extent, combined with the fact that it is known from only the one horizon, it may throw little light on the origin of the Coal Measure non-marine lamellibranchs. It must be borne in mind that the Limestone Coal Group lies at about the horizon of the base of the Namurian and, in the light of recent evidence, it may be Upper Carboniferous in age, so that it is unlikely that there were many areas where similar conditions favourable to a *Carbonicola* fauna existed at that time.

VII. Palaeontology - the *Naiadites* fauna of the Maich Shell Bed.

The lamellibranchs of the Maich Shell Bed are a large naiaditiform type. They have thick calcite shells which thicken anteriorly to such an extent that they are almost solid in the region of the umbones. The umbo is very near to the anterior end in some variants and the shells are approaching a triangular shape.

The preservation is very poor for two reasons:

(i) The shells have been partially dissolved and the outer layer of shell material thus removed.

(ii) The shells have been subjected to crushing which has caused distortion. The degree and nature of this distortion can be related to the position of the shell relative to the bedding.

Because of the somewhat unsatisfactory material little work has so far been done on these shells. In the North Ayrshire Memoir (1930) it is stated "The prevalent shell is a thick-walled *Myalina*, specifically indeterminable on account of the distorted condition of the specimens." The shells have been referred to the genus *Naiadites* by Leitch (1941), although Leitch does not use the term Maich Shell Bed. His figured specimens are/

are stated to be from the Dalry Blackband Ironstone which lies at a slightly higher horizon. Weir and Leitch (1942) record shells from approximately the same horizon in the Motherwell region which they also refer to the genus Naiadites maintaining that the original record of Myalina sublamellosa from that horizon cannot be sustained.

It is clear that there has been some doubt about the correct identification of the Maich Shell Bed specimens. The basis for maintaining the two separate genera was laid down by Hind and further light has been shed on the problem by Newell (1940). The following characters observed in the shells under discussion establish that they are, beyond all doubt, Naiadites:

(i) They are edentulous, while rudimentary teeth may be present in Myalina.

(ii) The shells lack a rostral plate which is characteristic of Myalina.

(iii) The umbones, although anterior in position, are rarely terminal.

(iv) The muscles (which unfortunately have not been worked out for the type species of Naiadites, N. carbonaris Dawson) are not as close together as in the case of Myalina/

Myalina.

(v) The ratio of H/L is lower than in _Myalina_ where the height generally exceeds the length.

Variation in the community.

The community is extremely variable due chiefly to the following factors:

(a) The position of the umbo; in some variants it moves towards the anterior end becoming in the extreme case almost terminal.

(b) The curvature of the ventral margin which may vary from a gently rounded convex curve to being concave.

(c) The arching of the dorsal margin near to the posterior end of the shell.

(d) The projecting of the umbo above the hinge-line.

(e) A tendency to become quadrangular in shape through the ventral margin becoming nearly straight and parallel to the dorsal margin, accompanied by a blunt truncation of the posterior end.

(f) Variation of the carinal feature. The carina may be prominent or flattened. It may divide the shell into two nearly equal halves but the ratio of the area above/

above the carina to the area below it may vary considerably.

Most of the above mentioned features may be affected by the crushing of the shells and the relative effect of this is discussed later. The figured specimens were chosen to avoid the most obvious cases of distortion.

The variation in each character shows a continuous passage from one extreme to the other. The variants resulting from the above changes, (and combinations of those changes), have been arranged in series illustrating the nature and degree of variation from the norm of the community. Figure 13 is an arrangement of variants, on a purely morphological basis, into series of transitional intergrades. Figure 14 shows the distribution of the community, each individual is represented by a circle, relative to the figured intergrades of figure 13, represented by black circles. The main trends of variation are summarised in figure 15.

Specimens placed in the upper half of figure 13, above the norm, show a relative increase in the area below the carina. Specimens B and C represent a trend in which the carina is conspicuous, and specimens F, G and H a trend where the carina is low and flattened.

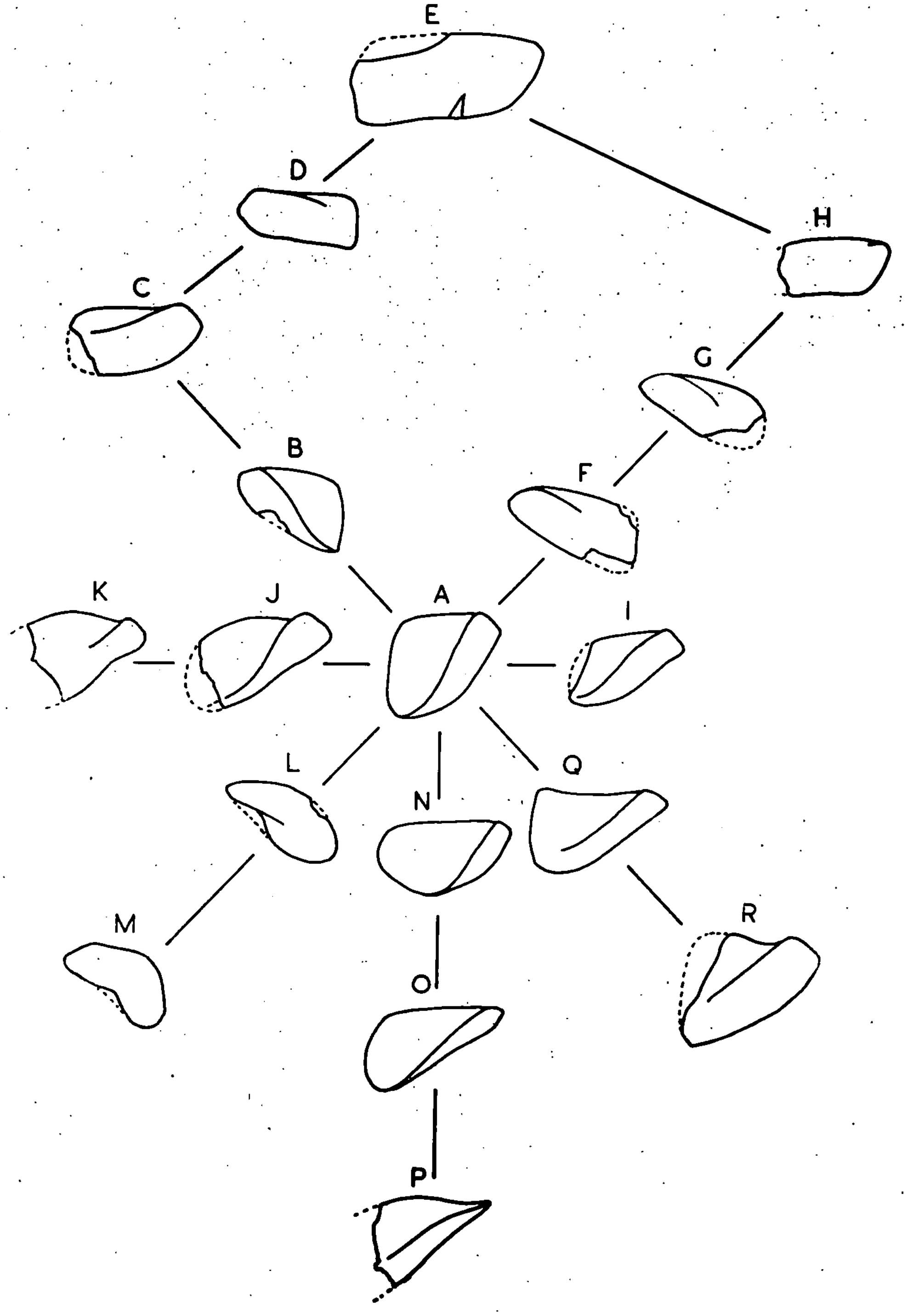


Figure 13.- Variation intergrades of *Naiadites* arranged in series. Maich Shell Bed.

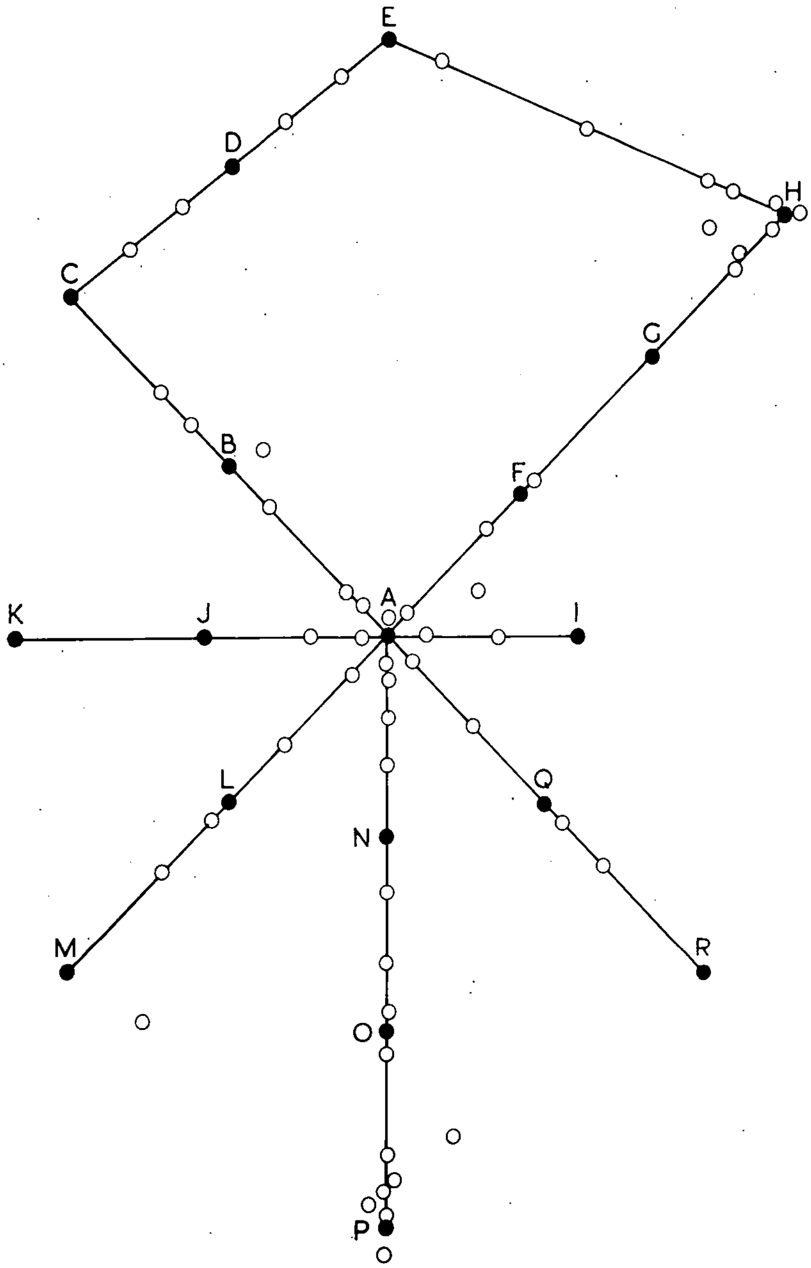


Figure 14.- Distribution scatter of variants of *Naiadites*. Lettered circles represent figured intergrades of figure 13.

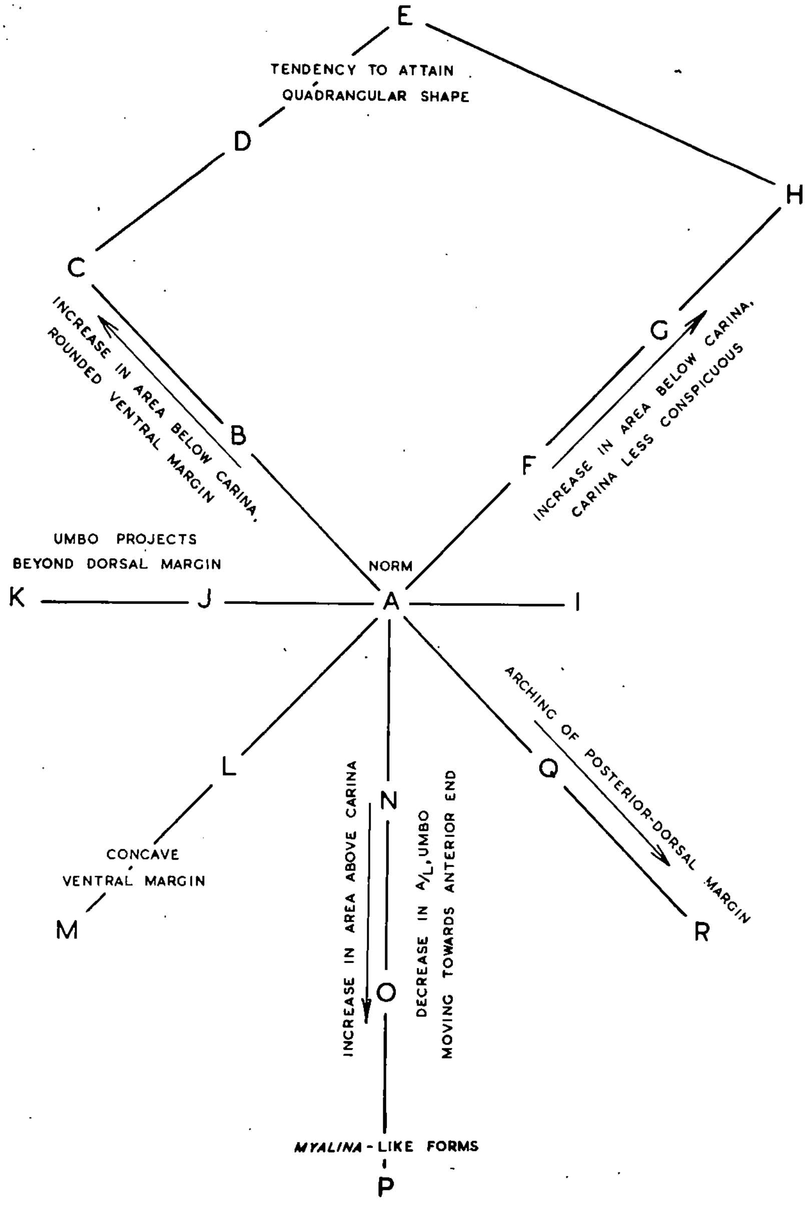


Figure 15.- Variation of characters shown by figured specimens of figure 13.

Specimens D and E represent a trend in which the ventral margin becomes less curved and is nearly parallel to the dorsal margin. The shells tend to aquire a quadrangular shape.

Specimens J and K possess umbones projecting above the hinge-line. Both shells are incomplete but it is apparent that the carina bisects the valve and for this reason they are placed on a level with the norm in figure 13.

The specimens figured in the lower half of the diagram show a tendency for the area below the carina to become relatively reduced. This is accompanied in the chief trend, represented by intergrades N, O and P, for the umbo to move towards the anterior end. L and M are representatives of forms with a concave ventral margin and tend to be kidney-shaped. Q and R represent a trend of variants with an arching of the dorsal margin near the posterior end.

Too few good specimens were obtained to fully display the distribution scatter of the community, but the majority of relatively uncrushed specimens lie close to the norm.

<u>Distortion of the shells.</u>

The scatter diagram, figure 14, shows a slight concentration of variants at two points on the diagram; in the region of intergrade H and in the region of intergrade P - as well as the concentration about the norm. Specimen H is an ovate type with a low, inconspicuous carina while specimen P is a triangular shell with a very high, angular carina and with the umbo almost terminal.

There is, superimposed upon the natural inherent variation, an effect due to crushing of the shells. The first type, with the low, flattened carina, comprises those shells which were fossilised with the plane of the valves parallel to the bedding, i.e. they lie on the bedding planes as far as can be determined for the mudstone is not well bedded. The second type with the accentuated carina were lying at right angles to the bedding planes. Thus the direction of crushing was perpendicular to the bedding and seems to have been largely due to compaction of the sediment under the weight of overlying strata. Naturally some of the shells would be found lying at oblique angles to the bedding planes, (although it is clear why the majority are parallel to or/

or perpendicular to the bedding), and the precise effect of crushing on these shells is difficult to determine. It is possible that those variants with markedly concave ventral margins, the kidney-shaped shells, may, at least in part, owe their shape to crushing in a direction oblique to the plane of the valves.

A series of specimens is shown in plate IV to illustrate the range of variation in the height of the carina; the chief factor affecting this character being, probably, the crushing. The central specimen is an uncrushed specimen lying close to the norm of the variation diagram.

General characters.

The shells are, as previously noted, very thick-shelled and are almost solid in the region of the umbones. They are large ranging from 18 mms. to 35 mms. in length and from 11 mms. to 20 mms. in height. The shape of shell is very variable.

The ornamentation of the shells is unknown for the outer layer of shell material is dissolved away in every case. The layer of shell material thus revealed is seen to be made up of distinct crystals of calcite and it is perforate.

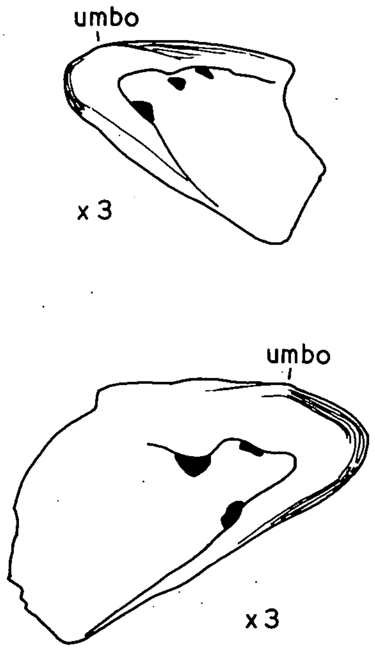
The shells are edentulous. The hinge plate is striated/

striated in order to provide a good hold for the attachment of the ligament.. Despite the frequence of internal casts, impressions of the muscles or mussel pits are rarely seen. Three muscle pits are situated in the umbonal cavity near to the anterior end. These are shown in figure 16 and can just be discerned in plate V. It is believed that these pits correspond to the points of attachment of the anterior adductor muscle and two pedal muscles.

Affinities.

Leitch (1941) figures four specimens from Dalry as Naiadites tumida. They are stated to be from the horizon of the Dalry Blackband Ironstone.

The conventional measurements were made of thirteen relatively uncrushed specimens, see figure 17. While these were not sufficient to give a representative picture of the community they were chosen for their proximity to the norm of the community, which is also believed to be near to the mode. Their means were used therefore in lieu of their modes, and compared with the means for other Lower Carboniferous Naiadites, N. tumida and N. obesa. The figures are given in table 1 but are summarised here:



muscle pits shown in black

Figure 16.- Internal characters of *Naiadites.*
Maich Water.

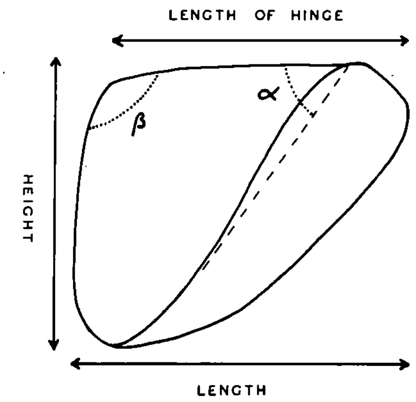


Figure 17.- Diagram of *Naiadites* to illustrate directions of measurement.

	L	H	H/L x 100	$\angle\alpha$	$\angle\beta$
Maich Shell Bed forms	24.4	15.5	64.9	35.3	110.6
N. obesa	24.3	18.0	76.7	48.5	103
N. tumida	22.7	19.1	84.2	45.0	111

The above figures for *N. obesa* and *N. tumida* are quoted from Leitch's paper.

Hind (1894-6) figures a number of shells from the Lower Carboniferous Limestone of Scotland which he refers to the genus *Naiadites* although none of his examples are specifically cited as coming from the Limestone Coal Group.

The ratios for *N. crassa* (Fléming) which Hind records, and figures two specimens from the Lower Limestone Group near Beith, are very close to those for the Maich Shell Bed community.

	H/L x 100	$\angle\alpha$	$\angle\beta$
Maich Shell Bed forms	64.9	35.3	110.6
Naiadites crassa	60.5	30	120

The figures compared are derived from a very limited sample/

sample but there is, further, a morphological similarity between the Maich Shell Bed forms and *N. crassa*, though the latter are relatively, perhaps, not so thick shelled. The shell thickness and the size are probably a function of the ecological station of which we know very little. Although the Maich Shell Bed forms lie several hundred feet higher in the succession than the Crassids recorded by Hind there is no evidence that the latter are of restricted stratigraphical range and, on the evidence available the Maich Shell Bed forms are assigned to the species *N. crassa* (Fleming).

The Westphalian Coal Measure *Naiadites* are clearly differentiated from the other five non-marine genera; the Lower Carboniferous forms, as pointed out by Leitch (1941), are not. A study was made initially of small lamellibranchs from the Calciferous Sandstone Series from St. Andrews (material collected by Mr. Manson from the shore near to the Rock and Spindle). This is like the assemblage described by Leitch from the vicinity. He showed that two groups of shells occur, one tending to *Naiadites*, one to *Anthraconaia*. Leitch interprets the characters of the Lower Carboniferous forms as suggesting that *Naiadites* was at that time branching off from/

from Anthraconaia stock. It is also probable that they were evolving from marine lamellibranchs; their habitat was such that they were able to co-exist with Lingula and marine forms and they show a marked morphological similarity to Myalina.

Naiadites crassa from the Limestone Coal Group stands midway, stratigraphically at least, between the Calciferous Sandstone forms and the Westphalian forms, but in character it is essentially a Lower Carboniferous type.

VIII. Evidence as to the Ecology of the Faunas.

There are two quite distinct and separate methods of approaching the problem of the ecology of the mussels. One is by a detailed study of their relation to the associated fauna. If the mussels are found in close conjunction with other fossils, i.e. on the same bedding planes, and of the same distribution, both geographically and in time, we can infer that they shared the same environment. We need therefore to know something of the ecology of the other fossils present, and we shall have to estimate from the closeness of their cohabitation the degree to which they shared a common environment. Further, if their normal habitats are not quite identical we must consider which of the forms has adapted itself to the ecological conditions indigenous of the other.

An alternative method of investigating the ecology of a fauna, which is here discussed in some detail also, and which has been given insufficient attention in the past, is to consider the lithology of the strata in which the fossils occur. More generally the conditions of deposition of a bed are inferred from the contained fauna but here, where little is known of the ecology of the faunas, an attempt has been made to reconstruct a picture/

picture of the sedimentary environment with a view to inferring that ecology.

The Johnstone Shell Bed.

The lamellibranchs of the upper part of the Johnstone Shell Bed are, we have seen, of the genus Carbonicola and therefore normally of non-marine habitat. They succeed immediately a marine brachiopod fauna which, though it contains no forms of stratigraphical value, is a useful widespread marker horizon and the bed is, in all respects, a normal marine band. Its faunal content has been briefly listed and it implies a typically shallow water, neritic marine environment.

Although the upper part of the shell bed containing the mussels is apparently lithologically identical with the lower marine part, the marine shells are not found in the upper part of the shell bed, and the change from a marine to a 'non-marine' fauna is quite abrupt; marine shells and mussels are mutually exclusive of each other. This would be a normal relationship but there is one exception; that of the marine brachiopod Lingula which always occurs together with the mussels. The relationship is intimate and they have been observed lying on the same bedding plane. While at some localities the mussels/

mussels are absent and *Lingula* occurs in the upper part of the shell bed, the converse has not been found, and nowhere do the mussels occur without *Lingula* also being present.

The key to the problem of the ecology of the mussels would then appear to be found by studying the ecology of *Lingula*. The ecology of modern *Lingula* has been described by Yatsu (1920a and b) and he has shown it to be marine although it has a wider range of tolerance to variation in salinity than the other animals which shared its habitat; this provides a clue to its relationship to the mussels under discussion.

Lingula is a burrowing, mud-loving form, and we may assume that the mussels as well only flourished on a muddy bottom; also, *Lingula* is essentially a shallow water form, rarely occurring below about twenty-five fathoms, and ranging from this depth upto low water mark; so that here again we can envisage the mussels sharing its environment. Unfortunately less is known of the range of tolerance of salinity of living Lingulids. Furthermore, evidence of salinity of ancient seas is scanty, and it can only be inferred that in this respect *Lingula* has not changed its habits appreciably. Yatsu (1920b)/

(1920b) has described the prolonged survival of Lingula in water which became brackish, and several writers have noted that it frequently exists in close proximity to the estuaries of rivers bringing such quantities of fresh water as must appreciably lower the salinity of the sea. The fossil evidence of Lingula occurring alone in the impoverished marine bands of the Coal Measures, also points to Lingula being able to tolerate a lower salinity than many marine forms; although it is recorded as occurring in many varied fossil communities. Thus we might assume that the abrupt change from a marine fauna to one comprising only Lingula and Carbonicola was due to a sudden decrease in salinity. If we assume then that the mussels were brackish and could not exist in marine conditions, and that the marine brachiopod fauna required a truly marine environment, with the exception of Lingula, (the tolerance to salinity of which was so great as to allow it to co-exist with marine forms and with mussels), then the principal factors are accounted for. Now it is necessary to study more closely the relationship of Lingula to the mussels. While they are now found in close proximity as fossils, they are not in the position of growth - fossilised in a vertical position - like/

like those found by Craig (1952). These shells are often fragmented, and though they must have existed simultaneously with the mussels to be found lying on the same bedding planes, the Lingula may have been transported some little distance. This could mean that they did not share precisely the same ecological station but only generally similar conditions. A further observed fact requires explanation: while mussels and Lingula are found together within the upper part of the shell bed, the mussels decrease in numbers upwards and are very rare towards the top of the bed, but Lingula (with the exception of the top few inches of the shell bed) increases numerically upwards. Thus the more numerous is Lingula the less numerous are the mussels so that we find a tendency for them to be mutually exclusive of each other. A slight increase in salinity is postulated to account for this, and the possible changes in salinity are shown graphically (figure 18) though no figures can be given and only relative salinity can be inferred. It does seem likely however, on the evidence available, that Carbonicola Beithensis tolerated a higher degree of salinity than that normally attributed to Coal Measure species. The changes in salinity could readily/

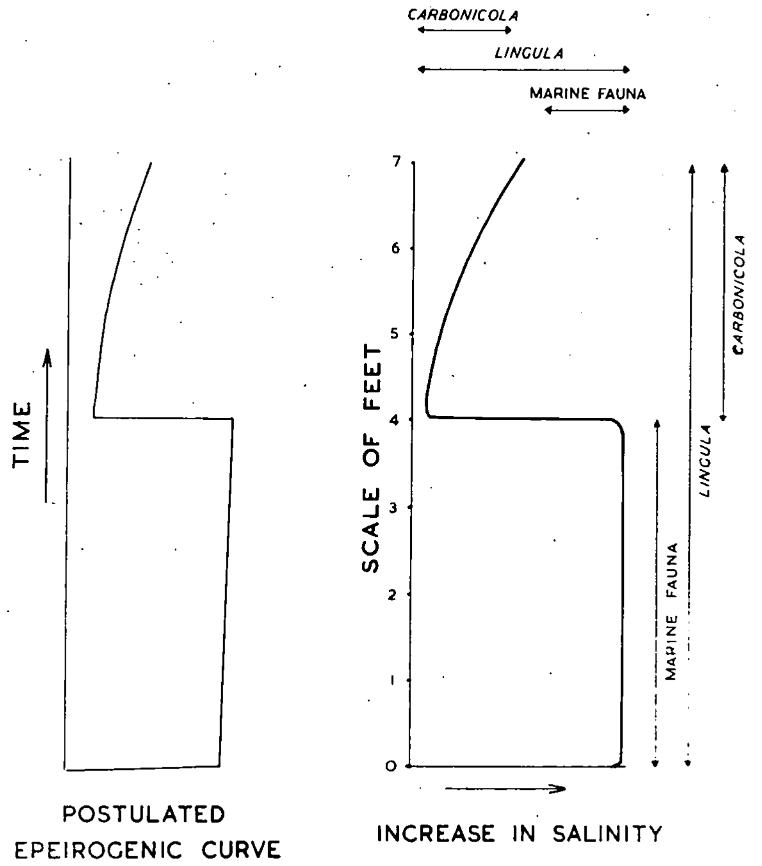


Figure 18.- Diagram to show the probable relationship of the vertical distribution of the fauna of the Johnstone Shell Bed to the variation in salinity.

readily be brought about in an area of deposition such as this by very small changes in level, and a hypothetical epeirogenic curve has been drawn.

The Maich Shell Bed.

The Maich Shell Bed fauna is in marked contrast to that of the Johnstone Shell Bed and comprises only *Naiadites* and *Lingula*. A few marine fossils have been recorded other than *Lingula* but none was found and even *Lingula* is not abundant. The very presence of *Naiadites* and *Lingula* together, but with the complete absence of *Carbonicola* such as occurs in the lower shell bed of the group, indicates that a peculiar environment existed. In addition to explaining the cohabitation of *Naiadites* and *Lingula* an explanation is also necessary for the non-appearance of *Carbonicola*, if a brackish-water environment is postulated. (In the Johnstone Shell Bed a few *Naiadites* are found along with the *Carbonicola* community but here in the Maich Shell Bed the converse does not hold). The naiaditiform shells are unlike the typical Coal Measure forms having thick calcite shells. They are much broken up, partially dissolved, so that in most cases the outer layer of shell material has been removed and any ornamentation that may have been present has been/

been eradicated. Again, on this evidence, we cannot assume that the shells are found in the precise position in which they lived. The presence of Lingula, while it is not abundant, cannot be ignored and in fact it provides almost the only faunal evidence of the habitat. Again it is postulated that Naiadites and Lingula shared a marine, though somewhat specialised marine, environment, and that Naiadites is here found to have existed in conditions "more marine" (i.e. of higher salinity), than was usual. The fact that Lingula is not abundant suggests that it was incompletely adapted to the conditions indigenous to Naiadites, and it is apparent that the controlling factor was again salinity.

Summarising the conclusions it is found that both the shell beds were formed under specialised, and rather brackish, marine conditions. The salinity was in both cases too low to permit the existence of a marine fauna, with the exception of Lingula, (and in the case of the Maich Shell Bed, a very few marine forms). For Lingula a wide range of tolerance to degree of salinity is postulated, perhaps the chief obstacle to the theory, but a point on which there is insufficient evidence: further study of its physical environments are necessary before its present ecology and its palaeoecology can be completely/

completely known. It is most difficult to estimate the relative salinity of the two shell bed environments, but taking the presence of *Lingula* as a criterion of marine conditions, it would seem that its relatively greater abundance in the Johnstone Shell Bed would suggest higher salinity, although this will be seen to conflict with the findings based on lithological evidence. Perhaps the evidence of recorded marine fossils from the Maich Shell Bed provides the more conclusive evidence pointing to the fact that this was the "more marine" environment, since no marine shells have ever been recorded, nor any found, in the Johnstone Shell Bed.

Lithological Evidence.

The mussel fauna of the Johnstone Shell Bed occurs in dark blueish shaly mudstones, and the Maich Shell Bed consists of ironstone with shells and again dark shaly mudstone. In both cases the mudstones are, at first, indistinguishable from the shales or mudstones of the marine leaf of the Johnstone Shell Bed - or even some of the barren mudstones. If the prime factor controlling the faunal content, as has been postulated, is salinity, this would not of course be reflected in the lithology.

An examination of three types of mudstone, both in thin/

thin section and ground to powder, under a petrological microscope revealed nothing save that in every case the grain size was too small to be observed by normal methods, using a magnification of the order of two hundred. Other physical tests, grittiness, density, etc., also failed to distinguish between the mudstones bearing a marine or a specialised marine fauna, or no fauna.

A spectrographical analysis was carried out on two samples from the marine leaf of the Johnstone Shell Bed, two samples from the upper leaf containing the Carbonicola - Lingula fauna, and one sample from the Maich Shell Bed. The chief purpose of this was to investigate the relative abundance of the trace elements which might have some influence on the growth of the invertebrate animals. The results are tabulated (table 2) and, while they are inconclusive, the relative amounts of Caesium, Manganese, Nickel, Strontium and Ytrium present seem significant. On these criteria the Maich Shell Bed specimen is similar to the marine mudstone of the Johnstone Shell Bed, but the specimens from the upper part of the Johnstone Shell Bed are readily distinguishable.

The most promising results in this field of research were from an investigation of the adsorbed cations present/

present. Clay, it has been demonstrated, consists of minute platelets of colloidal size, and some of them at least carry a negative electric charge. The ability of the platelets to remain for long periods in suspension is therefore presumed to be due to the mutual repulsion of the negative charges they carry, and flocculation (or coagulation and precipitation) of a clay suspension is considered to be due to a loss of potential in their particles. The charges on clay colloidal platelets are related to their ability to adsorb cations, such as calcium or sodium, from any salt solution with which they come in contact. These cations are considered to be held on the surface of the clay platelet by attraction of electrical charges of opposite sign, in the manner shown in figure 19. Now the nature of the adsorbed cation has a pronounced effect on the total charge of the colloidal particles. The effect on the colloidal charge is a product of the diameters of the various cations and of their various degrees of hydration. Cations are presumed to be surrounded by a hull or sheath of water. The greater their diameters and the greater the thickness of this water sheath (which is proportional to their degree of hydration), the greater will be the distance of/

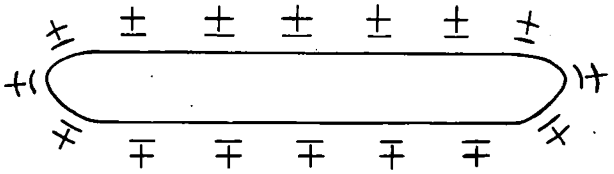


Figure 19.- Diagrammatic representation of the charge on a clay particle.

of the cation, positive charge from the outer and negative charges of the clay particles, and the less will be their effect in nullifying these negative charges. Thus clay particles which have adsorbed large-diameter, highly hydrated cations are more strongly charged than clay particles with smaller-diameter, less-hydrated, cations, and therefore display a stronger tendency to remain dispersed in suspension. The radii of various cations are shown in table 3, which also shows the migration velocities of clay particles which have adsorbed various cations. These velocities are proportional to, and give a measure of, the relative charges on the various colloidal particles. In practice, the variation in cation diameters is small compared with the variation in cation plus water-sheath diameter, and it is the latter which determines the charge on the adsorbing clay colloids. The electrical charge on clay particles varies with the adsorbed cation in the following manner:

$Li^{+} > Na^{+} > K^{+} \simeq NH_4^{+} > Rb^{+} > Mg^{++} > Ca^{++} > Sr^{++} > Cs^{+} > Ba^{++} > H^{+}$

It will be noted that, on the whole, clay colloids with adsorbed monovalent cations are more strongly dispersed, or more highly charged than clays with bivalent cations, (Hydrogen/

(Hydrogen is anomolous), so that we might expect mudstones containing clay minerals, and formed under marine conditions, to have sodium - and to a lesser extent-potassium - as the adsorbed cations, while non-marine mudstones would probably have calcium as their chief adsorbed cation, since it is the dominant adsorbed cation in most soils.

The relative dispersion of suspensions of mudstones (powdered) will then indicate the nature of the adsorbed cations and this was examined.

Two samples of marine mudstone from the lower leaf of the Johnstone Shell Bed, two from the upper part bearing the Carbonicola-Lingula fauna, and one from the Maich Shell Bed were taken. Each was ground to powder, and then with water was ground to a smooth paste. This was considered necessary, for while the size of individual particles was so small, and probably of the same order in each case, and therefore the effect on the settling times could be ignored, any aggregations of particles could seriously affect the rate of flocculation. A weighed amount of each sample was washed into a tall jar and topped up to 500 mL with CO_2-free distilled water. This was then shaken up for exactly two minutes and allowed/

allowed to stand. After a given time interval 20 mL. were withdrawn by means of a pipette inserted to a depth of 10 cms. and this was evaporated to dryness and dessicated before weighing. The weight of this evaporite as a percentage of the weight of the original sample gives a measure of the dispersion. The results are presented in table 4, and show a significant difference between the marine mudstones and the mudstone of the Carbonicola bed. The specimen from the Maich Shell Bed is however indistinguishable from the marine mudstones. In the first instance a time interval of ten minutes was taken but the experiment was repeated with times of thirty minutes since it was hoped that this would further reduce the effects of gravitational settling. The results were strictly comparable.

Despite the apparent significance of the above results, two important considerations must be taken into account: firstly, that the actual cations present are not known, and, secondly, that the clays dealt with are, in every case, found in rocks of Carboniferous age, laid down, and now outcropping, in the same area so that they must have suffered the same history.

An important consideration is that the amount of base/

base exchange which may have taken place could seriously affect the results. If clay characterised by one type of cation, e.g. calcium, is mixed with a solution of another type of salt (e.g. a sodium salt) a certain proportion of the original adsorbed cations will be displaced by a corresponding number of the cations of the salt solution, or in this case quoted, by double that number since the valency of calcium is two and that of sodium is only one. The phenomenon, which takes place very readily, is known as Base Exchange. The proportion of original cations displaced will depend on:

(a) The nature of the displaced and displacing ions,

(b) The concentration of the salt solution,

but if leaching is prolonged then ultimately all the original cations will be replaced. This has, surprisingly, not happened in the clays here discussed.

Here, then, is additional evidence that the Carbonicola fauna, now found in what is probably a dominantly calcium shale, thrived in an environment which was certainly not marine. The Naiaidtes fauna may have had a marine habitat, though as other evidence has shown, a specialised and perhaps rather brackish marine type.

Finally it has been suggested by Professor T. C. Phemister than an examination of the clay mineral content of the mudstones might serve a useful purpose, although little work has so far been done on the relationship between clay mineralogy and sedimentary environment. Boswell (1952) in a review of the contribution of clay mineralogy to the study of the diagenesis of sediments states that the London Clay (marine) contains chiefly illite (70%) but also kaolinite and montmorillonite but that the fresh-water ball-clay of the Dorset Eocene is predominantly kaolinitic as are the Wealden fresh-water clays. The X-ray work is not considered to be within the scope of this thesis, nor are the researches sufficiently advanced but preliminary examination of the marine mudstone (of the Johnstone Shell Bed) indicates that muscovite, quartz and probably montmorillonite may all be present.

The Maich Shell Bed Ironstone.

The shells of the Maich Shell Bed occur not only in shaly mudstone, which has been discussed, but also in ironstone:

Maich Shell Bed 1 ft. 1½ ins.	3 ins. Ironstone with shells.
	1½ ins. Ironstone, barren.
	9 ins. Shaly mudstone, with shells.

If the ironstone is original, (i.e. not a secondary enrichment), then it must have formed under conditions not dissimilar from those of the shaly mudstone, for they both bear a similar fauna. The concensus of opinion is that the ironstones of the Carboniferous are original bedded ores and there is no evidence of replacement, hydrothermal or otherwise, having taken place. The ironstone of the Maich Shell Bed, like the others of the Limestone Coal Group, is an ordinary bedded clay ironstone. It therefore contains a considerable amount of clay material, presumably like that of the shales immediately adjacent the ironstone; but for a time, in addition to deposition of mud, there must have been precipitation of iron. The relative abundance of iron in the water, clearly does not appear to have affected the fauna in any way, and as has been stated, the shells from the ironstone band appear to be similar to those from the mudstone. No ready explanation is forthcoming for the absence of shells from the lowest one and a half inches of ironstone beyond the obvious fact that temporarily conditions were unsuitable for the continued existence of the lamellibranchs, but after a brief interval they were able to re-establish themselves.

A number/

A number of bands of ironstone occur in the group, two such lie a few feet below the Maich Shell Bed, and they are also barren.

It is difficult to attribute a definite position in the rhythmic cycle to the ironstones, and for this reason they have sometimes been erroniously regarded as secondary enrichments. They are found more commonly in the lower half of the Limestone Coal Group, i.e. in the cycles which commence with a marine or quasi-marine bed, and they are generally found within a few feet of a Lingula bed; for example the Pundeavon Ironstone, the ironstones just below the Maich Shell Bed and the Dalry Blackband Ironstone. Only in the case of the Maich Shell Bed ironstone is the relationship to the fauna so intimate. It appears then that some factor, to some extent independent of the sedimentary rhythm, was responsible for the deposition of iron. Since it is not known in what original state the iron existed, (possibly carbonate or bicarbonate, and perhaps in colloidal form), it is impossible to estimate which of the factors that could cause precipitation was dominant. It is generally agreed that ironstones of this type are of fresh-water origin, but beyond that their presence contributes/

contributes little to the problem of the ecology of the fauna. Conversely the postulated ecology is insufficiently substantiated to make any contribution to our knowledge of the conditions of deposition of the clay ironstones.

The analogy between the Limestone Coal Group shell beds and other Lower Carboniferous lagoon phases.

The shell beds of the Limestone Coal Group bear a considerable resemblance to the Modiola Phases of the Avonian of Gower described by Dixon and Vaughan (1911). Three of these phases are recorded as occurring at the base of the K and C_2 zones and at the top of S_2. They are considered to be lagoon phases, the latter being defined as deposits of wide extent, deposited in coastal areas, "So extremely shallow as to have been, in effect, isolated from the deeper part of the sea and thus to have become the site of peculiar types of sediment and fauna." They yield Modiola, Sanguinolites, Spirorbis-like annelids and abundant ostracods. The sediments, in part, show typically shallow water characters but they include very fine grained mudstone, so fine that they resemble deep sea deposits.

The mudstones are regarded as having been deposited under conditions of extreme isolation and are most restricted in faunal content. Some are barren, others yield only a special phasal fauna. It is suggested that either extensive shallows or a bar separated the lagoonal area from deeper water, and such an area would be favourable to great increases in salinity or, if near a river, to decreases in salinity.

The part played by salinity is not reviewed but it is suggested that the mere shallowness could not account for the characteristic feature - barrenness, or a peculiar fauna rich in individuals but not in species.

The postulated conditions for the Modiola phases have been quoted in some detail for the analogy with the Carbonicola bed (the upper part of the Johnstone Shell Bed) and the Maich Shell Bed is close. Here too, the faunas are rich in individuals of one species. The shells occur also, in very fine grained mudstone. In the case of the Limestone Coal Group, however, these specialised faunal phases were much more transitory than those described by Dixon and Vaughan, and pisolites and other shallow water features are quite absent.

A certain similarity between the mode of occurrence of the lamellibranchs of the Limestone Coal Group and those described by Eagar (1947) from the Lower Coal Measures of Yorkshire has been noted, although there are some significant differences. As pointed out by Eagar non-marine lamellibranchs are rare in the Millstone Grit. In the Middle Coal Measures, where the rhythm is shorter, the non-marine lamellibranchs are usually restricted to a thickness of a few inches above the roof of a coal seam; although they may occur higher in the rhythm few thick bands have been reported. "Here in the Lower Coal Measures, above the Soft Coal Bed we have the intermediate case where pene-marine bands are closely associated with rich non-marine bands, the latter extending through a considerable thickness of the unit cycle." Also here in the *Lenisulcata* zone shells are found just below the *Lingula* beds as well as above them. (There is apparently no record of non-marine lamellibranchs occurring with *Lingula* as in the Johnstone Shell Bed.) The shells found immediately above the *Lingula* bed are described by Eagar as small, elongate forms referrable to *Anthraconaia*, but they are replaced upwards, in the coarsening shale, by *Carbonicola*.

The relation of the lamellibranchs of non-marine type to the marine bed in the Johnstone Shell Bed is seen to be similar in one respect to the relationship existing in the measures above the Soft Coal Bed: they occur in mudstones immediately succeeding a marine bed. There are, however, the following significant differences:

(i) Lamellibranchs of non-marine type are restricted to three or four feet of strata above the marine bed in the case of the Johnstone Shell Bed, and they are quite absent from the rest of the cycle. In the strata above the Soft Coal Bed non-marine lamellibranchs extend through the greater part of the unit cycle. This fact may be related to the occurrence of mudstones which, in the case of the Lower Coal Measures make up a much greater part of the cycle than in the Limestone Coal Group.

(ii) Also the non-marine lamellibranchs of the Lower Coal Measures are found in a greater variety of rock types including sandy mudstone.

(iii) Carbonicola does not precede the marine bed or the Lingula fauna in the Johnstone Shell Bed but is found in close association with Lingula.

Probably not all the differences in the mode of occurrence of the mussels can be related to differences in the rhythmic cycles; the somewhat unusual ecology of the Johnstone Shell Bed Carbonicola must be a factor of some importance.

IX. Fossils from horizons below the Limestone Coal Group.

The strata immediately below the Limestone Coal Group were examined with the intention of comparing their fauna with that of the overlying group.

The shales immediately beneath the *Posidonia* bed are barren, but for a few feet above the Top Hosie Limestone and between the several Hosie Limestones there are limy shales with an abundant marine fauna. This was examined at several localities but chiefly in Hindog Glen one mile north of Dalry. The specimens collected do not present such a complete picture, nor are they individually as good, as those collected by John Smith. His specimens, now in the Geological Survey collection at Edinburgh, are described therefore. The fossils are chiefly marine lamellibranchs, of which the majority are typical *Nucula*. They are large, some attaining a length of 50 mms. They possess strong ridges concentric about the umbo, and which are inclined at an angle to the ventral margin in the upper part of the shell. The shape variation is considerable but many of the shells tend to be rectangular, (egs. specimens JS. 12727 and JS. 12740, figure 20). These marine/

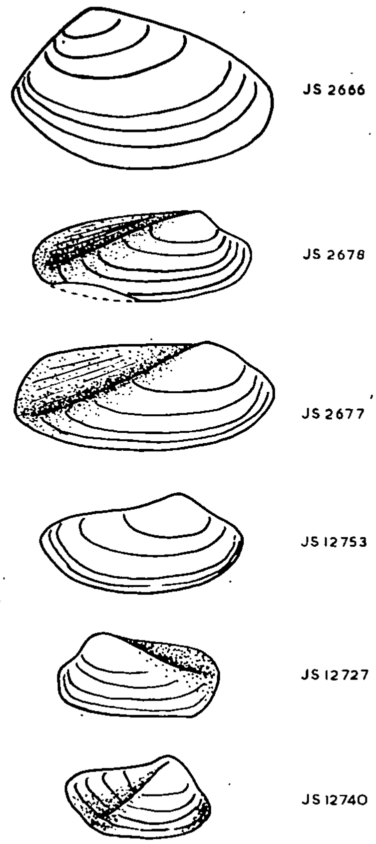


Figure 20.- Lamellibranchs from the Lower Limestone Group, [Dalry]

marine lamellibranchs are similar to those found in the (lower) marine part of the Johnstone Shell Bed some sixty or seventy feet higher in the succession. They do not bear any kinship to the *Carbonicola* fauna of the upper part of this shell bed.

Smith also collected from about this same horizon at Lugton specimens of *Naiadites crassa*. Hind (1894-6) too figures *N. crassa* from Lugton Water. Although they are here found in association with marine fossils there is no doubt of their affinity with the fossils of the Maich Shell Bed.

Thus it appears there is no evidence of the origin of the *Carbonicola* fauna, which is a solitary phase restricted to one horizon, the Johnstone Shell Bed, but on the other hand the *Naiadites* fauna is known from several horizons in the Lower Limestone Group as well as from the Johnstone Shell Bed and the Maich Shell Bed, but it is only in the latter that the shells are abundant.

X. Conclusions.

The Limestone Coal Group, north of the Dusk Water Fault where it attains a maximum thickness (in Ayrshire) of over six hundred feet, consists of rhythmic sediments. No less than thirteen partially complete cyclothems can be recognised.

In the lower half of the group the cyclic units commence with a marine or Lingula bed and in two cases this is followed by a bed containing lamellibranchs of non-marine type. These are the Johnstone Shell Bed (upper part) and the Maich Shell Bed.

The development of these musselbands is seen to be exceptional. The Johnstone Shell Bed, which is of very wide extent - occurring throughout Ayrshire and most of the Midland Valley of Scotland - is normally a marine band with a chiefly brachiopod fauna. The upper 'leaf' of the shell bed containing Lingula and Carbonicola is in Ayrshire restricted to the area north of the Dusk Water Fault - an area where the Limestone Coal Group is best developed and which was, as shown by Richey, a contemporaneously, differentially downfaulted area. The upper part of the shell bed containing Lingula alone is, however, found between the Dusk Water/

Water and the Inchgotrick Faults. In one other area outside Ayrshire, near Strathaven, the Carbonicola fauna is found.

These changes in faunal content of the Johnstone Shell Bed can be related to the variations in thickness of the group. Ayrshire is divided into four areas by major contemporaneous faults (of Carboniferous age), the Dusk Water, the Inchgotrick and the Kerse Loch Faults. South of the Dusk Water Fault the group is attenuated to less than half its thickness in the Beith-Kilbirnie district. Associated with this thinning is the loss of the Carbonicola fauna from the upper part of the shell bed. Further thinning takes place at the Inchgotrick Fault and south of this line the Johnstone Shell Bed is merely a marine bed similar in character to its occurrence elsewhere in the Midland Valley. Despite a thickening of the group south of the Kerse Loch Fault to over forty percent of its thickness in North Ayrshire, there is no reappearance of an upper bed with Lingula or Carbonicola.

The attenuation of the strata takes place, not so much by the absence of complete cyclothems, except perhaps in area C between the Inchgotrick and Kerse Loch Faults/

Faults where the group is very thin, but by the incompletion of the individual cycles. Thus south of Dusk Water only on one occasion was subsidence sufficient to permit a marine incursion - that which gave rise to the Johnstone Shell Bed.

The Maich Shell Bed is of very limited extent and is found at only three localities, all of them north of the Dusk Water Fault, although a fossiliferous bed which occurs in the East Kilbride-Motherwell area at about this horizon has been correlated with it.

The _Carbonicola_ fauna is very similar in character at all the exposures. The assemblage shows great variation and, on first examination, might be thought to include several species of _Carbonicola_. The widely varying forms can, however, all be linked by intergrades to a centre or focus of variation, the norm, and the whole assemblage belongs to one species group. There is a definite affinity with the Calciferous Sandstone forms, _Carbonicola antiqua_ Hind and _Carbonicola elegans_ (Kirby), but the shells have been referred to _Carbonicola beithensis_ sp. nov. since the community is distinct when considered as a whole. A full description of/

of the new species is given (see page 47). It must be emphasised that a species such as this is a morphological one and not necessarily a Linnean species.

The *Naiadites* fauna of the Maich Shell Bed has been confirmed as belonging to that genus and not, as it has sometimes been assigned, to *Myalina*. The widely varying forms of this community have been shown to belong to one species group. A comparison with other Lower Carboniferous *Naiadites* has led to the conclusion that the community is referrable to the species *Naiadites crassa* (Fleming).

The ecology of the *Carbonicola* and *Naiadites* faunas was investigated using two separate lines of evidence, that provided by the associated fossils, chiefly *Lingula*, and the evidence of the lithology. The closeness of the association of the lamellibranchs with *Lingula*, of which the ecology and palaeoecology are briefly discussed, shows that *Carbonicola* must have existed in more saline conditions than are usually attributed to it. *Naiadites*, which occurs with some marine fossils including *Lingula* must have had a definitly marine, though admittedly a specialised marine, environment. Work on the lithology of the shell/

shell beds, particularly that indicating the nature of the adsorbed cations, confirms the palaeontological evidence. A comparison has been made with other Carboniferous faunal phases and a similar sedimentary environment to that of the Modiola Phases of the Lower Carboniferous of Gower has been adduced.

In neither case can the lamellibranchs of the Limestone Coal Group shell beds be called non-marine and, of the two, Naiadites is the 'more marine', that is to say it tolerated a greater degree of salinity.

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TABLE 1.

TABLE OF MEASUREMENTS OF NAIADITES CRASSA FROM THE MAICH SHELL BED COMPARED WITH OTHER NAIADITES FROM THE LOWER CARBONIFEROUS.

	L	H	H/L x 100	∠α	∠β
1.	22.5	19.5	86.2	43	90
2.	31.0	18.5	59.5	27	111
3.	35.0	20.0	57.0	39	104
4.	19.5	16.0	81.8	40	-
5.	18.5	15.5	83.6	47	137
6.	27.0	20.0	73.9	42	-
7.	33.0	17.0	51.4	21	108
8.	18.3	11.5	62.6	39	105
9.	28.0	17.0	60.5	24	104
10.	25.5	11.0	43.2	33	-
11.	18.2	12.0	66.0	29	126
12.	23.0	12.0	52.0	29	-
13.	18.0	12.0	66.6	46	-
Means:	24.4	15.5	64.9	35.3	110.6
N. obesa.	24.3	-	76.7	48.4	102.8
N. tumida.	22.7	-	84.2	44.9	111.1

(Figures for N. obesa and N. tumida derived from Leitch (1941).)

TABLE 2.

TABLE TO SHOW THE AMOUNTS OF TRACE ELEMENTS PRESENT IN MUDSTONES FROM THE LIMESTONE COAL GROUP.

Specimen 1.- Johnstone Shell Bed, marine leaf, Gowkhouse Burn.

Specimen 2.- Johnstone Shell Bed, marine leaf, Kersland Glen.

Specimen 3.- Maich Shell Bed, Maich Water.

Specimen 4.- Johnstone Shell Bed, (*Carbonicola* fauna), Paduff Burn.

Specimen 5.- Johnstone Shell Bed, (*Carbonicola* fauna), Beith Station.

Figures are parts per million. ND - not detectable.

+ - present, ++ - abundant but not determined.

	1	2	3	4	5
Ag	<1	<1	<1	10	1
Al	+	+	+	+	+
As	ND	ND	ND	ND	ND
Ba	1,000-3,000	1,000-3,000	1,000-3,000	1,000-3,000	1,000-3,000
Be	ND	ND	ND	ND	ND
Bi	ND	ND	ND	ND	ND

	1	2	3	4	5
Ca	tr.	tr.	++	tr.	tr.
Cd	ND	ND	ND	ND	ND
Co	30	30	50	30	30
Cr	300	300	300	300	300
* Cs	300	200	100	100	100
Cu	300	250	250	300	300
Fe	$\gg$1%	$\gg$1%	$\gg$1%	$\gg$1%	$\gg$1%
Ge	50	50	50	50	50
* Hg	1,000	1,000	ND	ND	ND
K	+	+	+	+	+
La	150	30-100	ND	30-100	30
Li	300- 1,000	300- 1,000	1,000	300- 1,000	300- 1,000
Mg	+	+	+	+	+
* Mn	3,000	3,000	3,000	3,000- 10,000	10,000
Mo	30	30	20	30	50
Na	+	+	+	+	+
* Ni	300	300	200	150	200
Pb	100	300	200	300	500
Rb	2,000	2,000	2,000	2,000	2,000
Sb	ND	ND	ND	ND	ND

	1	2	3	4	5
Si	+	+	+	+	+
* Sr	200	200	400	100	30
Su	ND	ND	ND	ND	ND
Th	100	100	100	100	100
Ti	+	+	+	+	+
Tl	ND	ND	ND	ND	ND
V	300	300	300	300	300
* Y	100	70	100	30	10
Zn	ND	ND	ND	ND	ND
Zr	1,000	300	300	300	200

* denotes significant differences.

TABLE 3.

TABLE OF IONIC SIZES & MIGRATION VELOCITIES.

Ion saturating the colloidal clay	Size of ion - radii in Angstroms Dehydrated	Hydrated	Migration Velocities (all negative)
	A°	A°	u/sec./volt/cm.
Li^+	0.78	10.03	3.45
Na^+	0.98	7.90	3.31
K^+	1.33	5.32	....
NH_4^+	1.43	5.37	3.48
Rb^+	1.49	5.09	3.25
Cs^+	1.65	5.05	3.02
H^+	?	?	2.84
Mg^{++}	0.78	....	3.18
Ca^{++}	1.06	....	3.27
Sr^{++}	1.27	....	3.06
Ba^{++}	1.43	....	3.01
La^{+++}	1.22	....	2.74
Th^{++++}	....	....	3.11

Angstrom unit, A^o - 10^{-8} cms.

(Data after Jenny and Reitemeier.)

TABLE 4.

TABLE TO SHOW THE RELATIVE DISPERSION OF SUSPENSIONS OF POWDERED MUDSTONES FROM THE LIMESTONE COAL GROUP.

Specimen 1.- Johnstone Shell Bed, marine leaf, Gowkhouse Burn.

Specimen 2.- Johnstone Shell Bed, marine leaf, Kersland Glen.

Specimen 3.- Maich Shell Bed, (*Naiadites* fauna), Maich Water.

Specimen 4.- Johnstone Shell Bed, (*Carbonicola* fauna), Paduff Burn.

Specimen 5.- Johnstone Shell Bed, (*Carbonicola* fauna), Beith Station.

	Ratios of evaporite / original sample.	
	After 10 minutes.	After 30 minutes.
	%	%
Specimen 1	0.800	1.167
Specimen 2	1.283	1.152
Specimen 3	1.131	1.361
Specimen 4	0.406	0.354
Specimen 5	0.666	0.959

Plate I

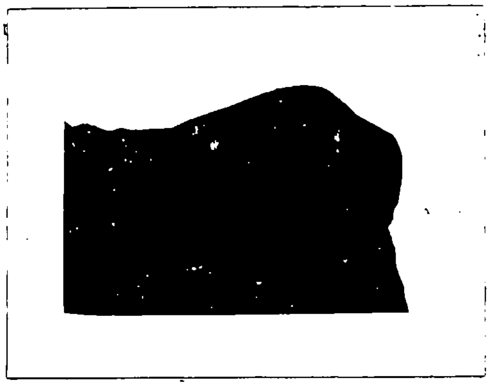
Plate I.

x 5

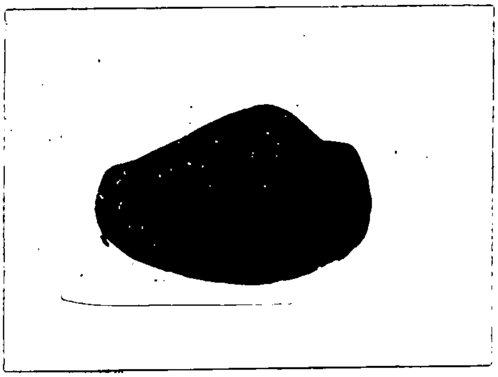
Interior of a right valve of Carbonicola beithensis sp. nov. showing a cardinal dental socket and the anterior adductor impression. From the Johnstone Shell Bed, Kersland Glen.

Plate II

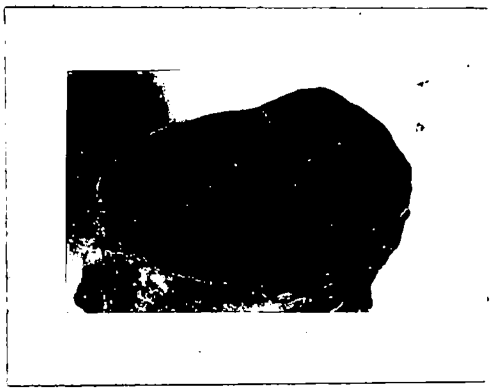
Plate II.



II a.



II b.



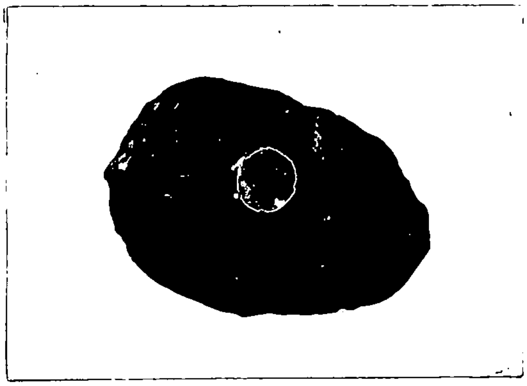
II c.

The holotype (II a) and paratypes (II b and c) of Carbonicola beithensis sp. nov. From the Johnstone Shell Bed, Kersland Glen.

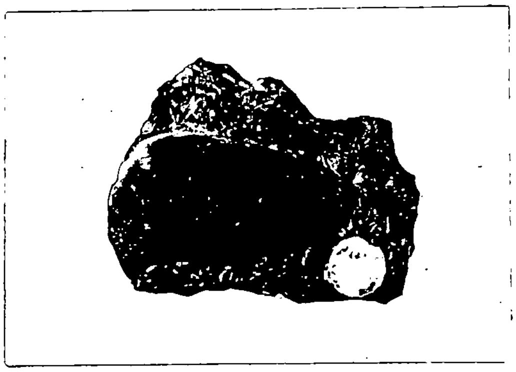
(All x 3)

Plate III

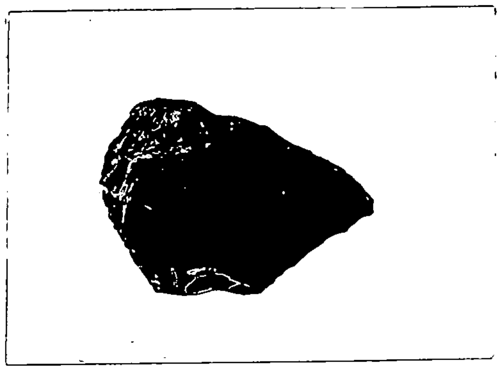
Plate III.



III a.



III b.



III c.

Type specimens of Carbonicola antiqua Hind (III a) L. 46890 and Carbonicola elegans (Kirby) (III b and c) L. 47165 and L. 47163. From the Calciferous Sandstone, Fife. (Specimens in the collections of the British Museum, (Natural History).)

(All x 2)

Plate IV

Plate IV.

Naiadites crassa (Fleming) from the Maich Shell Bed, Maich Water. A series of shells arranged to show the effects of crushing on the carinal feature.

(All natural size)

Plate V

Plate V.

Interior of the anterior end of two specimens of Naiadites crassa (Fleming) to show muscle pits in the umbonal cavity. From the Maich Shell Bed, Maich Water.

(Both x 4)

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