# MORPHOLOGY AND DISTRIBUTION OF CERTAIN BRITISH CARBONIFEROUS FORAMINIFERA.

by

Robert.H.Cummings.

# CONTENTS.

# PART A.

## MATERIAL & TECHNIQUE.

### CHAPTER I - INTRODUCTION.

In the main this thesis is a study of the morphology and systematics of certain species of smaller foraminifera present in the Lower Carboniferous deposits of Britain. It is based on material represented in the collections of several institutions and in personal collections made from various areas of Avonian sediments. Since the scope of the work is confined to certain species little or no mention is made in the following pages of the British Carboniferous representatives of the Textulariidae, the Ammodiscidae, the Opthalmidiidae or the host of forms whose affinity to the foraminifera remains doubtful.

In addition to the morphological aspects a general outline of the distribution of the smaller foraminifera in the British Avonian, especially in the case of Scotland and North-Western England, is included.

#### HISTORY OF RESEARCH.

Before 1870 the smaller foraminifera of the Carboniferous were known only from isolated records. The first reference was that made by Buckland before the Ashmolean Society in 1841 followed a few years later by the description of *Endothyra bowmani*, first by Brown in 1843, and later by Phillips in 1846. In 1849 M'Coy described *Nodosaria fusulinaformis* (*Saccammina carteri* of later authors) from the Irish Carboniferous, and Rouillier and Vosinsky published their description of *Nummulina antiquior* in Russia. Later Ehrenberg (1854) and Eichwald (1860) recognised such forms as *Nonionina globulus* and *Nonionina rotula* in the Russian deposits. About the same time Hall (1856) recorded *Rotalia baileyi* from the Lower Carboniferous of America. Thus until about the mid-century only incidental accounts of isolated species had been given.

Between 1869 and 1876 the main centre of research lay in Britain, where the work of Brady culminated in the "Monograph of Carboniferous and Permian Foraminifera" of 1876. Brady's account was based not only on extensive collections from British areas but included material from Europe and the United States. Unifying all the previous isolated records, including his own, Brady described in detail the morphology, systematics, and stratigraphical distribution.

This Monograph has formed the basis for nearly all later research. Nevertheless it must be recognised that Brady had a strong inclination to group widely divergent forms together and often showed great reluctance to recognise what now seems to be obvious differences. Furthermore the material used by Brady has been shown to be contaminated in some instances by a mixing of forms of very different ages. At the time of the Monograph's preparation the stratigraphical sequence of the Lower Carboniferous was imperfectly known and the value of the faunas in stratigraphy could not be properly assessed; in fact most of Brady's forms were obtained from beds now known to be of Upper Avonian age.

In Britain little has been published since 1876. Howchin (1888) listed a few new species from the Lower Carboniferous of Northumberland and discussed their distribution. Sollas (1921) re-described the wall-structure of Saccammina carteri and introduced the new generic name Saccamminopsis. It was not until the late 1930's that interest in Britain revived chiefly through the activities of Mr.A.G.Davis of the Anglo-Iranian Oil Company. As part of the search for petroleum in this country Mr.Davis has carried out an extensive study of these foraminifera but unfortunately only a very small part of his results have been published (Davis 1945).

Soon after the publication of Brady's Monograph there appeared a series of important papers by Valerian von Moller (1877-1878-1880) on the foraminifera of the Russian Carboniferous. In these von Moller revised some of Brady's work and attempted somewhat unsuccessfully to relate mathematical formulae to the morphology of the tests. One other major contribution by the Russian was his observation of the occurrence of pores in the wall of some of the

Endothyridae.

No further research appeared in Russia until the late 1930's. During the past decade however, the intensity of the study to which this group is being subjected is shown by the great number of papers which have appeared, notably in the use of Carboniferous foraminifera for the zonation of petroliferous and coal-bearing sediments in the Southern Urals and Siberian areas. Rich faunas have been discovered at all horizons and many new species and some new genera have been described. Up to the present day, however, individual records have been more or less isolated and little assessment has been made of the value of these discoveries in relation to the phylogeny of the foraminifera as a whole.

In America no major research, apart from Whitfield's revision in 1881 of Hall's earlier work, was carried out until 1927 when a number of papers b Cushman and Waters on the foraminifera of the Upper Carboniferous appeared. In the following twenty five years over 600 new species and 40 new genera have been recorded from the American Pennsylvanian. No equivalent study has been conducted on the Mississippian, apart from a few papers on the Barnett Shale and allied formations. Work on the Mississippian as a whole did not appear until 1950 when Zeller summarised the evolutionary succession in the Endothyridae and discussed the phylogenetic and stratigraphical implications of his results.

Outside Britain, the United States, and the U.S.S.R. very little research has been carried on. Schubert (1907), by introducing such genera as <u>Valvulinella</u> and <u>Nuditaxis</u>, corrected some obvious errors of Brady's work, and Liebus (1931) outlined the widespread occurrence of foraminifera in the German and Austrian Lower Carboniferous. Other records, such as those of Schwager (1883) in China and Meyer (1914) in South America, indicate the world-wide distribution of this group of foraminifera.

<u>ACKNOWLEDGEMENTS.</u>

In the preparation of this work I have been permitted to draw on the resources and materials of several institutions and have benefited by the expert advice and assistance freely given by various authorities. To Professor T.Neville George especially my thanks are due not only for providing the original opportunity to carry out this research but for his guidance and encouragement during its progress. I am indebted to Mr.F.M.Anderson of H.M. Geological Survey of Scotland for his valuable co-operation in the preparation of several aspects of the work, particularly those appertaining directly to Scottish geology. In like manner I would record my appreciation of the helpful consideration given to me during the course of the work in London by Dr.C.J.Stubblefield of H.M. Geological Survey, Mr.C.D.Ovey of the British Museum, Mr.Carter of Imperial

College, University of London, and Mr.A.G.Davis of the Anglo-Iranian Oil Company. Others who have advised and assisted during the progress of the research include Professor A.Wood of the University of Wales, several American geologists of whom the late Dr.J.A.Cushman and Dr.Alfred Loeblich should be mentioned individually, the librarians of various institutions especially Miss Barber and Mrs.Hussein of the Geological Society, and colleagues in the University of Glasgow. To all of these people I am indebted to a varying degree and finally I would like to thank my wife, Diana Cummings, for her encouragement and for her assistence in many of the more tedious tasks of field and laboratory.

## CHAPTER II.

## MATERIAL AND PRESERVATION.

The material on which the results are based amounts to more than 13,000 specimens and to over 14,800 identifiable sections of foraminifera in 850 thin-sections of consolidated rock. These are representative of the Lower Carboniferous sediments of three areas in the main; the Midland Valley of Scotland, the North-Western Province of England, and the Gower Peninsula in South Wales.

A summary of and notes on the various collections examined and prepared is given below:

(i) Collection of the Geological Survey of Scotland: Originally collected by Smith, Bennie and Macconochie. Approximately 9,400 Scottish specimens.

(ii) The Tullis-Young Collection, Kelvingrove Museum, Glasgow: Prepared by the late John Young from the Ayrshire and Lanarkshire successions. Approximately 775 specimens together with 66 slides containing 2100 identifiable sections.

(iii) Collection of the Geological Survey, South Kensington: Approximately 600 specimens together with 56 slides containing 750 sections, from a number of scattered British localities.

(iv) Collection of the Hunterian Museum, University of

Glasgow: Material from localities in Scotland, the Midlands, and the South-Western Province. Approximately 875 specimens.

(v) The Type Collection of H.B.Brady and the General Carboniferous Collection in the British Museum, South Kensington: From localities throughout Great Britain, and includes American material. Approximately 2000 specimens together with 91 slides containing 850 sections.

(vi) Collection from the North-Western Province: Made during the course of personal field-work in the Lower Carboniferous of Westmorland. Approximately 1050 specimens together with 170 slides containing 5500 sections, deposited in the Hunterian Museum.

(vii) Collection of Professor T.Neville George: Representing in the main material of Lower Avonian age from the Gower Peninsula and Breconshire. Some 303 slides containing 4200 sections.

(viii) Collection of the Kendal Museum, Westmorland: Four slides were located in this museum during the search for the missing type of Endothyra bowmanni Phillips. One of the specimens is closely similar to that figured by Phillips.

(ix) Minor Collections: A number of small collections have been examined for purposes of comparison. These include material collected from the Irish

Carboniferous by Mr.I.M.Simpson, and from the Mosic Limestone by Mr.G.Craig; some 230 speci ens and 145 slides containing 1250 sections.

Preservation of the Fauna.

On the whole the foraminifera are remarkably well preserved. Frequently such features as the fibrous wall-structure and pores of Archaediscus karreri are preserved in the minutest detail. But in every assemblage there occurs a varying proportion of specimens in which the structure is obscured.

This may be due to alteration of wall-structure, to distortion of form, or to actual test destruction following normal weathering and the process of fossilisation.

The effects of recrystallisation, dolomitization, silicification and compaction are discussed in a later chapter.

Contamination.

Within the collections examined there are a number of examples of contamination either known or suspected. This arises from admixture of material by careless laboratory technique or from incorrect sampling or labelling in the field. Such contamination is known to be the explanation for the Carboniferous record of Nummulina pristina and is the suspected reason for a number of other anomalous records.

# CHAPTER III.

## OCCURRENCE.

Where correlation by assemblage is practised in stratigraphy the relative abundance of the particular groups being used as well as their geographical distribution are of prime importance. An analysis of the occurrence and the factors controlling occurrence forms a necessary prelude therefore to any assessment of the value of the smaller foraminifera in Lower Carboniferous stratigraphy. Such an analysis has been carried out in each of the main areas considered viz. Scotland, Wales and particularly North-West England.

### Occurrence in North-West England.

In unconsolidated material - material readily disintegrated in the laboratory to yield solid specimens - the method of estimating relative abundance has been to determine the number of foraminifera present in 10 gm. of the prepared residue of the sample. Where the number ranges between 1 and 10 they are regarded as rare, 10-50 present, 50-150 common, and 150 and over abundant.

On this basis the figures shown in Table A have been obtained in a series of fifty samples ranging from the basal conglomerate of the Athyris glabristria Zone to the Dibunophyllum Zone (Garwood, 1912 p.449).

## TABLE A.

RELATIVE OCCURRENCE OF FREE SPECIMENS IN THE NORTH-WESTERN PROVINCE

| Relative Abundance | No. of Samples | Perc'nt of Total | LITHOLOGY |
|---|---|---|---|
| No Foraminifera | 31 | 62% | Pebbly Grits<br>Friable Sandsts.<br>Non-calc. Clays<br>Carbon. Shales<br>Weathered Dolomites |
| Rare | 9 | 18% | Calcareous Clays<br>Calcareous Shales |
| Present | 4 | 8% | |
| Common | 4 | 8% | Argillaceous Lmsts.<br>Weathered Lmsts. |
| Abundant | 2 | 4% | |

The consolidated material has been studied only in thin-section. Here the method of computation has been to calculate the number of identifiable sections of foraminifera present in one square centimetre of the thin-section. Where the number of these ranges between 1 and 5 they are regarded as rare, 5-10 present, 10-15 common and over 15 abundant. The ratio between the number of fragments of foraminiferal tests to the identifiable section ranges from 2:1 to as high as 10:1 dependent on the nature of the sediment. The results for this analysis in the North-West Province are based on a total of 155 samples ranging from the Solenopora Sub-Zone to the lower part of the Upper Dibunophyllum Zone (Garwood, 1912.p.449). and are summarised in Table B.

The differences in methods of computation are arranged in this manner to offset the observed and often large scale destruction of tests which takes place during the preparation of washed residues.

## Factors controlling Occurrence.

These results show that foraminifera are present in a little over half the sediment-types of the Lower Carboniferous of Britain. Their relative abundance varies from rock type to rock-type but in spite of this they usually occur in sufficient numbers to be utilised for stratigraphical work.

As discussed in later chapters the factors which control the occurrence or affect the presence of foraminifera in the sediments can be summarised under four headings:

(a) Environment of Deposition

(b) Mode of Evolution

(c) Effects of Diagenesis

(d) Wastage in Laboratory Preparation.

TABLE B. Relative Occurrence in Consolidated Material in N.W. Province.

| Number of Samples & Relative Abundance | STRATIGRAPHICAL HORIZON: Athyris glabristria Zone & Basal Beds |  | MICHELINIA ZONE |  | Productus corrugato-hemisphericus Zone |  | DIBUNOPHYLLUM ZONE |  | TOTALS |  |
|---|---|---|---|---|---|---|---|---|---|---|
| No Foraminifera | 28 | 41% | – |  | 1 | 7% | 5 | 12% | 34 | 22% |
| Rare | 27 | 40% | 13 | 43% | 7 | 47% | 13 | 32% | 60 | 39% |
| Present | 9 | 13% | 10 | 33% | 3 | 20% | 12 | 29% | 34 | 22% |
| Common | 2 | 2% | 5 | 17% | 4 | 26% | 5 | 12% | 16 | 10% |
| Abundant | 3 | 4% | 2 | 7% | – |  | 6 | 15% | 11 | 7% |
| Total No. of Samples | 69 |  | 30 |  | 15 |  | 41 |  | 155 |  |
| Number of Samples & Lithology. |  |  |  |  |  |  |  |  |  |  |
| Pebbly Grit & Sdsts. | 3 |  | – |  | – |  | 3 |  | 6 |  |
| Sandy Limestone. | 2 |  | 6 |  | – |  | 2 |  | 10 |  |
| Oolitic Limestone. | 16 |  | 7 |  | 11 |  | – |  | 34 |  |
| Shelly Limestone. | 5 |  | 7 |  | 2 |  | 23 |  | 37 |  |
| Dolomitised Oolite. | 11 |  | 4 |  | – |  | – |  | 15 |  |
| Dolomitised Limestone. | 29 |  | 1 |  | 2 |  | – |  | 32 |  |
| Argillaceous Limestone. | 3 |  | 2 |  | – |  | 13 |  | 18 |  |
| Calcareous Shale. | – |  | 3 |  | – |  | – |  | 3 |  |

# CHAPTER IV.

## POST-DEPOSITIONAL CHANGES.

A close relationship exists between the assemblages of the Palaeozoic smaller foraminifera on the one hand and the petrology of the host sediments on the other, both in respect of original environment of deposition and of subsequent diagenesis.

Briefly the effects of diagenesis on foraminiferal content may be summarised as destruction or obliteration of specimens, as distortion of form, and as alteration of wall-structure, brought about by recrystallisation, redistribution, dolomitisation, silicification, and compaction.

### Effect of Recrystallisation and Redistribution.

Little is known of the diagenetic processes in sediments, but the results are evident in a great many of the British Lower Carboniferous deposits. The materials which are especially liable to redistribution are slightly soluble substances in a finely disseminated condition and compounds in an unstable crystalline form. The calcareous sediments are particularly affected by changes of this kind. Whilst recrystallisation in a sediment may often be suspected the actual proof of its having occurred is often difficult to establish.

The effect on microfaunal content, in particular the foraminifera, is highly variable. The tests of the granular calcareous forms such as *Endothyra* appear to be able to withstand an appreciable degree of recrystallisation; but where the original matrix of the sediment is thought to have been finely disseminated calcite subsequent alteration of this type leads to a "fading" of the form (Fig.1).

Tests of fibrous calcite, as in *Archaediscus karreri*, seem to be particularly prone to alteration in shaly sediments but are much more resistant in limestone.

## The Effect of Dolomitization.

Of these post-depositional changes dolomitization seems to have the most profound effect and is undoubtedly the most widespread as an agent of destruction of the microfaunal content.

The relationship of foraminiferal occurrence and dolomitization have been overlooked or neglected by the great majority of foraminiferal workers and only in a small number of papers dealing with sedimentary petrology has it received a passing mention. Brady (1876, p.6) remarks that "the minute structure of the Carboniferous and Permian rocks only affects the subject incidentally". The fallacy of such a statement is readily apparent in the accompanying Table C. The dominantly morphological approach of modern American workers also overlooks the relevance of diagenesis to assemblage patterns.

<u>The Hallhead Quarry Traverse.</u>

The effect of dolomitization is well seen in the sampling traverse made in the Hallhead Quarry. Lying two miles north of Kendal on the Crook Road, at the foot of Cunswick Scar, this has been cut in the upper part of the Athyris glabristria Zone about the level of the Thysanophyllum Band (refer Garwood, 1912.p.449).

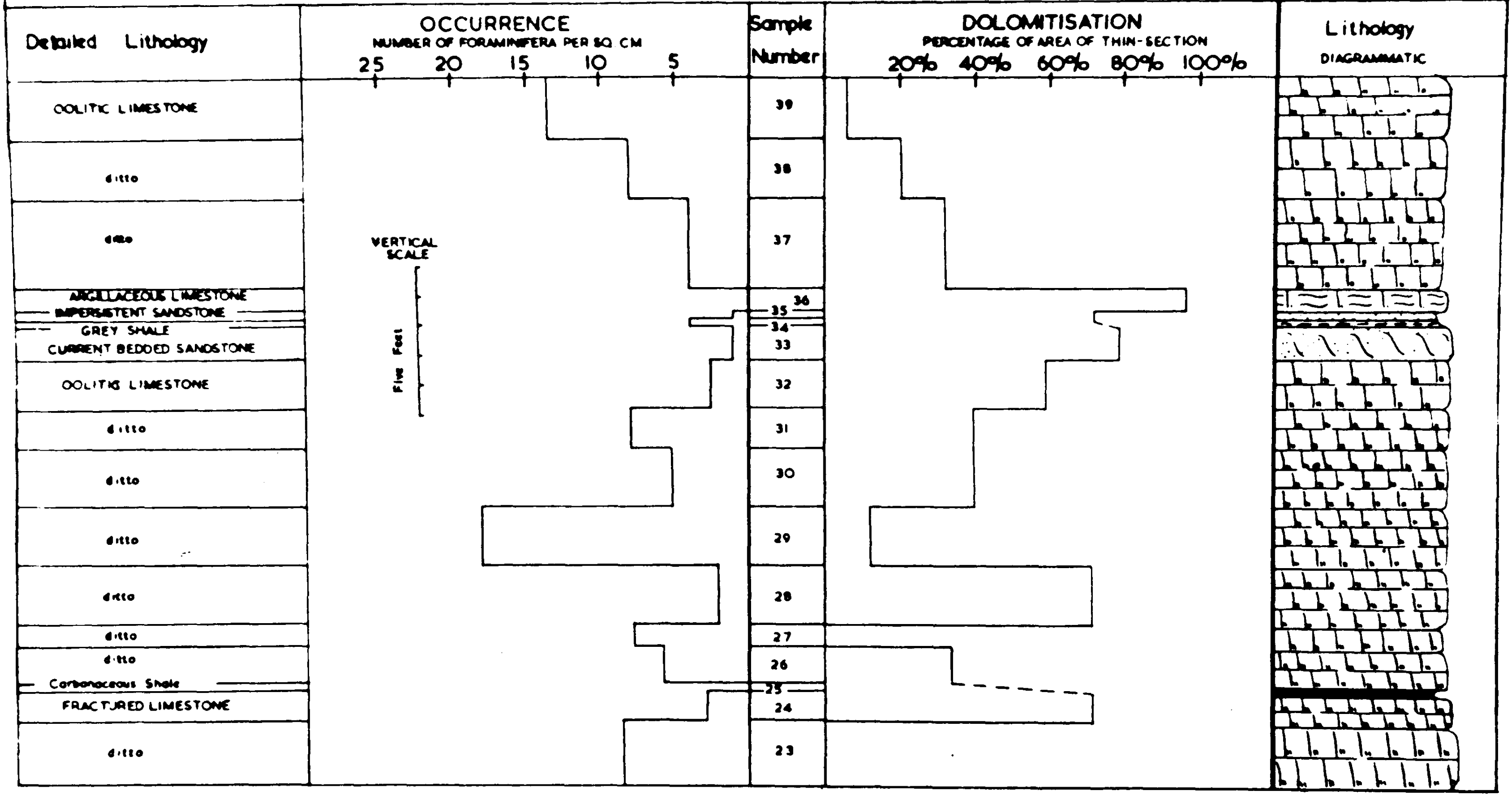
The details of this traverse are presented in diagrammatic form in Table C. Using Lemberg's solution (see p. 28) and by measuring the area occupied by dolomite rhombs in thin-section an approximate estimation of dolomitization at successive levels can be computed. The results for the lower part of this traverse are plotted against the average number of foraminiferal sections per square centimetre of thin-section.

In Table C the direct relationship that exists between dolomitization and faunal content is shown. Thus within the same type of lithology when facies control is a constant - as between Sampling Position 29 and 32 - the abundance of foraminifera depends directly on the amount of dolomitization present in the sample.

<u>The Manner of Faunal Destruction.</u>

The manner in which the faunal content is destroyed by dolomitization is of a twofold character. The effect of the redistribution of magnesuim carbonate leads to a general recrystallisation of the rock which may or may not

TABLE C Relationship between Faunal Occurrence & Dolomitisation Hallhead Quarry Traverse



be selective. In some cases the mollusca are destroyed or partly altered whilst the foraminifera remain. In others the converse is true. Usually the fragments of the Echinoderma withstand alteration or are merely 'feathered' about their edges. This selectivity is not fully understood but I believe the presence of aragonite in certain types of shell may supply a partial explanation.

In those cases where rhombs of dolomite are developed the process is merely one of growth of the dolomite crystal at the expense of the foraminiferal test. A perfect example of this type of destruction is shown in Text Fig.2.

The Effect of Silicification.

In the present work silicification has been found only as a rather limited and localised feature except in the case of the Saccammina carteri Band.

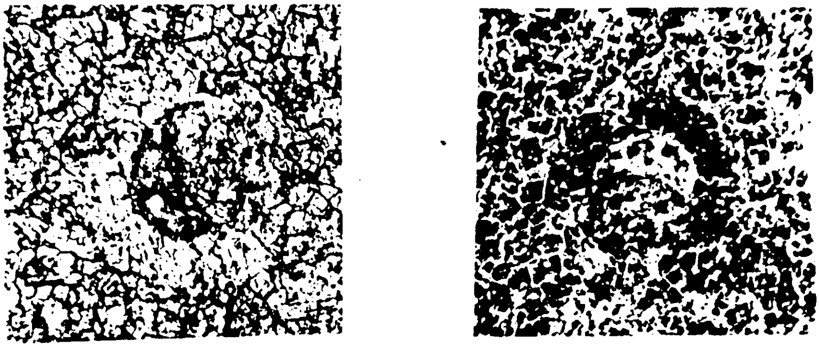
Garwood (1912 p.519) records beekitised forms from several horizons and localities, especially in the Michelinia Zone. The silicification of this zone appears to be highly selective, only the brachiopods and corals being affected, the foraminifera remaining unaltered.

In Scotland silicification of the Hosie Limestone in Law Quarry, Cubside, north of Dalry, Ayrshire is probably the best and most typical instance. Here perfectly preserved silicified internal moulds of foraminifera belonging to the Endothyrinae and Textrataxinae have been found.

# EFFECTS OF DIAGENESIS

Text Fig. 1

a b



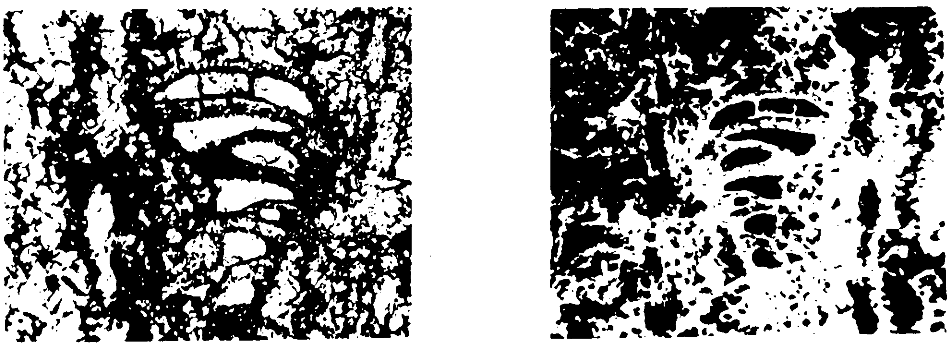
0·5 MM. 0·5 MM.

FADING OF ENDOTHYRID IN RECRYSTALLISED LIMESTONE.

a. NORMAL PHOTO; b. "TRACE" PHOTO.

Text Fig. 2

a b



0·5 MM. 0·5 MM.

DESTRUCTION OF TETRATAXINID BY GROWTH OF DOLOMITE CRYSTALS.

a. NORMAL PHOTO; b. "TRACE" PHOTO.

Secondary silicification may obviously affect the nature of the test wall. Thus a well-preserved specimen of *Plectogyra*, from the shales of Law Quarry, dissolved in dilute hydrochloric acid, yielded an appreciable residue of very minute but distinct quartz grains, whilst a closely similar specimen from the shales of the Dockra Limestone in Lugton Quarry yielded a negligible residue.

These differences are significant for three reasons. They demonstrate the inadequacy of the dilute hydrochloric acid test so extensively used by Cushman and others as an indicator of wall-composition. They illustrate the necessity of studying thin-sections for interpreting wall-structure. They demand a consideration of studying each assemblage in relation to the environment and alteration of its host sediment.

It should be noted that the familiar appearance of the weathered specimens in limestones of the Saccammina Band is by no means wholly due to silicification. In many of the specimens examined the more resistant tests have not been silicified but have undergone recrystallisation.

## The Effect of Compaction.

The granular calcareous and agglutinated foraminifera seem to have possessed a shell-wall which was to some extent flexible, in which therefore compaction usually produces a distortion of form in turn giving rise to frequent difficulties in morphological study. Thus *Endothyra oblique* Brady (1876) is probably merely a crushed *Endothyra ornata*. (see page 116).

Distortion is much common in argillaceous sediments than in limestones. Its common occurrence in some types of foraminifera is frequently overlooked or receives scant reference though obviously it may prove highly significant in the interpretation of wall-structure.

# CHAPTER V.

## TECHNIQUE.

Of the wide choice of method which exists that adopted in the present work is outlined below.

The host material may be divided into two classes: consolidated sediments which can be studied only in thin-section, and unconsolidated sediments which can be disintegrated to yield free specimens.

Previous work has tended to be based on only one or other of these classes of material but, since the Lower Carboniferous foraminifera are not confined to a single environment, a unified analysis is necessary to measure the full effect of facies control. In view of this every attempt has been made to collect both types of material at all horizons.

### Field Collection.

In the North-Western Province, where the greater part of personal field-work has been conducted, the normal proceedure has been to collect samples at fixed intervals and from every bed along dip traverse sections, irrespective of lithology. On the other hand Scottish field-work has consisted of visits to isolated localities for checking purposes or for the collection of additional material.

Selection of material in the field has been found to be of little value for often the samples which are the most fossiliferous are the ones which show no trace of fauna in hand-specimen. At horizons where post-depositional alteration is known or suspected scatter sampling has been employed to reduce the possibility of negative results. Sample orientation defined by the bedding planes (Zeller, 1905 p.9) has proved to be of little use and - as might be expected in the case of the oolites - foraminifera are usually distributed haphazardly.

Consolidated Material.

The average dimensions of the thin-sections prepared from indurated samples has been 4cm. x 3cm. Although etching with hydrochloric and acetic acids (Moreman, 1930) has been attempted, no positive results have been obtained because of the rarity of beekitised faunas. Stains have been used in a number of cases (see p. 26 ); and the Saccammina carteri Band has been studied using cellulose pulls, a method which has been extended to prepare serial sections of individual foraminifera.

Thin-sections of free specimens and sediments have been examined under the petrological microscope. In the case of the sediments a graduated moving stage has been employed to ensure complete coverage and after the recording of petrographical details, faunal abundance, etc., a trace photograph has been made of each identifiable section present (see p. 28).

Unconsolidated Material.

After collection, thorough drying by slow evaporation - not rapid heating - has been found to facilitate the later disintegration of the sample.

In the preparation of this type of material the method of using a "pilot" sample described by Plummer (1946) has been used. Should the "pilot" prove to be devoid of fauna this is taken to be the case for the whole sample but, if positive results are obtained, then, in addition to the 50 grams of the pilot sample, the remaining 200 grams are prepared also. Quantitative tests reveal this method to be correct in over 90% of the cases tested.

Some shales and clays will disperse in water whilst others have to be broken down mechanically as a preliminary. By far the greater number require chemical treatment before they disintegrate, the method used being a development of that described by Bartenstein (1950). The dried sample is placed in a 10% solution of hydrogen peroxide and, after settling, is slowly heated and maintained slightly below boiling point for a period varying from 30 minutes to 3 hours. Variation in the time of treatment is preferable to higher concentrations of hydrogen peroxide which lead to test disruption. Although the majority of samples are washed through sieves (range 40 - 200) the decantation method, advocated by Plummer (1946), has also been adopted and found to yield better results.

Separation of the foraminifera from residues using such liquids as carbon tetrachloride and bromoform has been unsuccessful due to the frequent infilling of tests.

During the course of this work a new method to obtain orientated thin-sections of individual foraminifera obtained from washed residues has been evolved (Cummings 1950).

Prepared residues have been examined under a binocular microscope using a magnification of x15 and x30 and the microfauna picked out of a squared tray using a damp camel hair brush. Free specimens have been mounted in Chapman slides using gum tragacanth. In morphological study magnifications up to x180 have been used together with such aids as stains, immersion in clove oil or xylol, and acid etching.

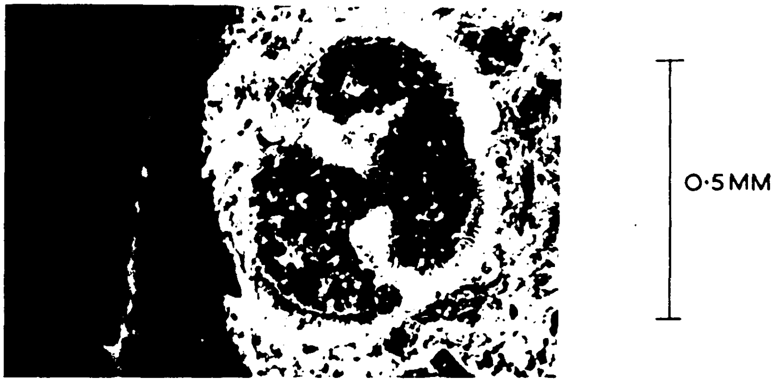
Staining Techniques.

These have been employed in a variety of ways and the various types and methods are listed below - for further details see Henbest (1931).

Malachite Green. Used for detailing the wall-structure of Tetrataxinae and for estimating the percentage of clay in some limestone slides this appears to be of considerable value in enhancing algal structures. I have employed the second method listed by Henbest and find this should be applied during, and not after, the preparation of the slide.

Alizarine. Various members of the oxyquinone group

Text Fig. 3 Example of "Trace" Photograph




CROSS-SECTION OF TEXTULARID SHOWING DOUBLE LAYER OF WALL - PRESENT IN LIMESTONE SLIDE (e.g. alizarine, alizarine-red, and pupurin) may prove of value in the determination of alteration in wall-structure. Henbest has used these to detect foraminifera on polished limestone surfaces and in enhancing detail, as in Bradyina. In addition I have used pupurin to define crystal structure in the Endothyrinae though difficulties have arisen in the tendency of this dye to settle unevenly.

Lemberg's stain. This well-known stain, prepared according to Fairbank's modification (see Henbest 1931) has been used in estimations of dolomitization. Its differential character in recrystallised sediments is a problem for further research.

Illustration.

Three types of illustration have been employed, line-drawings, 'trace' photographs, and normal photographs.

Wood (1948) described a rapid method of making accurate drawings of small microscopic objects. As a development of this I have prepared a micro-projector using a normal petrological microscope and a simple peep-hole camera. This instrument has been used chiefly for the recording of foraminiferal sections in rock-slices by means of 'trace' photographs. In transmitted light an image is focused on a ground-glass screen and the latter replaced by an adapted plate-holder containing sheets of ordinary contact printing paper, usually Ilford Bromide B.S.1.P.(single

Weight, Hard Glossy). These paper sheets are exposed and, after developing, "trace" photographs are produced. All variations in contrast and intensity can be achieved (see Text Fig.3) magnifications up to X250 can be attained.

Due to lack of facilities at the British Museum no photography of specimens in the 'Brady Collection' could be attempted. Hence illustrations of type material are confined in this study to camera-lucida drawings, only Scottish material has been photographed.

# PART B

# SYSTEMATIC PALAEONTOLOGY.

## CHAPTER VI GENERAL CONSIDERATIONS.

### The Principles of Classification.

As Cushman (1948) points out the ideal classification is one based on phylogeny. But since the phylogenetic development of a particular series is inferred from the morphology and ontogeny of individuals in stratigraphical succession, the primary task in classification is the detailed morphological and ontogenetic analysis of members of bioseries. It then becomes possible to delineate the arbitrary units of species and genera within one gens and to trace the morphogeny of particular biocharacters in time. Only when this is complete can the phylogeny of the group be inferred.

One of the first essentials is the selection of a reliable differential biocharacter as the basis of the classification. This should reveal a fundamental subdivision within the group and have an elementary role in the physiology of the individual. Recent research has shown that the most suitable biocharacter in the case of the foraminifera is the wall-structure of the test; and the classifications of Cushman (1948) and Glaessner (1945) are based of this feature. There are indications, however, which may be extended with further research that this biocharacter is not truly differential but progressive, in that its pattern of changes reveals the evolution of the group. The full value of the character can be obtained only if the detailed microstructure, as seen in thin-section, is examined. This has been demonstrated by Wood (1949).

In the interpretation of phylogeny in the foraminifera the major difficulty is the lack of detailed information on the Palaeozoic faunas. The differing views of Cushman and Galloway on the evolution of the group both rest on very slender and often doubtful evidence, and any detailed examination of the Palaeozoic foraminifera has thus a great intrinsic importance.

The Major Groups and Wall-structure.

Wood (1949) has detailed the various types of wall-structure and has illustrated their fundamental importance in the classification of the foraminifera. In addition to the more common types he has noted the granular calcareous type of the Upper Palaeozoic, which reaches its fullest expression in the Fusulinidae. He has also mentioned the possibility of this being a product of the recrystallisation of another primary calcareous structure, though more probably it is itself primary and distinct from all others. It is true that it may be combined with other types, as in the case of the Tetrataxinae and the archaediscids, but these combinations may be expected if wall-structure is a progressive biocharacter. Cushman (1948) regards the granular calcareous wall-structure as a mere variation of the arenaceous type and hence, for example, includes the Endothyridae in the Lituolidae. On the other hand, Glaessner (1945) believes that forms possessing a granular calcareous wall are a distinct stock. The results of this work agree closely with such a viewpoint and hence I have adopted the classification of Glaessner throughout the greater part with minor modifications at various stages.

Taxonomy, Description, and Dimorphism.

The concept of the holotype as the basis for the definition and description of a species creates a special problem in the case of the foraminifera where the life cycle is of a dimorphic pattern. The usual practice is to overlook the possibility of alternating generations or to describe these as different species where the divergence of form is sufficiently marked. The relationship between the two types can be shown by biometrical methods in some cases. Where I have been able to detect dimorphism this has been noted in the description of the species, one generation being represented by the holotype and the other by an appropriately labelled paratype.

Contamination in the "Brady Collection".

Nearly the whole of British research and a large part of the entire research on the smaller foraminifera of the

Carboniferous is based on Brady's "The Monograph of Carboniferous and Permian Foraminifera" (1876). The type specimens of his species form the "Brady Collection" of the British Museum (Natural History).

A feature of the collection is that it is contaminated with material which is not of Carboniferous or Permian age. Thus _Nummulina pristina_ was described by Brady (1874) on the basis of material forwarded by Van den Broeck from one locality, the Carriere du Fond d'Arquet, Namur, Belgium. Later Van den Broeck (1898) demonstrated that this "Carboniferous" record of _Nummulina_ was incorrect and that the material despatched to Brady had been mixed inadvertently with some of Mesozoic age. _Nummulina pristina_ was in fact _Nummulina variolana_ Lamarck.

Although Van den Broeck referred only to _Nummulina_ it is highly probable that other species known only from this one Belgian locality are not of Carboniferous age. These include the following records by Brady:- _Calcarina ambigua_, _Pulvinulina broeckiana_, _Truncatulina boueana_ and _Truncatulina carbonifera_. Reichel (1945) has advanced the same opinion in the case of these anomalous records. The Belgian records of _Globivalvulina bulloides_ (Brady) are based on specimens of _Globigerina_ amongst the syntypes and I regard the presence of _Amphistegina minuta_ Brady and of _Ammothyra subtilissima_ Brady as being due to contamination, possibly from glacial clays.

The Revision of Earlier Work.

In the study of distribution and in the re-examination of old collections I have noted many new and hitherto undescribed forms, some of which possess both a stratigraphical and a morphological value. The scope of this present work does not allow of their inclusion and I have concentrated on a revision of certain previously described species and genera and a new delineation of their morphological importance.

Application of Biometrics.

Quantitative methods have been used extensively in the analysis of species and faunas as a further aid in the preparation of qualitative description. Examples of the biometrical methods used are included at various points in the following chapters.

# CHAPTER VII

## NODOSINELLA AND ASSOCIATED FORMS.

The rectilinear smaller foraminifera of the Carboniferous are referred usually to the Hyperammininae or to the Reophacidae though, on the basis of wall-structure, three groups may be recognised.

The Hyperammininae have an arenaceous or siliceous wall-structure and possess a spherical proloculum followed by a more or less straight unsegmented tube. They occur in abundance in the Pennsylvanian of America but were unknown in the Lower Carboniferous of Britain until their discovery in the North-Western Province during the present work.

The Reophacidae are characterised by an arenaceous wall largely composed of foreign, agglutinated material, such as quartz grains, and a rectilinear, uniserial chambering. True reophacids have not been recorded so far from the Lower Carboniferous rocks but are abundant and of stratigraphical value in the Pennsylvanian (see Plummer (1945)).

Distinct from either of these groups in wall-structure are the species included in the genus <u>Nodosinella</u> Brady. These differ from the normal reophacids in having a granular calcareous wall-structure of equidimensional grains of calcite bound by calcareous cement, frequently occurring in a twofold layer. Both Cushman and Glaessner place

Nodosinella in the Reophacidae though Glaessner notes the uncertainty of such grouping. In view of the differing nature of the wall this inclusion is very questionable. Indeed, on the basis of this biocharacter, Nodosinella shows a greater affinity to the Endothyridae. It may well prove on further investigation that Nodosinella represents an independent stock related to the Endothyridae and isomorphous with the Reophacidae.

Genus NODOSINELLA Brady (1876).

Type Species. Nodosinella digitata Brady (1876 p.103)

Dentalina (part) of authors (non d'Orbigny 1826).

Description: Test free, straight or arcuate, wholly or partly tapering; chambers usually distinct, simple; septa at times only partly developed; wall-structure granular calcareous with calcareous cement, layering present, frequent concentration of cement on exterior; aperture usually simple, terminal. Carboniferous - Cretaceous.

Remarks: Adventitious material has been recorded in the wall of several species but all of these are very doubtfully referred to the genus on the basis of other features.

Distribution: Nodosinella is widespread in the Upper Palaeozoic, being recorded from the Lower Carboniferous of Britain, Germany, and Russia and in the Pennsylvanian of the United States.

Nodosinella? concinna Brady (1876 p.106)

Text-fig.4.

Description: Test free, uniserial, straight, translucent in clove-oil, relatively broad, tapering, composed of series of sub-globular chambers. Initial large globular proloculum followed by two spherical, intermediate chambers, and a final, large, inflated, conical chamber. Sutures well-marked, deep, broad. Wall relatively thick, non-calcareous due to secondary silicification. Aperture terminal, triangular, lying slightly offcentre of final apertural face.

Dimensions:

| | Length. | Width. |
|---|---|---|
| Total. | 0.96mm. | - - |
| Last chamber. | 0.41mm. | 0.37mm. |
| Intermediate chamber. | 0.10mm. | 0.34mm. |
| Proloculum. | 0.20mm. | 0.31mm. |

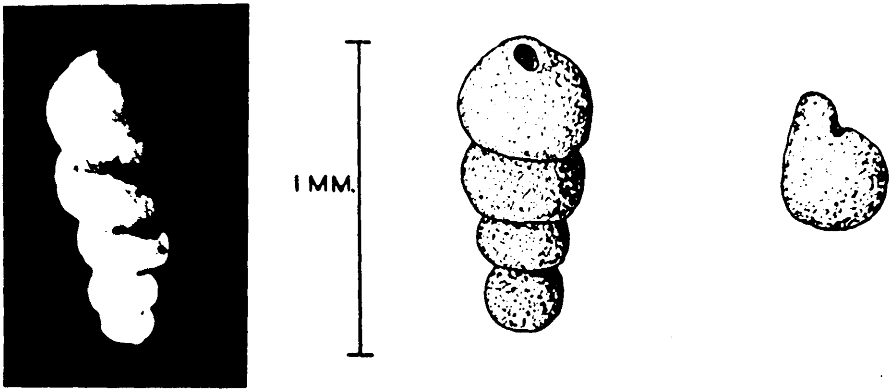
Distribution: Upper part of the succession of the North-Western Province; Lower and Upper Limestone Groups of Scotland.

Remarks: Lateral crushing frequently produces an ellipsoidal instead of circular cross-section. The test may have had an original siliceous or arenaceous and not granular calcareous wall-structure since secondary silicification appears to have occurred in all cases,

## NODOSINELLA

Text Fig. 4

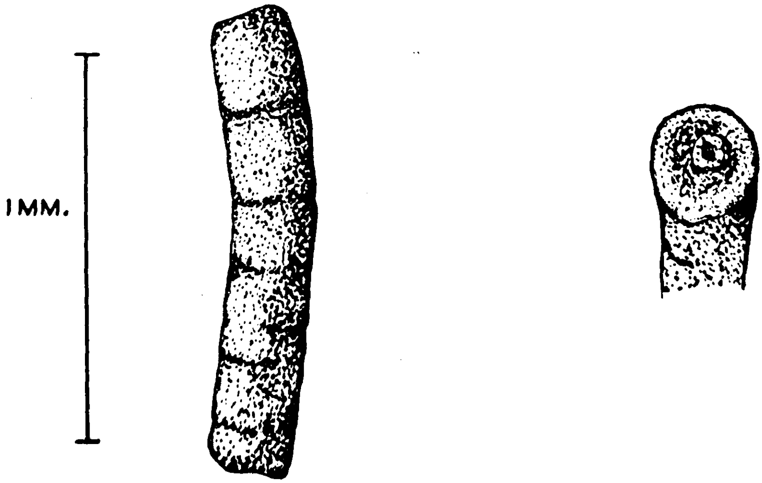
a b c




NODOSINELLA? CONCINNA (BRADY), a. CRUSHED & SILICIFIED - LATERAL VIEW; b. LATERAL VIEW - ?MEGALOSPHERIC; C. FINAL CHAMBER - PARTLY CRUSHED.

Text Fig. 5

a b




NODOSINELLA CYLINDRICA BRADY; a. INCOMPLETE TEST - LATERAL VIEW; b. LATERALLY CRUSHED APERTURAL FACE.

destroying primary features. The species is therefore doubtfully referred to Nodosinella. In external form it resembles species of Hormosina (hitherto known only from Mesozoic and Tertiary rocks) to which it may prove to belong.

Nodosinella cylindrica Brady (1876 p.104)

Text-fig. 5.

Description: Test large, uniserial, moderately curved, round in cross-section, opaque in clove-oil. Spherical proloculum followed by tube showing no apparent increase in diameter until distinct inflation takes place at apertural end. Inflation may be due to distortion of thinner wall of final portion. No definite or regular chambering but irregularly spaced, thin, depressed sutures indicate position of internal, partially developed septa which are more pronounced in final portion. Surface smooth. Wall-structure of fine-grained calcitic particles bound by calcareous cement, latter concentrated on exterior and layering present. Aperture round, terminal, about one-fifth diameter of tube, with lip.

Dimensions: Length of test 2.5mm, of proloculum 0.13mm., diameter of test - 0.57mm., width of aperture 0.05mm.

Distribution: Known throughout the Avonian of the North-Western Province this species exhibits an increase in size and a trend towards regularity of form at successively higher levels. It has also been found at one or two localities in both the Lower and Upper Limestone Groups of Scotland.

Remarks: Lateral crushing and pyritisation are common in this form and the apertural region is usually destroyed. Included amongst Brady's original syntypes (British Museum Slide P.35487) are some specimens of textularids and one of N.? concinna.

Nodosinella lingulinoides Brady (1876 p.106)

Examination of the syntypes shows this species to be based on very unsatisfactory specimens. Of the two slides in the Brady Collection the first (Brit.Mus.Slide P.35490) contains two specimens of N.?concinna, two belonging to species of the genus Stacheia, and a fifth (Brady Pl.VII, fig.24) is apparently biserial. In the second slide (Brit.Mus.Slide P.35491) there is one specimen present (Brady Pl.VII, fig.25) and this is a laterally compressed member of the Textulariidae. This record of Nodosinella must be discounted therefore.

Nodosinella digitata Brady (1876 p.103)

The syntypes (British Museum Slides P.35488/9) of this species are from the Permian of Tunstall Hill, Co.Durham. Though Brady lists this form as present in the Yoredales no Carboniferous specimens have been noted in any of the collections or areas examined.

## CHAPTER VIII

## "SPIRILLININAE".

I have included in this subfamily of the Spirillinidae, itself a family of the Rotaliidea, the two genera Spirillina and Archaediscus. The morphology and phylogeny of these two forms are largely unknown, however, and this classification may need to be revised when details of new genera given in Russian literature become available.

Genus SPIRILLINA Ehrenberg (1843).

Type species: Spirillina vivipara Ehrenberg (1843 p.422)

This genus is known to have existed from the Jurassic to Recent. Forms are also recorded from the American Pennsylvanian and the Lower Carboniferous of Russia but it is doubtful if any of these are properly referrable to the genus.

Thus, in the case of the American records, the wall-structure of one species is not described and that of the others is given as imperforate and hyaline. This may imply either isomorphy or inadequate study, since Cushman (1948), Glaessner (1945), and Wood (1949) all describe the wall of the type species as perforate and Wood adds that the structure is never radial hyaline but is irregularly fibrous.

The Russian records are due to Moller (1879) who described three species of Spirillina from the Lower

Kohlenkalk. Of these Mikhailov (1938) selected *Spirillina irregularis* as the type species of his genus *Brunsia*, and another, *Spirillina subangulata*, as the type species of his genus *Forschia*. Details of Mikhailov's work are not available in this country but it would appear that these Russian species are grouped now within the Ammodiscidae, not the Spirillininae.

It would seem highly probably therefore that no species truly referrable to the genus *Spirillina* exist in the Palaeozoic but that there do occur forms which bear a close resemblance. It is very probable that an entirely independent Palaeozoic stock has been regarded in the past as part of what is in reality an isomorphous series of later date. In view of this the inclusion of such Carboniferous genera as *Archaediscus* in the Spirillininae is regarded as provisional pending further study.

Genus *ARCHAEDISCUS* Brady (1873).

Type species. *Archaediscus karreri* Brady (1873 p.286).

*Archaediscus* Brady (1873) and (1876, p.142).
*Trochammina* (part) of Brady 1876.

*Description:* Test free, lenticular to sub-spherical, more or less asymmetrical, consisting of proloculum and long non-septate (?) second chamber close-coiled in varying directions. Wall calcareous, usually perforate, with a fibrous structure showing secondary thickening and in more primitive species with a thin, indistinct, inner, granular calcareous layer. Aperture at open end of second chamber.

Distribution: The earliest occurrences are those recorded by Le Maitre (1930, 1931) from the Devonian of France. In Lower Carboniferous rocks Archaediscus is abundant and widespread being recorded from Europe, South America, and Russia where it is regarded as particularly characteristic of the "Upper Visean" and "Lower Namurian". The absence of North American records is possibly due to the lack of detailed work in the Mississippian. The distribution in Britain is discussed below.

Remarks: The systematic position of Archaediscus is doubtful. Brady (1876) placed it within the Nummulinida on the basis of several analogous ontogenic and morphological features. Cushman (1948) included the genus as a sub-family within the Camerinidae implying an ancestral role to Archaediscus in the evolution of the nummulites. On the other hand Glaessner (1945) doubtfully places the genus within the Spirillininae and Davis (1945) also notes the affinity of Archaediscus to this subfamily. Whilst it is obvious that a close connection exists between Archaediscus and the so-called spirillinids of the Palaeozoic the inclusion of the genus in the Spirillininae is a tentative move pending further study.

Forms referred to Nubecularia by Derville (1936) are in need of revision and probably belong to Archaediscus.

Archaediscus karreri Brady (1873 p.286).

Text fig.6.

Trochammina gordialis (part) Brady 1876

Description: Test free, lenticular and asymmetrically biconvex with absence of external detail due to secondary thickening. Formed of proloculum and non-septate (?) tube coiled in a dominantly planispiral manner but with axis of coiling moving irregularly in a plane at right angles to that of coiling. Spiral suture not seen except in last half volution where it is indicated by inflation of tube. Wall composed of fibrous calcite with perforations of two sizes, subject to secondary thickening, rare traces of inner granular calcareous layer. Aperture formed by open end of tube.

Dimensions:

| | Max. diameter. | Min. diameter. | Thickness. |
|---|---|---|---|
| Fig. Specimen (Brady Pl.IX). | 0.99mm. | 0.90mm. | 0.47mm. |
| Fig. Specimen (text.fig 6). | 1.02mm. | 0.90mm. | 0.52mm. |
| Range of Scottish Specimens. | 0.90mm-1.06mm. | 0.82mm-0.96mm | 0.42mm-0.56mm. |

Distribution: This species has been recorded from most Lower Carboniferous deposits. In the past nearly all forms of the genus have been placed in this species and therefore the range and distribution need revision.

_Archaediscus karreri sensu stricto_ is known to occur in Germany, Russia, and throughout the British area, where it appears to be characteristic of the middle part of the Dibunophyllum Zone.

_Remarks_: In cross-section this species is characterised by a sub-ellipsoidal outline, by the almost hemispherical shape of the tube, by the marked asymmetry of the coiling and the trace lines of the surface of earlier whorls (see Text fig.8 No.5).

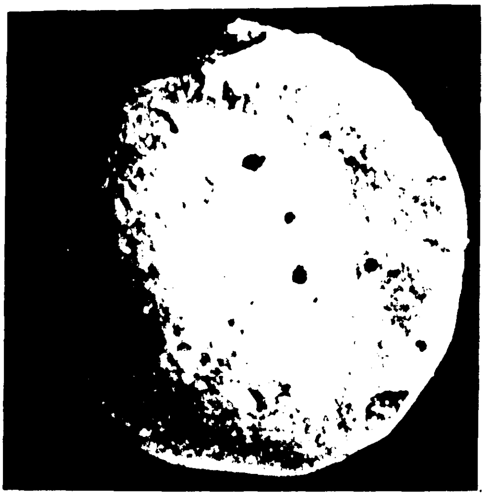
Recently the non-septate character of the tube has been questioned by L.M. Davies (personal communication) who has recognised partitions in the early part of the tube and believes them to be septa which undergo resorption. I have only seen this feature in the specimens studied by Davies (Brit.Mus.Slide P.4313) although some 2000 other thin-sections of this species have been examined; and it is doubtful if presence of septa can be regarded as an essential morphological character.

In nearly all cases there is destruction of the apertural region where the wall is thin and secondary thickening absent. Casts of the interior are common, one being the large example of _Trochammina centralis_ Jones and Parker figured by Brady (1876 Pl.III, fig.3) (see also Text fig.6).

The inner granular calcareous layer of the wall is not

Text Fig. 6

a



1 MM

b

1 MM

ARCHAEDISCUS KARRERI BRADY

a LATERAL VIEW - TYPICAL SCOTTISH SPECIMEN

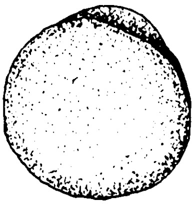
b CAST SHOWING REMNANTS OF WALL

Text Fig. 7

a

0·5 MM

b



c

0·5 MM

ARCHAEDISCUS GEORGEI SP. NOV.

a HOLOTYPE - LATERAL VIEW

b PARATYPE - LATERAL VIEW

c PARATYPE - SHOWING DESTRUCTION OF APERTURAL REGION usually recognisable but in rare specimens, where recrystallisation of the interior of the tube is not advanced, faint traces can be made out.

Archaediscus georgei sp.nov.

Text fig. 7.

Trochammina incerta (part) Brady (1876 p.73)
Trochammina gordialis (part) of authors.

Description: Test free, lenticular showing slight asymmetry and absence of external detail due to secondary thickening. Formed of proloculum coiled in a manner similar to A.karreri but with less divergence from the planispiral mode. Spiral suture seen only in last half volution. Wall calcareous, perforate, of two layers, a thin and often discontinuous inner granular calcareous layer and an outer irregularly fibrous layer showing secondary thickening. Aperture open end of tube.

Dimensions:

| | Max.Diameter. | Min.Diameter. | Thickness. |
|---|---|---|---|
| Holotype: | 0.38mm. | 0.34mm. | 0.18mm. |
| Range (based on 20 paratypes) | 0.32mm-0.44mm | 0.30mm-0.39mm | 0.10mm-0.21mm. |

Depositories etc.

Holotype. British Museum slide P.40869 ex P.35609 of the Brady Collection - Trochammina incerta, Colster Cleugh, near Alsdon.

Paratypes. British Museum Slide P.35669.

Distribution: Ranges from the upper part of the Michelinia Zone into the Dibunophyllum Zone in the North-Western Province and is known in the Calciferous Sandstone Series and the Lower Limestone Group of Scotland.

Remarks: Externally the surface is often roughened due to secondary alteration. In form this species bears a resemblance to A.karreri from which, however, it differs in the smaller size, the relatively smaller thickness, the greater degree of symmetry in coiling, the presence of an inner granular calcareous wall, and the more lunate outline of the tube in cross-section.

This species was included by Brady under Trochammina incerta and described as the biconvex form. Small siliceous casts occurring in the Carboniferous and previously referred to Trochammina cordialis should be included in this new species.

## Development of Archaediscus in Scotland and the North-Western Province.

Archaediscus has been recorded in Britain throughout the greater part of the Lower Carboniferous succession and in nearly every instance the specimens have been referred to Archaediscus karreri. A study of the development of the genus has been made in two of the areas under consideration and the results summarised in Text fig.8.

No.1. Archaediscus sp. Prevalent in the Seminula gregaria sub-zone and ranging upwards, this form exhibits dominantly planispiral coiling with only a slight variation from the plane. The test is small, disc-like, with a wall-structure of two distinct layers. Though the most primitive form it is not the earliest record of the genus.

No.2. Archaediscus sp. This appears to develop from No.1. in the Lower Part of the Michelinia Zone. Compared with the earlier form, No.2. is larger, with the inner granular layer much thinner, the tube more lunate and showing a greater acceleration in height, the coiling still largely planispiral, but showing some axial rotation in the embryonic stages, and the outer fibrous layer thicker giving the test an ellipsoidal outline.

No.3. Archaediscus georgei sp.nov. Apparently developing from No.1. independently of No.3., this form appears for the first time in the upper part of the Michelinia Zone and extends upwards into the Dibunophyllum Zone, being known from equivalent horizons in the Scottish Area. For details of morphology see above.

No.4. Archaediscus sp. Having an ancestral form similar to No.2, No.4. is rare and confined to the shale facies of the upper part of the Michelinia Zone. Basically it is an enlarged form of No.2. but shows a greater irregularity of coiling, a tendency towards a spherical form whilst the tube has a sub-rectangular appearance in cross-section. (The wall of the final whorl in both Nos. 2 and 4 shows no secondary thickening and is composed of the granular inner layer only. The fragility of this structure may explain in part the frequent destruction of the apertural regions of the archaediscids).

No.5. Archaediscus karreri Brady. Possibly stemming from A.gorgei by an increasing sphericity and irregularity of coiling this species is characteristic of the middle Dibunophyllum Zone of the Lake District and the Hurlet horizon of Scotland. For morphological details see above.

No.6. Archaediscus sp. Arising from A.gorgei by a resumption of planispiral coiling and a reduction in thickness, this form is abundant in the shale facies of the North-Western Province and in both the Lower and Upper Limestone Groups of Scotland.

The archaediscids are much more complex than has been hitherto thought and demand further research. Their development in the Lower Carboniferous is seemingly expressed in a reduction and final disappearance of the inner granular wall layer, in an increasing irregularity of coiling in some lines, and (though also no doubt of local environmental induction) in an increase in size.

# CHAPTER IX

## TETRATAXINAE.

### The Relationships and Position of the Tetrataxinae.

The Relationships and Position of the Tetrataxinae. In the lower part of the Lower Carboniferous and almost immediately gained a world-wide distribution and abundance. Since they possess a trochospiral form they are usually referred to the Trochamminidae and have been looked upon as developments from Trochammina. Too little is known of their early history to make definite statements on origin but, in view of basic differences in morphology, this relationship may be doubted and they are probably not closely related to the Trochamminidae.

Throughout their long evolutionary history, Silurian to Recent, the Trochammininae have shown themselves to be an extremely conservative stock and to have preserved an arenaceous character of the wall in which adventitious material forms an integral part with calcareous fragments and cement. On the other hand, the Tetrataxinae, confined to the Upper Palaeozoic, have the test-wall composed of calcareous grains bound by calcareous cement and in many species exhibit a layering by the introduction of fibrous, almost hyaline, bands and buttresses. No adventitious matter is present. Indeed, as far as the wall-structure is concerned, the Tetrataxinae, show a much greater affinity to the Endothyridae than to the Trochamminidae and may have a common ancestry with the Endothyridae.

## The Systematic Palaeontology of the Tetrataxinae.

Not only are the systematics of the family open to question, but the use of certain morphological features in the recognition of genera and species is to be doubted also. Since the tests are prone to collapse during fossilisation such features as the height of the cone and the apical angle, used extensively in the past as biocharacters in the recognition of species, must be unreliable in this role. A number of species have been described on very inadequate evidence, some being based on a single thin-section in limestone and others on neanic specimens, and no great reliance can be placed on them in stratigraphical work.

As a result of extensive biometrical work it has become evident that a valid subdivision below generic rank is that based on the chamberal arrangement when this is examined in serial section. Size is conditioned by environment, but the growth-rate, as expressed in the increase of the peripheral margin of the chambers, has a phyletic value. The volume of the umbilical cavity - the "nabelhohlung" of Schellwien - may also prove of value where distortion is small.

Genus TETRATAXIS Ehrenberg 1843.

Type species. Tetrataxis conica Ehrenberg (1843 p.422)

Valvulina (part) Brady 1876 (non d'Orbigny 1826).

Description. Test free, trochospirally coiled, composed of numerous elongate, crescentiform chambers lying with broader edge to periphery; number per whorl varying between adults and in growth; umbilical cavity wide and deep with lobes projecting to centre from chamber-floors; wall consisting of two layers, an outer granular calcareous layer and an inner fibrous layer, at times alveolar, buttressing various parts of the chamber; apertures at inner end of each chamber opening into umbilicus.

Distribution. This genus appears for the first time in the North-Western Province in the Michelinia Zone and rapidly becomes dominant in the beds of this area and of the Scottish Province.

Tetrataxis conica Ehrenberg (1843 p.422)

Text Fig.9

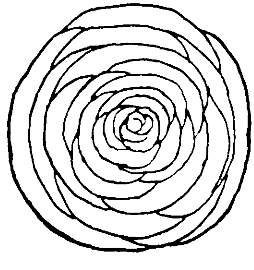
Involutina conica Brady 1871
Valvulina palaeotrochus Brady 1873

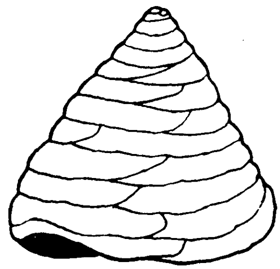
Description. Test free or possibly attached, conical, with flattened, circular base slightly concave or even convex; apex of cone pointed; chambers numerous, lunate in outline, embracing to slight degree, closely adpressed, forming a

Text Fig. 9

a

b





c

0·5MM.

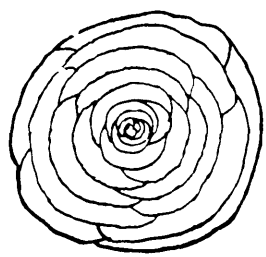
0·5MM.

TETRATAXIS CONICA EHRENBERG; a.& b. APICAL VIEW; c. LATERAL VIEW.

Text Fig. 10

a

b



c

0·5MM.

0·5MM.

TETRATAXIS DECURRENS (BRADY); a.& b. APICAL VIEW; c LATERAL VIEW.

quadriserial arrangement after initial stage; wall of calcite granules bound by calcareous cement, often with fibrous inner buttressing of chambers. Surface smooth. Aperture opening into umbilicus, covered with valvular flap.

Dimensions.

| | Height. | Max. Diameter of Base. |
|---|---|---|
| Figured spec. Brady. Pl. IV. fig. la, b. | 0.69mm. | 0.78mm. |

Distribution. Of world-wide occurrence this species is present in the Upper Avonian of the North-Western and Scottish areas.

Remarks. T. conica passes through all stages of transition into T. decurrens, the relationship between the two being shown graphically in Text. fig. 11.

Tetrataxis decurrens (Brady) (1873 p.65)

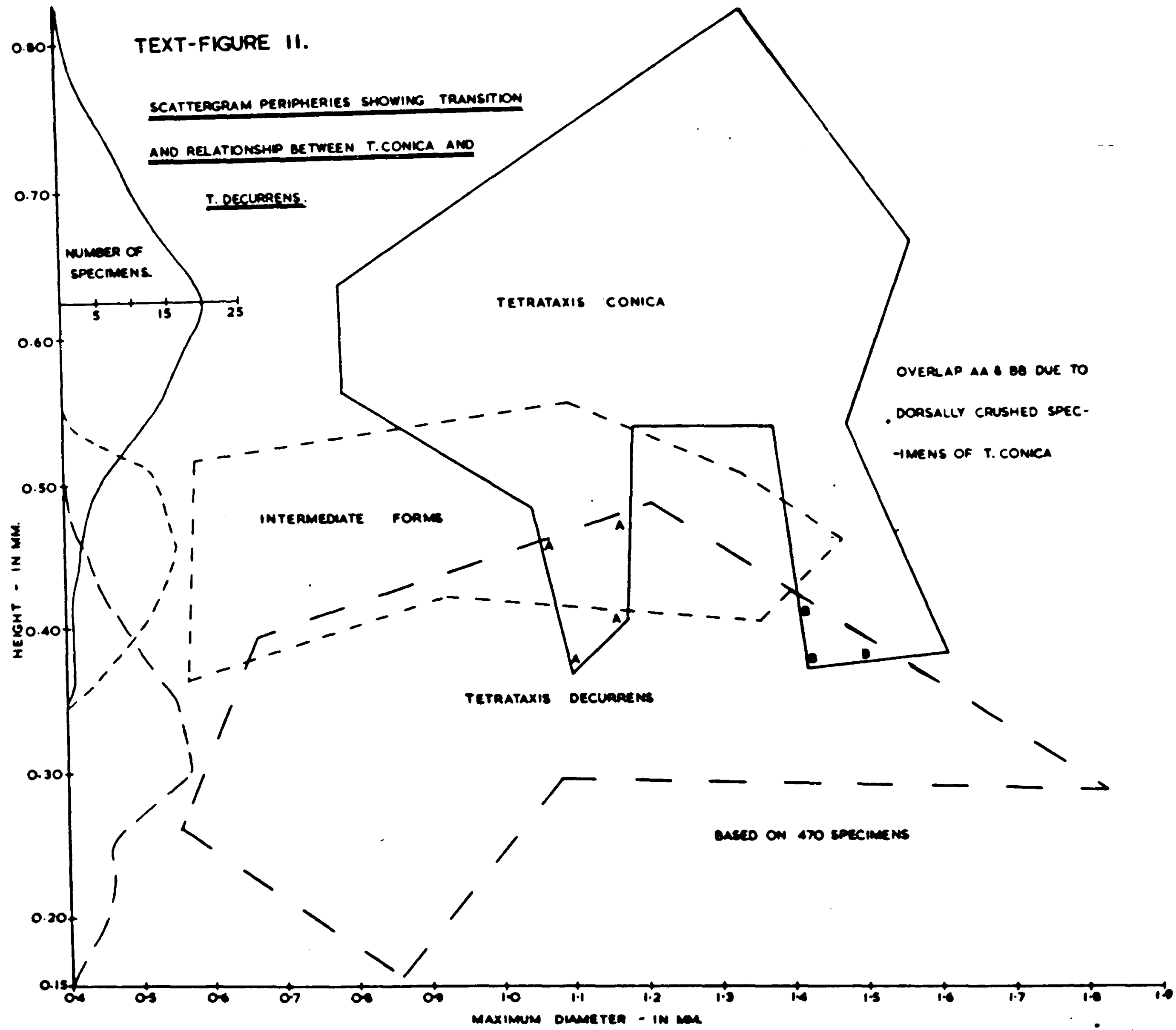
Text fig. 10.

Valvulina decurrens Brady 1873

Description. Test free or possibly attached; formed of a low cone with outspread base; composed of a trochospirally arranged series of crescentiform chambers; base flat or concave; chambers quadriserial with indistinct septation; thin and closely appressed. Wall of calcite granules bound by calcareous cement often with inner fibrous patches.

# TEXT-FIGURE 11.

SCATTERGRAM PERIPHERIES SHOWING TRANSITION AND RELATIONSHIP BETWEEN T. CONICA AND T. DECURRENS.



Aperture opening into umbilicus and covered with valvular flap.

Dimensions.

| | Height. | Max. Diameter of Base. |
|---|---|---|
| Figured spec. Brady. Pl. III. Fig. 17. | 0.2mm. | 0.70mm. |

Distribution. This species is known in the American Pennsylvanian. It has the same stratigraphical range in Britain as T. conica.

Genus POLYTAXIS Cushman & Waters (1928 p.51).

Type species: Polytaxis laheei Cushman & Waters 1928.

Tetrataxis (part) of authors (non Ehrenberg 1843).

"Early part of test similar to Tetrataxis, in adult spreading, chambers numerous in each whorl, ventral side concave, irregular; apertures several, on ventral side".

Apparently a direct development from Tetrataxis this genus has hitherto been recorded only from the American Pennsylvanian, but apparently congeneric forms have been noted from the Upper Limestone Group of Scotland.

Genus RUDITAXIS Schubert (1920 p.180).

Type species. Valvulina rudis Brady (1876 p.90).

Valvulina (Part) Brady 1876

"Test similar to Tetrataxis but interior of chambers labyrinthine; wall more coarsely and roughly arenaceous".

It seems probable, after examination of the type species, that this somewhat unsatisfactory genus is based on specimens of Tetrataxis that have undergone distortion and alteration. The labyrinthic interior is more likely to be due to secondary infilling than to primary structure - a feature already noted in the case of Saccamminopsis fusulinaformis (M'Coy) and other early records.

Genus VALVULINELLA Schubert (1907 p.211).

Type species: Valvulina youngi Brady (1873 p.63).

Valvulina (part) of authors.

Description. Test conical, coiled in a trochoid spiral; chambers few to a whorl and wholly or partly divided into two horizontal series of chamberlets, with division often showing through outer wall; wall structure of calcite granules with much cement; aperture on the ventral side.

Distribution. This genus is known only from the Carboniferous of Britain and Europe where it appears to be of stratigraphical importance.

Remarks. Cushman (1948) places the genus Valvulinella in the Orbitolinidae and remarks that forms intermediate between it and Orbitolina may be looked for in the Trias and Jurassic. Although there is a superficial similarity between the two genera in the external layer of cellules and a phylogenetic link may exist between them, Glaessner probably recognises the true affinities in placing *Valvulinella* within the Tetrataxinae.

The genus is derived from *Tetrataxis* by a subdivision of chambers into series of chamberlets and a reduction in the relative thickness of the wall. The earliest forms show only a partial subdivision of the chambers (see Text fig.12) whilst those of a slightly higher horizon exhibit complete development of the cellules. This development must have been extremely rapid and appears to have taken place in the Scottish Lower Carboniferous about the Hurlet horizon and at a similar level in the North-Western Province.

*Valvulinella youngi* (Brady) (1873 p.65)

Text fig.13.

*Valvulina youngi var contraria* Brady 1873 p.87

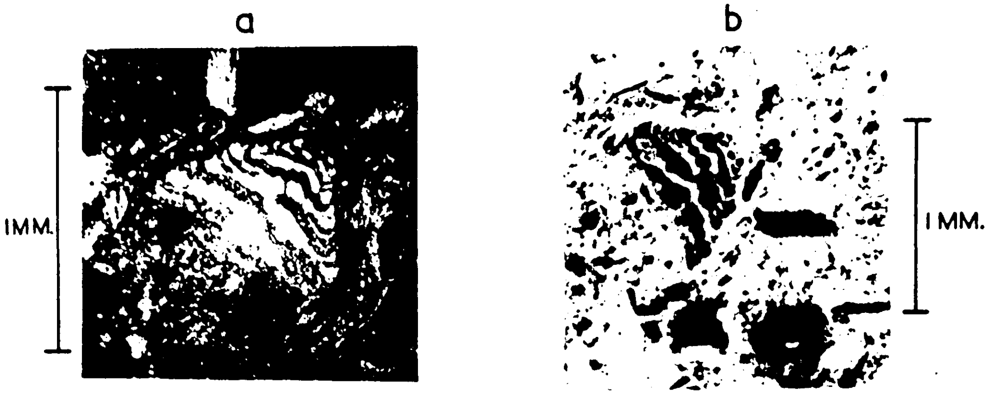
*Description.* Test free or possibly adherent at times, coiled in a trochospiral fashion into a high cone with curving margins. Composed of a large number of chambers with distinct sutures on exterior, internally subdivided into chamberlets. Wall composed of calcite granules bound by calcareous cement. Apertures of chambers opening into umbilicus.

*Dimensions.*

| | Height of Cone. | Max. diameter of Base. |
|---|---|---|
| Figured spec. Brady.Pl.IV. Fig.6a, b. | 0.61mm. | 0.66mm. |

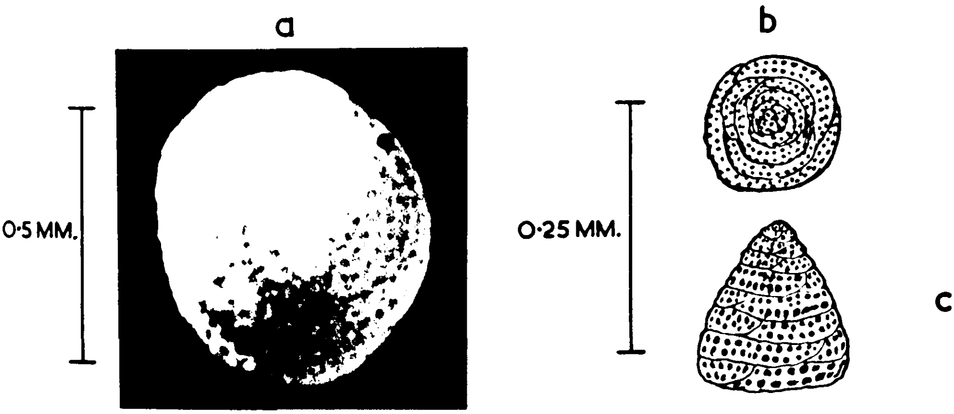
## VALVULINELLA

Text Fig. 12




VALVULINELLA CF YOUNGI - SHOWING PARTIAL SUBDIVISION OF CHAMBERS; a. NORMAL PHOTO; b. "TRACE" PHOTO.

Text Fig. 13




VALVULINELLA YOUNGI (BRADY) a & b. APICAL VIEW; c LATERAL VIEW.

Distribution. Of major importance as a marker fossil this form is characteristic of the Hurlet horizon in Scotland and the middle part of the Dibunophyllum Zone of the North-Western Province. It has been recorded by Liebus 1931 from the Posodonia Beds of Frenkhausen near Arnsberg.

Remarks. The test appears to have been flexible to a marked degree and crushed forms are common. Brady's V. youngi var. contraria is regarded as a distorted specimen. The relationships to the genus Stacheia are discussed in the following chapter.

The Systematic Palaeontology of Genera showing an affinity to the Tetrataxinae.

Two genera of the British fauna, Globivalvulina and Howchinia, are of unknown relationships but appear to be allied to the Tetrataxinae in some ways.

Genus GLOBIVALVULINA Schubert (1920 p.163).

Type species. Valvulina bulloides Brady (1876 p.89).

Valvulina (part) Brady 1876 (non d'Orbigny).

Description. Test free, hemispherical to subglobular, ventral side usually flattened and dorsal side strongly convex, formed of globular chambers arranged in a biserial fashion about an axis planispirally or trochospirally coiled. Dorsally all chambers are visible but ventrally only final pair seen.

Periphery broadly rounded to sharply angular. Wall granular calcareous with (according to Reichel) an additional thin outer fibrous layer and at times an inner perforate layer which only occurs on the septa. Apertural face depressed, made up of septa of last two chambers, with aperture a little below centre.

Distribution. This genus is rare in the Lower Carboniferous but is an important member of Pennsylvanian and Permian faunas.

Remarks. The morphology of *Globivalvulina* has been described in detail by Reichel (1945) and Plummer (1948). Both deal with the inadequacies of previous work and emphasise the biseriality of the form. Whilst Plummer suggests a close similarity to *Cassidulina*, Reichel implies the inclusion of the genus within the Tetrataxinae. The relationship to the genus *Biseriammina* Tchernysheva (1941) requires further study.

*Globivalvulina bristolensis* Reichel (1945 p.524).

This species was described by Reichel (ibid) from the Caninia Oolite of the Avon Gorge.

Genus HOWCHINIA Cushman (1927 p.42).

Type species: *Patellina bradyana* Howchin 1888.

*Patellina* Howchin 1888 (non Williamson 1858)

Mr.A.G.Davis tells me he has a paper in press on the morphology and distribution of the type species. He has stressed already the stratigraphical value of the form in a previous work (Davis 1945). In the meantime the fallacy of Cushman's including it in the Orbitolinidae may be noted. It has a value as a horizon marker in the No.2. Limestone of the east of the Scottish Area.

# CHAPTER X

## STACHEIA AND STACHEOIDES.

### The Systematic Position of the Genus Stacheia.

The relationships of the genus *Stacheia* are rather obscure. Cushman (1948) places it in the Placopsilinidae but this is an artificial group based on sessile habit and includes such different genera as *Placopsilina*, *Stylolina* and *Acruliammina*. Sessile habit in the foraminifera, far from being limited to a single phyletic stock, is adopted by members of a number of different stocks at different times; and thus attached forms are no more than crudely homeomorphic.

Glaessner (1945), doubtfully refers the genus to the Lituolidae: but the type species, by previous designation, is *Stacheia marginulinoides* Brady in which the test-wall is composed of calcite granules bound by calcareous cement, in contrast to the arenaceous structure typical of the lituolids.

Brady original conception of the genus included some forms, such as *Stacheia polytrematoides*, possessing a wall composed partly of quartz-grains and other adventitious material. These must be removed from the genus *Stacheia* and they are now referred to the new genus *Stacheoides*. Though the systematic position of this new genus is not yet settled, *Stacheia* emend. is itself without doubt a member of the Tetrataxinae.

## Chapman's Emendation of *Stacheia*.

In 1895 Chapman emended the genus *Stacheia* and erected four new species from the Rhaetic of Wedmore, Somerset. Later in 1901 he listed one new and one other species from rocks of Wenlock Age in Gotland. An examination of some of the types of these species in the British Museum shows that none are related to Carboniferous forms of *Stacheia*, and some may lie even outside the foraminifera.

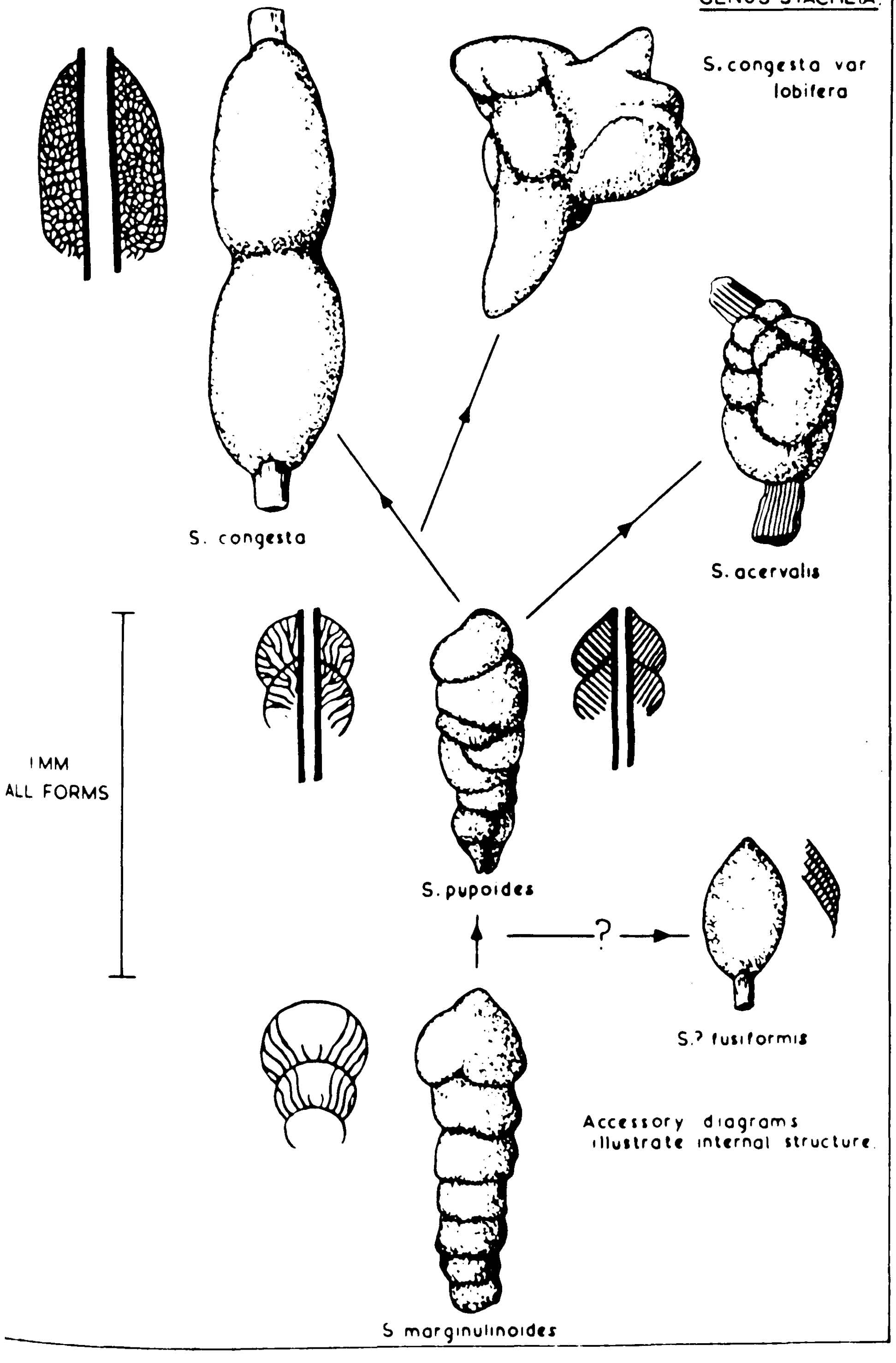
### Genus *STACHEIA* Brady (1876 p.107).

Type species. *Stacheia marginulinoides* Brady (1876 p.112)

*Description:* Test attached, with earliest chambers of some species suggesting a spiral arrangement. In the adult chambers relatively low in height, at times uniserial, in other cases irregularly arranged, and subdivided into chamberlets, with partitions frequently dichotomously branching; chamber walls and partitions of regular and constant thickness; wall of calcareous granules bound by calcareous cement; aperture usually hidden but probably simple, circular and may have neck.

*Distribution:* The many previous records of this genus in the Lower Carboniferous of Britain are now in need of revision. It is certainly present in the Lower and Upper

Text Fig. 14 DIAGRAM SHOWING MORPHOGENY WITHIN THE GENUS STACHEIA.



Limestone Groups of Scotland and the Dibunophyllum Zone of the North-Western Province.

Remarks: The ontogeny of Stacheia s.s. is very obscure. In some species there appears to be a very short trochospirally coiled stage immediately following the proloculum. Growth appears to take place by the addition of chambers in a uniserial or irregular pattern the last formed almost completely covering the earlier. The chambers are subdivided by vertical partitions into chamberlets throughout. The partitions may be simple or branching.

At the present time detailed phylogeny must remain largely guesswork, but two main trends appear to exist within the genus. The first is a trend towards irregularity by the abandonment of uniserial growth, by the disruption of chamberal form, and by the increasing branching of the septa. Thus the regular arrangement of S.marginulinoides yields to a greater irregularity in S.pupoides and reaches an acme in S.congesta. The second is a trend towards increasing the relative surface area. Thus the smooth form of S.marginulinoides yields by inflation of the test to the hummocky irregularity of S.congesta var.lobifera.

The genus, as a member of the Tetrataxinae, appears to have arisen from Tetrataxis through Valvulinella by a comparable emphasis on trends towards irregularity of form. The wall-structure of Stacheia is identical with that of

Valvulinella. Stacheia appears to possess a trochospiral nepionic stage which may be taken to indicate a tetrataxinid ancestry. The possession of chamberlets is seen as a progressive development within both genera. No definite records of Stacheia s.s. occurring earlier than Valvulinella are known and both appear for the first time at approximately the same stratigraphical level.

Stacheia congesta Brady (1876 p.117)
Text fig.15

Description: Test attached; fusiform to cylindrical outline. Interior subdivided into very large number of small chamberlets. Latter somewhat cubic, 0.02mm, and arranged in slightly arched layers, piled on top of one another, over-lapping at margins. Chamberlets separated by partitions, some 0.015mm. in thickness. Walls composed of minute calcite grains bound by calcareous cement, homogeneous throughout. No true aperture visible.

Dimensions: Length 4.2mm. Width 1.1mm.

Distribution: Abundant in the Lower Limestone Group of Scotland and the Dibunophyllum Zone of the North-Western Province.

Remarks: Brady (1876) and Harlton (1928) describe the chamberlets as irregular in shape and arrangement, but this may well be due to accidental variation in appearance

# STACHEIA

Text Fig. 15

1 MM.

STACHEIA CONGESTA BRADY – BILOBATE FORM – LATERAL VIEW.

Text Fig. 16

1 MM.

STACHEIA CONGESTA VAR. LOBIFERA VAR. NOV.
HOLOTYPE – LATERAL VIEW.

dependent on the plane of section.

<u>*Stacheia congesta* var. *lobifera*</u> var.nov.

Text Fig.16

<u>*Stacheia congesta*</u>(part) Brady 1876.

<u>Description</u>: Variety differs from typical form in having relatively large conical protuberances of unequal length forming greater part of test; typically cones have single rounded apices but some have double-crown. Chamberlets arranged as in <u>*Stacheia congesta*</u>, lying parallel to surface, small, closely compact about 0.02mm. in width, almost cubic; separated by walls, 0.015mm. thick throughout. No suturing or overfolding with growth visible but some cones, produced in adult stage, may cause overgrowth. Surface smooth. Wall of calcareous grains bound by calcareous cement. No distinct aperture; apices of cones sometimes worn, appearing as small rounded openings.

<u>Dimensions</u>: Length. 1.22mm. Breadth. 0.51mm.

Cones - approximately one third length of test, tapering bluntly rounded.

Width of cones at apices. 0.08mm. - 0.22mm.

<u>Depositories</u> etc:

<u>Holotype</u>. Geol.Surv.(Scotland) Slide No. R.9964.

<u>Type Locality</u>. Main Limestone, Poniel Water, Lanarkshire, Scotland.

Distribution: Occurs together with Stacheia congesta.

Remarks: This new variety carries the generic trends further than the typical form.

Stacheia marginulinoides Brady (1876 p.112)

Text fig.17

Description: Test attached, of moderate size, uniserial, elongate, slightly curved, subcylindrical, and tapering out from initial part. Composed of a number of convex chambers added uniserially and increasing in size as added. Chambers more or less embracing, superimposed, sub-divided into chamberlets. Surface smoothly rounded, broken only by thin depressed sutures giving periphery slightly lobulate appearance. Wall of calcareous grains bound by calcareous cement. Aperture terminal at infolding.

Dimensions: Length. 1.2mm. Maximum breadth. 0.8mm.

Maximum length of one segment. 0.31mm.

Distribution: Rather rare in the Lower and Upper Limestone Groups of Scotland and the Dibunophyllum Zone of the North-Western Province.

Remarks: This form bears a close relationship to Stacheia pupoides in manner of growth and form of chamberlets.

Stacheia? fusiformis Brady (1876 p.114)

Text fig.18

Description: Test attached, short, stout, symmetrical, fusiform with no superficial markings and round in cross-section. Composed of layers of chamberlets (or subdivided segments) symmetrically arranged round a thin columnar foreign body, each layer embracing the previous one at its peripheral margin. Chambers thin, numerous, and subdivided by secondary septa into minute chamberlets. Wall calcareous and homogeneous throughout. Aperture not visible but believed to be terminal.

Dimensions: Length. 0.67mm. Maximum breadth. 0.51mm.

Distribution: Present in the uppermost Avonian of North-Western England and Scotland.

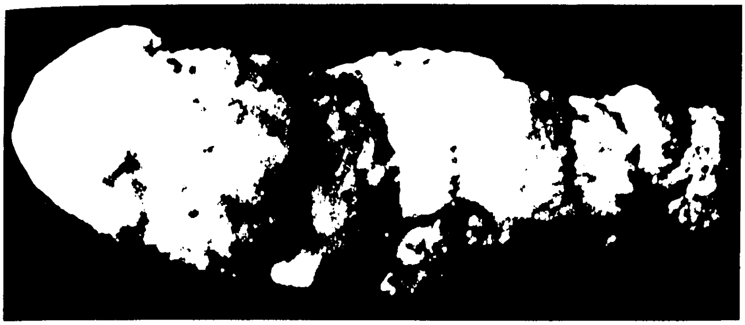
Remarks: This species is doubtfully referred to Stacheia since it shows several morphological differences from the type species, notably in the difference in thickness between septal partition and chamber floor.

Stacheia pupoides Brady (1876 p.115)

Text fig.19

Description: Test attached, elongate, uniserial, tapering; composed of a line of irregular convex segments lying on surface of a foreign body and partly embracing it; almost circular in cross-section. Chambers inflated and interiorly subdivided more or less regularly into chamberlets. Septa or partitions dividing these chambers may be simple or branching. Surface nearly smooth. Wall of calcite grains

# STACHEIA



Text Fig. 17

S. MARGINULINOIDES BRADY

LATERAL VIEW.

0·25 MM.

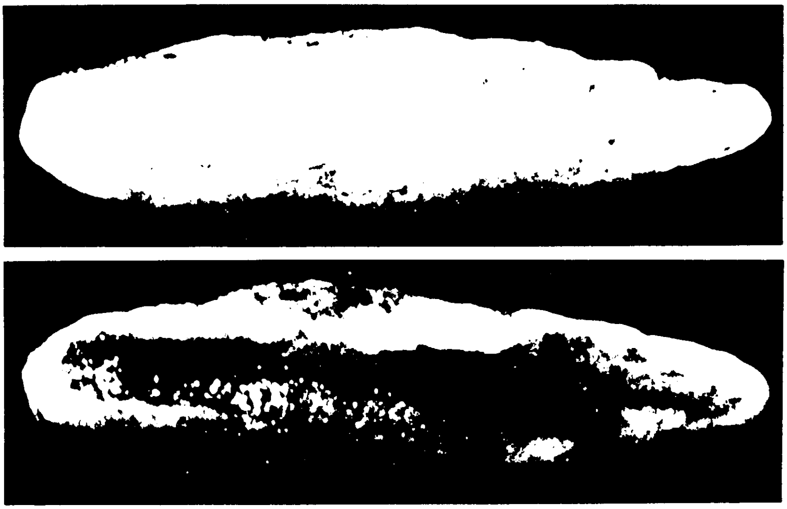
Text Fig. 18

S.? FUSIFORMIS BRADY

A. LATERAL VIEW.

0·25 MM.

B. LATERAL VIEW - REVERSE SIDE SHOWING INFOLDING.



Text Fig. 19

STACHEIA PUPOIDES BRADY

LATERAL VIEW - SHOWING INFOLDING AT APERTURAL END.

0·5 MM.

Text Fig. 20

STACHEIA ACERVALIS (BRADY)

LATERAL VIEW - TEST ATTACHED TO POLYZOAN.

1 MM.

bound by calcareous cement, homogeneous. Aperture terminal, basal.

Dimensions: Length. 1.0mm. Maximum breadth. 0.67mm.

Distribution: Lower and Upper Limestone Groups of the Scottish Carboniferous.

*Stacheia acervalis* (Brady) (1873 p.116)

Text fig. 20

*Webbina acervalis* Brady (1873 p.69).

Description: Test attached, of moderate size, composed of a small number of chambers of varying size arranged in acervuline or indefinite manner. Chambers subdivided into chamberlets. Surface smooth; wall composed of calcite grains bound by calcareous cement. Aperture terminal, on under surface of test, usually with neck.

Dimensions: Length. 1.35mm. Breadth. 0.6mm.

Distribution: Rare and known only in the Upper Avonian of Scotland and Northern England.

Genus STACHEOIDES gen.nov.

Type species. *Stacheia polytrematoides* Brady (1876 p.118)

*Stacheia* (part) Brady 1876 and others.

Description: Test attached or free in very rare cases, of irregular form dependent upon nature of host. Growth irregular and often reticulate with formation of numerous chamberlets arranged in approximately tubular pattern. Partitions separating chamberlets of different thickness than roofs and floors and often showing other irregularities. Wall composed of mixed material, largely granules of calcite with small proportion of quartz-grains and bound by calcareous cement. Apertures present on the apices of the irregularly scattered protuberances.

__Distribution:__ This genus is known to occur throughout the greater part of the British Lower Carboniferous.

__Remarks:__ The distinction between this genus and __Stacheia__ has been outlined below ( p. 80.).

__Stacheoides polytrematoides__ (Brady) 1876.

Text fig.21.

__Stacheia polytrematoides__ Brady 1876.

__Description:__ Test adherent, fusiform outline when attached to spines or polyzoans, irregularly spreading and encrusting on crinoid stems. Growth characterised by tubular habit but of an extremely irregular pattern with numerous small chamberlets piled upon one another and arranged in hummocky protuberances at rare intervals. Chamberlets roughly rectangular. No sutures but in-frequent growth ridges. Surface rough and often mammillated. Wall largely calcareous but with adventitious material. Distinct apertures on apices of the irregularly scattered protuberances.

__Dimensions:__ dependent on host;-(not confined to type material.)

On crinoids stems the size reaches 6.5mm. Maximum length on spine. 2.34mm., maximum breadth on spine 0.67mm. Average width of base of protuberance 0.17mm.

__Distribution:__ This species appears to range throughout the greater part of the Lower Carboniferous of Britain and to be especially common in the Upper Limestone Group of Scotland.

__Remarks:__ Polyzoan fragments have been placed under this species in the past in spite of the obvious differences.

__Stacheoides papillata__ sp.nov.

Text fig.22

__Description:__ Test attached though a few probably free examples found. General outline variable dependent on shape of host, usually fusiform but may be cylindrical or spherical. Surface characterised by numerous lobiferate, conical to sub-conical, relatively small protuberances possessing a circular aperture in an apertural depression at their apices. Internally composed of rows of chamberlets irregularly laid on top of one another and surrounding host, the floors thinner than the partitions. Size of the chamberlets 0.05mm. in length - average. No suturing present but over-folding occurs.

surface smooth. Wall largely made up of calcareous grains bound by calcareous cement but adventitious material included. Apertural openings apparently confined to apices of protuberances.

Dimensions: Largely dependent on host, figures for holotype:

Length. 1.34mm. Breadth 0.7mm.

Depositories etc:

Holotype. Geol.Surv.Scotland Slide No.R.9965.

Type Locality. Limestone near top of Calciferous Sandstone Series, Penton Linn, Dumfriesshire.

Distribution: Common in the Calciferous Sandstone Series and recorded in the Charlestown Main Limestone of Scotland; not yet recorded in the Lower Carboniferous of England.

Remarks: Though closely similar to Stacheia congesta, with which it has been confused in the past, this form is distinguished by the differences in wall-structure, position of the apertures, larger chamberlets, and variation in thickness of septal partitions. It is distinguished from Stacheoides polytrematoides by a difference in general form and in the larger number of protuberances.

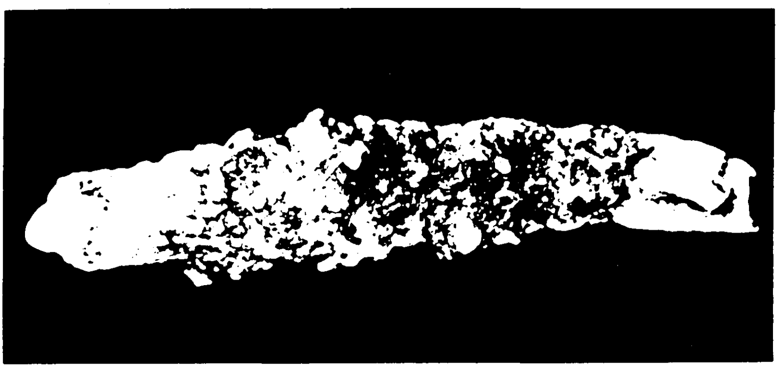
## Comparison of Stacheia and Stacheoides.

In order to emphasise the considerable differences that exist between these two genera both in their morphology and ontogeny and to validate their separation and the recognition of *Stacheoides*, a comparison in chart form is given below:

| | *Stacheia s.s.* | *Stacheoides.* |
|---|---|---|
| Sub-family. | Tetrataxinae. | Incerta sedis. |
| Type species. | *St.marginulinoides* Brady. by previous designation. | *Std.polytrematoides* Brady. by designation. |
| Wall - structure. | Granules of calcite bound by calcareous cement. | Arenaceous of mixed material, largely calcite and much cement. |
| Thickness of wall. | Constant throughout exterior wall and partitions. | Partitions thicker than roofs and floors of chambers - other irregularities. |
| Mode of Growth. | Formation of low chambers in uniserial or acervuline masses with sheet like habit. | Growth irregular and reticulate with a tubular habit. |
| Aperture. | Usually hidden terminal and basal. | Usually appears on superior surface as small orifices surmounting cones. |

# STACHEOIDES

Text Fig. 21



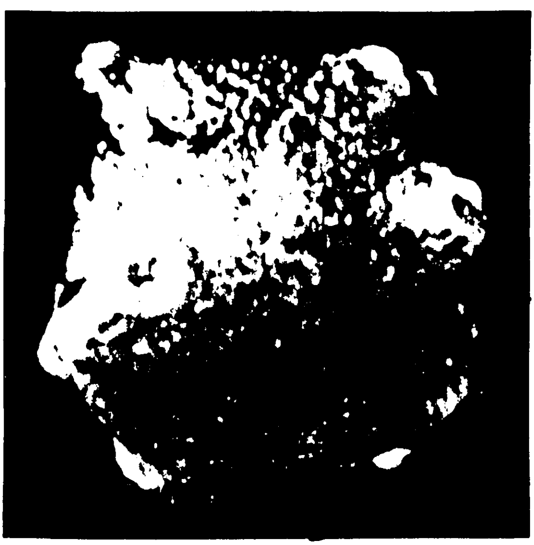
1 MM.

STACHEOIDES POLYTREMATOIDES BRADY - LATERAL VIEW - TEST ATTACHED TO PRODUCTID SPINE.

Text Fig. 22

b.

a.



1MM.

1MM

STACHEOIDES PAPILLATA SP. NOV.

a. ? FREE SPECIMEN - LATERAL VIEW.

b. HOLOTYPE - LATERAL VIEW.

# CHAPTER XI

## THE ENDOTHYRINAE.

### The Higher Taxonomic Grouping of the Endothyridae.

Cushman (1948) includes the endothyranid foraminifera as a subfamily within the Lituolidae but several major morphological differences oppose this procedure. The arrangement that I have adopted is essentially the same as that given by Glaessner (1945). As a development, however, I have divided the Endothyridae into two subfamilies, the Endothyrinae and the Bradyininae, on the basis of important differences of wall-structure and general form which have been overlooked by previous authors. Thus, in the Endothyrinae the wall is composed of granules of calcite bound by calcareous cement and has no perforations, whilst in the Bradyininae the wall is perforate and frequently contains adventitious material in addition to the basic calcareous constituents.

- Endothyridea
  - Endothyridae
    - Bradyininae
    - Endothyrinae
  - Fusulinidae

## Aspects of the Morphology of the Endothyrinae.

As the most important and most widespread group of smaller foraminifera in the Lower Carboniferous the Endothyrinae have been described in detail not only in the general studies by Cushman (1948) and Glaessner (1945) but also in the specialised work of Scott, Zeller, and Zeller (1947) and Zeller (1950). In spite of this several aspects of the morphology remain highly controversial.

### Variation in Form and Size.

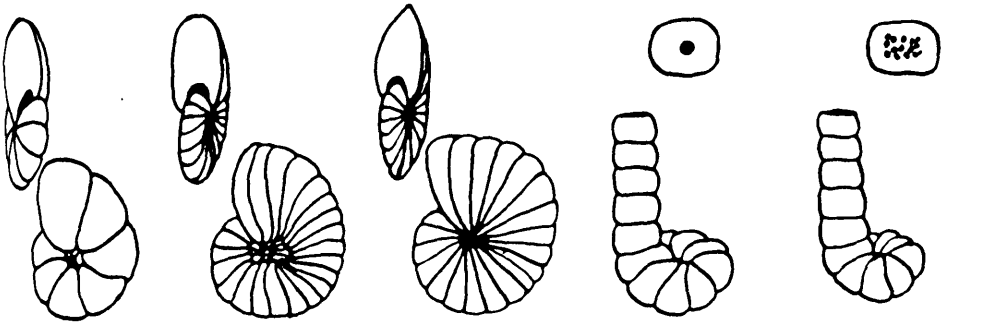
The variation in form of the Endothyrinae is summarised in diagrammatic form in Text.fig.25. The size differential is extremely large for within one genus there often occur specific forms some six or seven times larger than others. Although instances of grain-size sorting have been noted this variation would appear to be of specific value since it is usually independent of facies control. Zeller (1950) has noted the stratigraphical value of this size differential in the Mississippian and I have found it to be also of value in the stratigraphy of the North-Western Province (see p. 147.).

### Mode of Growth - Manner of Coiling.

The test of the Endothyrinae grows by the addition of chambers in a simple series and usually in a coiled pattern though this may be superseded in some cases by a

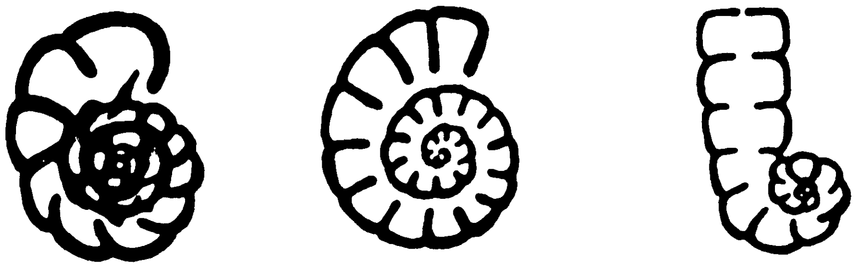
## ENDOTHYRINAE

Text Fig. 23 Variation in Form of the Endothyrinae.



PLECTOGYRA ENDOTHYRA MILLERELLA ENDOTHYRANELLA SEPTAMMINA

Text Fig. 24 Chamberal Arrangement – shown in section.



COILING SHOWING HIGH DEGREE OF AXIAL ROTATION

b PLANISPIRAL COILING

C COILED & RECTILINEAR PORTIONS

### TABLE D.

RELATIONSHIP BETWEEN GENERA OF ENDOTHYRINAE & COILING

| MODE OF COILING | IMPORTANT GENERA | RELATIVE ABUNDANCE<br>RARE — ABUNDANT |
|---|---|---|
| PLANISPIRAL | MILLERELLA | |
| OMINANTLY PLANISPIRAL | ENDOTHYRA | |
| OMINANTLY WITH HIGH AXIAL ROTATION | PLECTOGYRA | |
| COILED & RECTILINEAR | ENDOTHYRANELLA | |

rectilinear pattern in the neanic or ephebic stage.

Normally three types of chamberal arrangement are recognised (see Text fig.24) and are of major importance in generic distinction. Nevertheless, although in nearly all recent work these types have been regarded as distinct, they are in fact merely dominant, being linked at all stages by transitional forms.

Of the "planispiral" forms <u>Millerella</u> is the only genus in which species have a truly planispiral mode of coiling and, in some cases, this mode is not adopted until the neanic stage is reached.

Zeller (1950) recently defined the coiling in <u>Endothyra</u> as "planispiral" in contrast to the "plectogyroid" mode of <u>Plectogyra</u>. Reference to the figures of <u>Endothyra</u> given by Zeller, however shows conclusively that axial rotation is appreciable in the nepionic or neanic stages of all his forms. This is borne out by observations on my own material. Dr.Zeller (personal communication) now agrees that the coiling of <u>Endothyra</u> is not truly planispiral throughout, and that the boundary between <u>Endothyra</u> and <u>Plectogyra</u> is " a somewhat arbitrary one". He adds that any distortion in coiling of <u>Endothyra</u> is "of an irregular or haphazard nature", though in my experience the coiling of <u>Endothyra</u> shows a very low rate of axial rotation throughout, or is planispiral in later stages after earlier stages in which axial rotation of varying degree takes place.

In summary, only in some species of Millerella is the coiling truly planispiral. However there does occur a predominantly large group of forms in which the coiling approaches the planispiral mode, usually in the ephebic or neanic stages.

The second type of coiling was designated originally by Scott, Zeller and Zeller (1947) as "endothyranoid" and later changed by Zeller (1950) to "plectogyroid". Described as "a three-dimensional figure produced by a point moving in a plane so as to generate a logarithmic spiral while the plane is simultaneously rotated about an axis passing through the centre of the spiral" this mode of growth is in fact conceptual and has not been demonstrated to occur: it is indeed highly improbable except as a broad approximation. Observation shows the degree of "angular or rotational distortion" may vary irregularly within a single "plectogyroid" specimen and is a direct variable of the diameter in the more irregular forms. The term "plectogyroid" is therefore suspect and it is preferrable to refer to appropriate specimens as showing a high degree of axial rotation. Moreover, although specimens showing a high degree of axial rotation form a dominant group, all stages of transition exist to the dominant nearly planispiral group.

Finally in the third type of coiling, (coiled portion followed by rectilinear as in Endothyranella) the transition from the nepionic coiled stages to the adult rectilinear stage can be recognised in the ontogeny of one individual.

In the chart (Table D) I have summarised my views on the modes of coiling and their occurrence in the more important genera of the Endothyrinae. The definition of genera is purely arbitrary, being closely related to the dominant types of coiling.

The Test Wall.

Origin. There exists two diametrically opposed interpretations of the origin of the wall in the Endothyrinae. Brady (1876) described the wall as composed of calcareous sand ("the only source material in a limestone sea") bound by calcareous cement and hence implied that the Endothyrinae were agglutinated forms. His view has been supported by Cushman, Henbest and Glaessner, amongst others. In 1879 von Moller described the wall not only as porous but as having arisen from the direct secretion of the protoplasm and, in recent years, he has been supported by many authors including Harlton and Galloway. The frequent occurrence of resorption and of layering in some species, may indicate that the wall arises by direct secretion.

Composition and Micro-structure. It is now generally agreed that the wall is composed of calcareous particles bound by calcareous cement. Wood (1949) describes the test of

*Endothyra* as being made up "of very minute crystals of calcite in which the particles of calcite are equidimensional, subangular and closely fitted together". Although Zeller, Glaessner, and Rauser-Chernoussova are in agreement with this definition Cushman maintains that there occurs in every test a variable but small percentage of adventitious material which is revealed in thin-section and in the dilute hydrochloric acid test. The inadequacies of this test and the possibility of infiltrated foreign material have been discussed previously (see p. 21.) and should be recognised in an assessment of Cushman's interpretation.

The wall-structure of all the true endothyrids examined has proved to be entirely calcareous except in those cases where diagenesis of host sediments has taken place. *Endothyra crassa* Brady is an apparent exception but, as will be shown later, it falls outside the Endothyrinae.

*Layering of the wall.* This feature was described for the first time by Scott, Zeller and Zeller (1947) in the case of *Endothyra baileyi* (Hall). They believed this species exhibited a typical fusulinellid wall structure of tectum, diaphanotheca, and inner and outer tectoria, the last being referred to as the supplementary deposits. Zeller (1950) described these features as characteristic of both *Endothyra* and *Plectogyra*. He notes that "the third layer may be absent" but the relation of this to the others is rather vague.

It is significant that layering can be seen in only a few of the illustrations of recent American papers. Wood (1949 p.239) says "no British specimens of Endothyra I have seen shows the three layers in the test described by Scott, Zeller, and Zeller (1947)".

In an attempt to resolve these disagreements on morphology I have obtained from Dr.Zeller specimens of typical Mississippian Endothyrinae said to possess a layered wall-structure. These, from the Salem Limestone of Illinois, show in thin-section two layers approximating to the tectum and the inner tectorium mentioned above (see Text fig.25) but no third layer - the diaphanotheca - is recognisable, though the so-called supplementary deposits - the fourth layer of Zeller - are present in some cases.

Amongst British specimens examples of a layered wall-structure have been observed from a number of localities and one of the best British examples, from the upper part of the Avonian Succession, Avon Gorge, Bristol, is shown in Text fig.26.

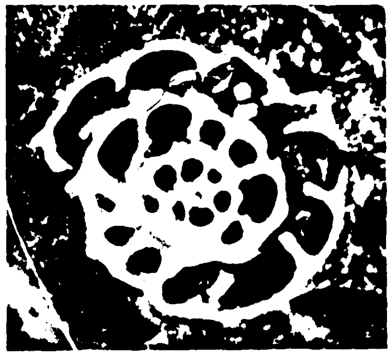
The composition of the inner of these two layers - the inner tectorium - is seen to be the normal one of equidimensional granules of calcite bound by calcareous cement. The outer layer - the tectum - is similar but is very much finer in texture and appears to contain a higher

Text Fig. 25

0·5 MM.

PLECTOGYRA SP. - AMERICAN FORM SHOWING LAYERING OF WALL-STRUCTURE ("TRACE" PHOTO).

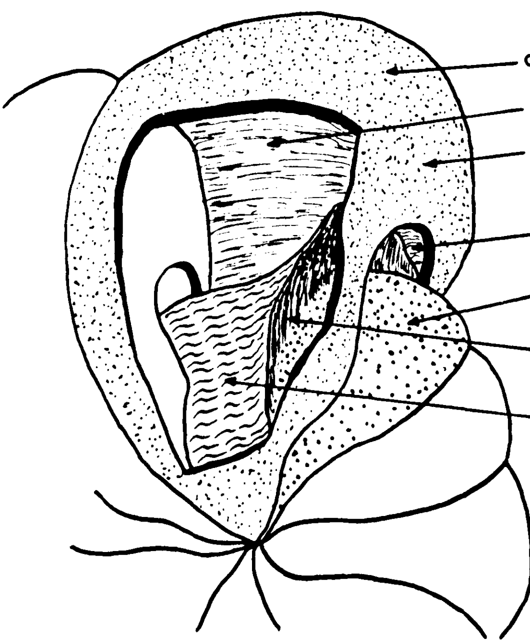
Text Fig. 26



0·5 MM.

PLECTOGYRA SP. - AVON GORGE, BRISTOL; SHOWING LAYERING OF WALL-STRUCTURE ("TRACE" PHOTO)

Text Fig. 27 Structure of "Secondary Deposits" in Final Chamber of a plectogyrid.



proportion of organic material. I believe the tectum represents an excessive development of cement on the outsid of the test.

Amongst some 5000 specimens of the Endothyrinae examined from the British Lower Carboniferous this layering of the wall-structure can be demonstrated conclusively only in the larger species of Plectogyra.

I believe that the differences of opinion between British and American workers is due to the fact that they have not been examining the same type of material. American research has centred, in the main, on the larger plectogyrids where layering is at a maximum development. Such forms have not been included into British studies until now.

Perforations. Moller (1878) first reported and illustrated pores in the wall of Endothyrinae but his records have been doubted by many later workers including Henbest (1931). Scott, Zeller and Zeller (1947), however, noted the presence of numerous closely packed, very fine dark lines orientated at right angles to the epitheca in the diaphanotheca of Plectogyra baileyi. They regarded these as pore canals which had been filled with foreign matter but doubted if they were indentical with those recorded by Moller. Wood (1949), however, considered the walls to be imperforate - a view subsequently accepted by Zeller (1950) and confirmed by my own observations.

<u>Alteration of the Test Wall.</u> Wood (1949) expressed the view that "it is not possible to say whether the test of <u>Endothyra</u> has recrystallised from a minutely crystalline test or was secreted in nearly its present state". I regard the normal structure of equidimensional grains of calcite bound by calcareous cement as primary or essentially so for the following reasons:-

(i) Recrystallisation would lead to the destruction of the layered type of wall in a manner independent of structural pattern.

(ii) Numerous cases occur of Endothyrinae showing the usual wall-structure in slides containing normal members of the fibrous walled archaediscids and in slides containing altered members of the same group.

(iii) As far as I can ascertain recrystallisation of the sediment leads to a fading of form in the Endothyrinae as seen in Text fig.1.

<u>Relation Wall-Structure to Classification.</u> It is now apparent that the genus <u>Endothyra</u> as conceived by Brady and other early workers was polyphyletic. Glaessner (1948) notes that Rauser-Chernoussova has distinguished three groups within the original limits of the genus, the one typified by <u>E.bowmanni</u> Phillips, the second by <u>E. globulus</u> (Eichwald), and the third by <u>E.crassa</u> Brady. <u>E.crassa</u> Brady and allied

species are, however, not properly ascribed to the subfamily (see p. 129 ) and the variations in wall-structure of the re-defined Endothyrinae are similar to those which take place within the Fusulinidae. They are variations of texture and arrangement within the one basic type of wall-structure and, though of generic importance, do not represent independent isomorphous stocks.

<u>Summary of Wall-structure.</u>

(i) Probably arising by direct secretion the wall is composed of closely compact, equidimensional, sub-angular grains of calcite bound by calcareous cement.

(ii) Variation in grain-size and increase of cement may lead to a layered structure, as in <u>Plectogyra baileyi</u>.

(iii) No perforations are present in the Endothyrinae and the normal wall-structure, as described above, has undergone little or no recrystallisation.

(iv) No agglutinated forms exist within the Endothyrinae as now re-defined.

<u>The "Secondary" Deposits.</u>

The presence of "secondary" deposits - the outer tectorium or supplementary deposits - in the Endothyrinae has been noted by several authors. They are known in <u>Endothyra sensu stricto</u> (see p. 101 ), in <u>Millerella</u>

(Thompson 1948) and reach their maximum development in *Plectogyra* (Zeller 1950).

Serial median sections of specimens probably belonging to *Plectogyra baileyi* (Hall) reveal the form of these deposits in their fullest expression. Because of resorption in the earlier chambers they are best seen in the final portion of the test, where the deposit takes the form of an anteriorly curved crescentiform shield lying slightly posterior to the apertural face (see Text fig.27). This shield has its maximum height on the median line and becomes lower towards the umbilici. Although this shield represents the maximum development deposits of this type are frequently seen as nodes or ridges or as mere thickenings of the chamber floors. As such they may exhibit an original form or indicate partial resorption, a feature prevalent in the earlier whorls.

Having their maximum development in the final chamber these deposits appear to form a baffle-plate behind the aperture so that no direct connection with the exterior exists. As new chambers are added they undergo resorption to increase the height of the tunnel and the vestibular character disappears.

Previous authors have regarded these deposits as secondary in origin but I am indebted to Professor Wood for the suggestion that they may represent an integral part of the chamber wall and hence be primary. It may be that as a new chamber is added not only is the outer wall and apertural face formed but a layer, continuous with the outer wall, is deposited along the floor of the new chamber and as a ridge behind the apertural opening. These deposits have an identical micro-structure with that of the outer wall, and resorption not only affects them but also the inner parts of the primary septa. Further evidence on the possible lateral confluence of septa and deposits is necessary before a final decision on the status of these deposits can be made. Hence they are provisionally described as "secondary".

Although Zeller (1950) has attached a stratigraphical value to this character of "secondary" deposits I have not been able to find evidence of this in the British material examined.

Relationship to the Fusulinidae.

The similarities that exist between the Endothyrinae and the Fusulinidae may be summarised:-

(i) The walls of both groups are calcareous and of similar structure.

(ii) The septa are mere incurvings of the spiral-wall whose growth is discontinuous in both cases.

(iii) Each group exhibits resorption and has "secondary" deposits.

(iv) A median tunnel is present in both groups.

(v) Certain fusulinids have an irregularly coiled juvenarium resembling endothyrids showing a high axial rotation of coiling.

Most authors consider these grounds as sufficient evidence for regarding the Endothyrinae as ancestral to the Fusulinidae. Recently Zeller (1950) has questioned this relationship on various morphological contrasts including apertural and wall structures, tunnel form, the manner of resorption, septal structure, and the position of "secondary" deposits.

Whilst agreeing with Zeller that these differences are sufficient to regard the two groups as distinct, I think there is a good deal of supplementary suggestion in these differences that a close relationship exists between them. Thus the Endothyrinae already exhibit a tendency to close the aperture in the forms possessing a vestibule and anticipate the complete closure of the aperture in the Fusulinidae, where pores are functionally equivalent.

Stratigraphical Range and Geographical Distribution.

The Endothyrinae are known to occur in Devonian rocks and they apparently became extinct towards the end of the Permian. Triassic records of the group are from the Bellerophon Limestone of the Alps which is known now to be of Permian age. Chapman's records of Rhaetic and Liassic species are unreliable.

These forms must be amongst the most widespread of foraminifera since they are known abundantly in the Upper

Palaeozoic of North and South America, the British Isles and the European and Mediterranean areas, central and eastern Russia, the Far East, and Australasia.

Systematic Palaeontology of the Endothyrinae.

The present-day systematics of the Endothyrinae is in many ways provisional, and the classification adopted can be regarded only as temporary: it may require drastic revision with further work.

Essentially I have concentrated on a revision of the Endothyrinae previously recognised in Britain. Although many new forms have been discovered during the progress of this work their full description awaits further morphological (including biometrical) study. They are, nevertheless, of some stratigraphical significance. The new species erected result from the revision of previously described British Endothyrinae.

ENDOTHYRIDEA Glaessner

ENDOTHYRIDAE Glaessner

ENDOTHYRINAE emend.

Genus ENDOTHYRA Brown 1843

Type species: Endothyra bowmani Brown 1843 (non Phillips 1846).

Endothyra Brown 1843 (non Phillips 1846 p.277).
Endothyra (part) Brady 1876 and others.
Involutina (part) of authors.
Nonionina (part) Eichwald 1860 (non d'Orbigny 1826).

__Description:__ Test free, close-coiled, often completely involute, in early stages exhibiting a varying degree of axial rotation in coiling and becoming largely planispiral in adult stages; chambers numerous, distinct, simple; wall composed of equidimensional calcite grains bound by calcareous cement, no pores or adventitious matter; exterior smoothly finished; aperture simple, typically narrow, at base of apertural face.

__Distribution:__ The known range of the genus as defined here appears to be from the middle of the Lower Carboniferous up to the Lower Permian.

__Remarks:__ A great deal of the confused systematics of the Endothyrinae arises from the original description of the type. Brown's original designation apparently rested on a manuscript belonging to Phillips, to whom the genus was ascribed. Phillips name being unpublished and not available, the genus clearly is Brown's.

Brown's original description and figures are inadequate for a complete definition of the genus. Moreover the type specimens of the type species are regarded as being lost. The whole question is at the present time being studied by Mr.C.D.Ovey but no comments or fuller descriptions have been published.

In the circumstances and for the time being I follow Zeller (1950) and, on the basis of available evidence, regard the type species as largely planispiral and covered by the provisional generic description given above.

*Endothyra davisella* sp.nov.

Text fig.28

*Endothyra globolus* (part) Brady 1873 p.63.
*Endothyra globulus* (part) Brady 1876 (non *Nonionina globolus* Eichwald 1860).

*Description*: Test free, moderately large, nautiloid, discoidal; low rate of axial rotation of coiling and slightly asymmetrical with later whorls appearing to cross over plane of test; this emphasised externally by presence of umbilicus on one side, revealing details of earlier coils, and by indistinct umbilical depression on other.

In adult 3½ whorls, showing regular and gradual increase in size and almost completely embracing; last half-whorl showing growth irregularity. Number of chambers in final whorl 14, in penultimate 11. Diameter of proloculum 0.01mm. but details of dimorphism unknown. Chambers moderately large, crescentic in form with a sub-rectangular outline in median section; towards apertural end chambers inflated, relatively large, and slightly irregular in position. Sutures thin, depressed lines.

Septa three-quarters height of whorl in length and about one-quarter breadth of adjacent chambers in thickness; inclined at about 70 degrees on sides of chambers but almost vertical to the tangent of the outer wall along the peripheral line; tapering slightly in outline and often thickened at

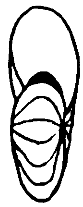
# ENDOTHYRA

## Text Fig. 28

a

0·5 MM.

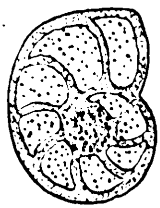
b



ENDOTHYRA DAVISELLA SR NOV.

a. HOLOTYPE – LATERAL VIEW; b. DIAGRAM OF APERTURAL VIEW.

## Text Fig. 29 SHOWING DISCREPANCIES IN BRADY'S FIGURE OF ENDOTHYRA SUBTILISSIMA.



a. HOLOTYPE – LATERAL VIEW.

b. APERTURAL VIEW AS SHOWN BY BRADY (PL. VI, FIG. 9).

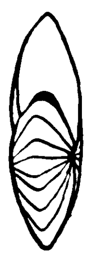
c. APERTURAL VIEW AS OBSERVED IN HOLOTYPE.

## Text Fig. 30

a

0·5 MM.

b



ENDOTHYRA RADIATA (BRADY).

a. LATERAL VIEW – TYPICAL SCOTTISH SPECIMEN; b. DIAGRAM OF APERTURAL VIEW.

their bases; formed by an infolding of outer wall. Periphery broad and smoothly rounded; peripheral margin with faint lobulation. Surface smooth and glassy. Wall composed of granules of calcite bound by calcareous cement; weak manifestation of "secondary deposits". Apertural face asymmetrical, with aperture a low crescentiform opening at base.

Dimensions:

| | Max. Diameter. | Min. Diameter. | Thickness. |
|---|---|---|---|
| Holotype. | 0.48mm. | 0.42mm. | 0.17mm |
| N. globulus. Brady Pl.V.fig.7. | 0.47mm. | 0.43mm. | 0.18mm. |
| Scottish Specimens. Average of 56 forms. | (0.35–0.6mm). | (0.31–0.48mm). | - - - |

Depositories etc:

Holotype: Geol. Surv. Scotland Collection Slide No. R.9966.

Type Locality: Main Limestone, Poniel Water, Lanarkshire.

Distribution: Characteristic of the Upper Avonian of the North-Western Province; in Scotland, abundant in the Lower Limestone Group, and recorded from several localities in the Upper Limestone Group.

Remarks: N. daviesella represents part of the material grouped by Brady under his N. globulus but it is not the same as Nonionina globolus d'Eichwald which is a smaller form, has a different arrangement of whorls and coiling, and fewer chambers.

The asymmetry is not well seen in median section. Due to variable weathering the sutures may show as thin lines, as broad bands, or as ridges.

**_Endothyra subtilissima_ Brady (1876 p.101).**

Despite repeated search this species is represented by a single specimen, the holotype, from the Brockley locality in Lanarkshire. The discrepancies between the figures given by Brady (Pl.VI.fig.9a, b) and the observed shape are shown in Text Fig.29.

The holotype appears to be a rotaliid, possibly referable to the genus _Gyroidina_. In view of the lack of confirmatory records, the very good state of preservation, the general morphology and the known contamination of the Brady Collection, I doubt very much if this species is a true Carboniferous foraminifer. In any case it cannot be referred to the Endothyrinae.

**_Endothyra radiata_ (Brady) 1869.**

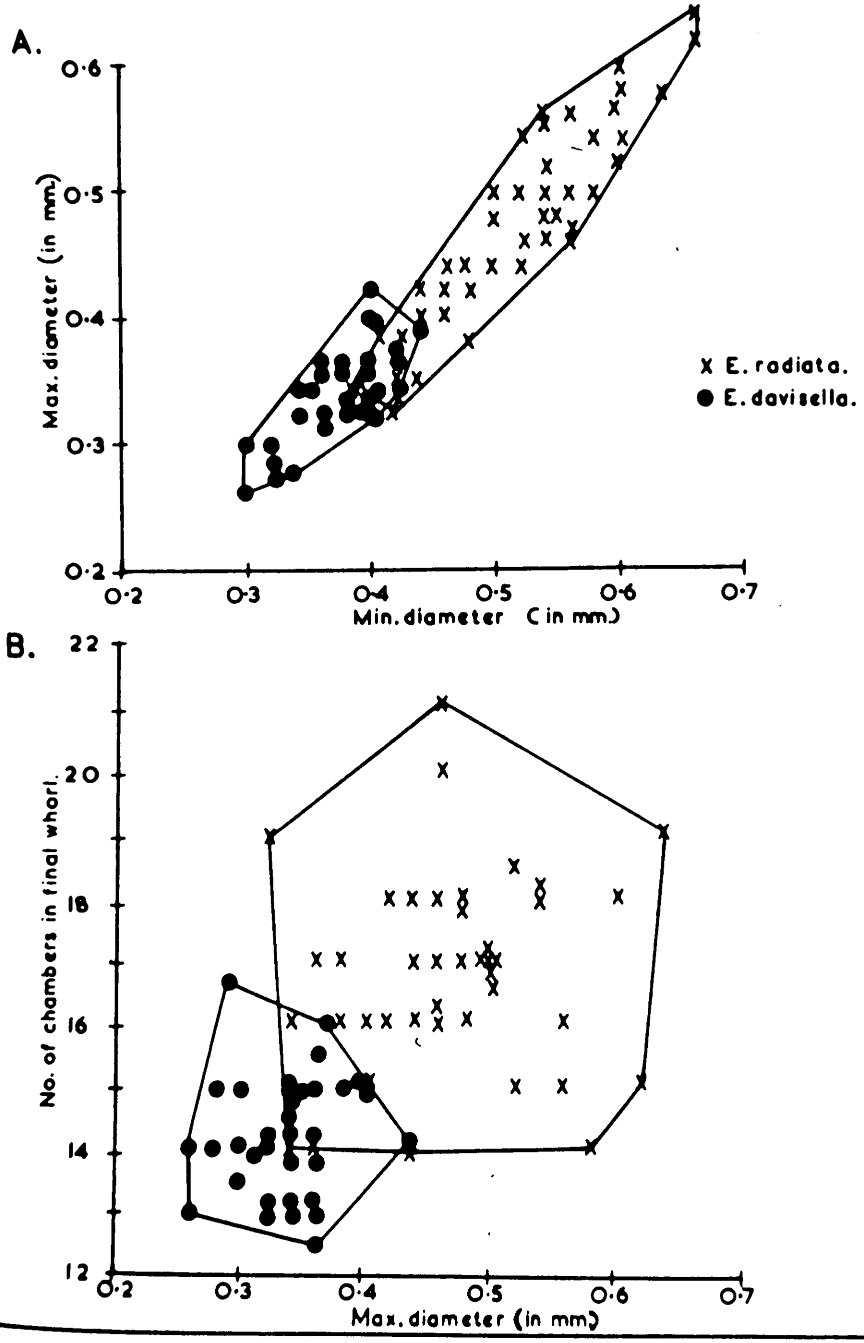
Text fig.30

_Involutina radiata_ Brady 1869 p.379.
_Globius radiata_ (Brady) Galloway and Harlton 1928.

_Description:_ Test free, of moderate size, nautiloid, discoidal, laterally compressed. Coiling largely planispiral but a slight degree of axial rotation leads to an equally slight asymmetry so that chambers adopt an involute pattern on one side and subtend a small umbilicus on other.

## ENDOTHYRA

**Text Fig. 31** RELATIONSHIP BETWEEN E. RADIATA & E. DAVISELLA
—overlap of scatter-areas showing transition.
Based on 55 specimens from one locality.



From 4-4½ whorls, slowly and regularly increasing in height with a variation in last four chambers due to very slight asymmetry and not to change in growth-rate; whorls almost completely embracing, appearing in cross-section as inverted chevron-shaped with curved margins. Number of chambers in final whorl 17-18, in penultimate 15. Diameter of proloculum 0.03mm. Chambers long, narrow, radial and slightly curved, tapering toward umbilical region and with rectangular outline in median-section.

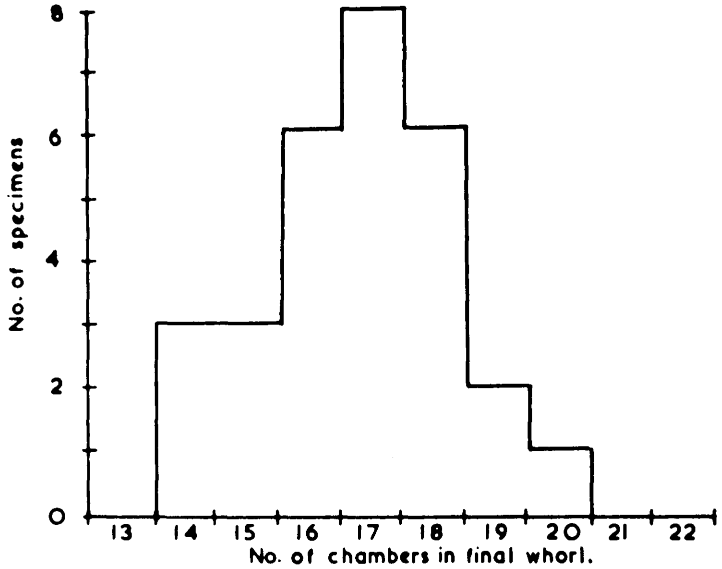
Sutures thin, faint, curved to straight, depressed lines. Septa extending down about three-quarters height of whorl, some one-third to one-quarter as thick as width of adjacent chambers; sometimes with bulbous extremities; in early part radial but in final portion longer, thinner and inclined at about sixty degrees; periphery markedly angular to sub-angular except in case of final chambers, and margin a smooth curve. Surface smooth and glassy. Wall homogeneous, composed of granules of calcite bound by calcareous cement, layering present in rare cases. Apertural face asymmetrical and aperture, low crescentiform opening at base.

<u>Dimensions:</u>

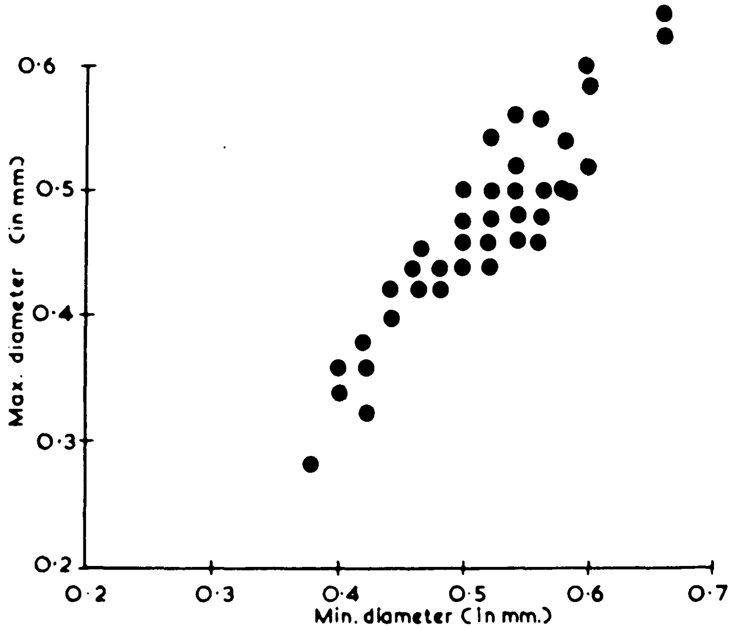
| | Max. Diameter. | Min. Diameter. | Thickness. |
|---|---|---|---|
| Figured spec. Brady Pl.V., Fig.11a, b. | 0.47mm. | 0.40mm. | 0.19mm. |
| Scottish spec. (35 specimens from one locality) | 0.44mm. (Range 0.31-0.61mm) | 0.40mm. Range 0.28-0.5[illegible]mm. | 0.20mm. - - - |

Text Fig. 32 Variation in E. radiata Brady
- BASED ON 40 SPECIMENS FROM ONE LOCALITY.

A.




B.



Distribution: First appears about the middle of the Lower Carboniferous in the North-West Province; in Scotland it ranges from the top of the Calciferous Sandstone Series to the Upper Limestone Group.

Remarks: Brady noted the close relationship that existed between E.globulus and E.radiata. This relationship is shown in graphical form in Text Fig.31 and the variation that occurs in E.radiata is shown in Text Fig.32.

This species has not been placed in Millerella because of the low number of whorls and the definite asymmetry of coiling. Nevertheless together E.daviselle and E.radiata show a trend towards the features which distinguish Millerella and are of importance as phylogenetic links.

Genus PLECTOGYRA Zeller 1950.

Type species: Plectogyra plectogyra Zeller (1950 p.3).

Endothyra (part) Brady 1876 and others (non Brown 1843).
Rotalia Hall 1856 (non Lamarck 1804).
Involutina (part) of authors.

Description: Test discoidal, umbilicate on one side, broadly rounded, coiled in a three-dimensional spiral with a high degree of axial rotation; chambers numerous, completely embracing, inflated; sutures well-defined; wall composed of calcareous granules bound by calcareous cement, often showing layering, imperforate and with no adventitious material, "secondary" deposits frequently present; apertural face asymmetrical with aperture low, slit-like, at centre of base.

Distribution: Known throughout the Lower Carboniferous of Britain and the Mississippian of America, this genus exhibits a wide range of variation and appears to be of value in stratigraphical subdivision of the latter area - see Zeller (1950).

Remarks: I have demonstrated above that no one type of coiling is characteristic of a particular genus in the Endothyrinae and that, on this criterion, the difference between Endothyra and Plectogyra is largely arbitrary. Nevertheless I regard the difference of mode of coiling combined with other aspects of the morphology as sufficient to warrant separate generic recognition. This recognition is, however, purely provisional until the morphology of the type of Endothyra is satisfactorily determined.

In past British work nearly all forms of this genus have been placed under Endothyra bowmanni Brady. A large number of new forms found in the North-Western Province are to be described at a later date.

Plectogyra baileyi (Hall) (1856 p.24).

Text fig.33.

Rotalia baileyi Hall 1856.
Endothyra baileyi (Hall) Whitfield 1886, Honbest 1931 and others.
Endothyra bowmanni (part) Brady 1876 and others.

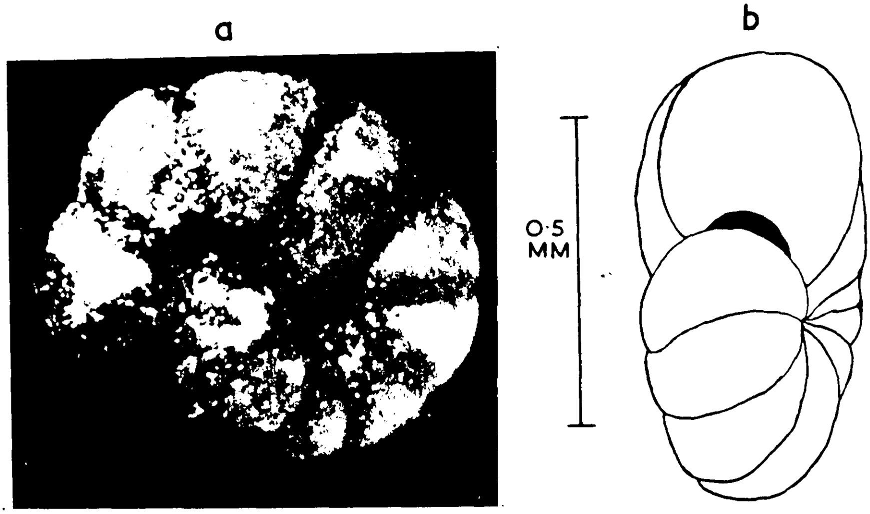
Description: Test free, large, nautiloid, laterally compressed; coiling shows high degree of axial rotation so that lateral view may vary from circular to ellipsoidal with a distinct umbilicus on one side and with a complex of the inner chambers showing in a shallow umbilical depression on the other.

About 4 whorls, exhibiting a gradual and regular increase in volume and height. 9 chambers in final whorl and approximately 8 in penultimate. Details of proloculum and earlier chambers obscure due to coiling. In median section chambers sub-rectangular in outline, and final chambers tending to overlap into umbilicus partly due to asymmetry of coiling and partly to lateral prolongation of chambers.

Sutures distinct, depressed, almost straight lines, separating slightly inflated chambers. Internally septa thin, perpendicular on median plane but inclined up to 70 degrees laterally; some two-thirds height of whorl in length and about one-six width of adjacent chambers in thickness; in median section frequently with cuspate terminal swelling.

Periphery broad and smoothly rounded; peripheral margin with slight lobulation. Surface smooth and often waxy. Wall homogeneous, of granules of calcite bound by calcareous cement and showing layering; well-developed nodes and ridges of "secondary" deposits on floors of chambers and baffle-plate behind aperture; effect of resorption apparent. Apertural face inflated and asymmetrical with low,

Text Fig. 33




PLECTOGYRA BAILEYI ( HALL ) - TYPICAL SCOTTISH SPECIMEN

a LATERALVIEW

b APERTURALVIEW - DIAGRAMMATIC

crescentiform, excentrically situated aperture leading into vestibule.

Dimensions:

| | Max.Diameter. | Min.Diameter. | Thickness. |
|---|---|---|---|
| Average of 30 Scottish specs. | 0.74mm. (0.61-0.85mm). | 0.64mm. (0.42-0.75mm). | 0.26mm. (0.19-0.29mm). |
| Topotype. Brit. Museum Coll. | 0.80mm. | 0.67mm. | 0.24mm. |

Distribution: In the North-Western Province this species ranges from the Productus corrugato-hemisphericus Zone to the middle of the Dibunophyllum Zone. In Scotland it has been recorded from the upper part of the Calciferous Sandstone Series and the Lower part of the Lower Limestone Group.

Remarks: The material examined includes some from the type locality of the Spergen Limestone of Iowa, U.S.A.

Brady grouped this species within his Endothyra bowmanni. Henbest (1931) and others have suggested that this is a distinct form and, having examined topotype material, I am convinced that they are correct.

Plectogyra sp.nov.

Involutina lobata Brady 1869 p.379.
Endothyra bowmanni (part) Brady 1876 and others (non Brown 1843).

The difficulties arising out of the early taxonomic history of the genus Endothyra have been discussed already (p. 98.) It can be stated quite definitely that the forms described by Brady (1876, p.92) as Endothyra bowmani are not the same as those originally figured and described by Brown. The former are referable to the genus *Plectogyra*, some to *P. baileyi* and others to new species, and one of the tasks to be carried out by Mr. C. R. Ovey in his research on the type of *Endothyra* will be a redescription of Brady's specimens under this new generic heading.

*Plectogyra circumplicata* (Howchin)(1888 p.533).

*Endothyra circumplicata* Howchin 1888.

This species was originally described by Howchin from the Lower Carboniferous of Northumberland. The type specimens have not been examined but recently forms almost identical with them (as described by Howchin) have been found in Westmorland. On the supplementary morphological evidence provided by these I have no hesitation in placing this species in *Plectogyra*.

Genus *ENDOTHYRANELLA* Galloway & Harlton 1930.

Type species: *Ammobaculites powersi* Harlton (1928 p.307).

*Ammobaculites* (part) of authors.
*Haplophragmium* (part) of authors including Brady 1876.
*Endothyra* (part) of authors.

*Description*: Test free, early chambers close coiled, later ones typically in a linear series, simple; wall composed of equidimensional grains of calcite bound by calcareous cement, no pores and no adventitious material; aperture at base of apertural face, in adult rounded, terminal, simple.

*Distribution*: Although common in the Pennsylvanian of America and the Lower Carboniferous of Russia this genus has hitherto not been recorded from localities in Britain.

Remarks: One or two new species of this genus have been noted in the Michelinia Zone of the Westmorland area but require further study. Haplophragmium rectum of Brady 1876 should be included in this genus.

Endothyranella recta (Brady) (1869 p.379).

Haplophragmium rectum Brady 1869.
Ammobaculites rectum (Brady) of authors.

This species is represented by only one specimen in the Brady Collection of the British Museum (slide P.35479). Of the three specimens on this slide only one possesses both a coiled and a rectilinear portion. Under high magnification the surface of the test shows no trace of adventitious matter and appears to be composed entirely of calcite grains. Therefore I do not regard this species as belonging to Ammobaculites. The other two specimens on the slide are broken fragments of rectilinear series of chambers and are much larger than the straight portion of the specimen described above and figured by Brady Pl.VIII, fig.8a,b. They resemble very closely species of Nodosinella and this is particularly true of that figured by Brady Pl.VIII, fig.9.

Genus SEPTAMMINA Meunier 1888.

Type species: Septammina renaulti Meunier (1888 p.236) (by designation).

Lituola (part) Brady 1876 (non Lamarck 1804).

"Form identical to Endothyranella but with a cribrate aperture".

Remarks: The validity of this genus is to be doubted since it is based on an extremely poor description together with an inadequate illustration made by Meunier from thin-section study only. Cushman (1948) apparently regards this form as possessing the same wall-structure as Endothyranella from his description quoted above. For this reason Septammina is included here in the Endothyrinae pending further study, though it might possibly possess an arenaceous wall-structure, in which case it would be included in the Bradyininae and would include the genus Haplophragmella Rauser-Chernoussova (1936) as a synonym.

Septammina bradyi Cushman 1948.

Lituola nautiloides Brady 1876 (non Lamarck 1804).

Brady's record is based on a single specimen (Brit.Mus. Nat.Hist.Slide P.35485) which appears to be a highly weathered cast of a form similar to Endothyranella but little can be determined of the wall-structure. Cushman has adopted Brady's record without question and introduced the new specific name on extremely slender evidence.

Genus MILLERELLA Thompson 1942.

Endothyra (part) of authors. rella marblensis Thompson (1942 p.404).
Orobias (part) of Galloway a
Fusulinella (part) of authors.
and Harlton 1930.
Fusulinella (part) of authors.
Staffella (part) of authors.

Description: Test free, discoidal, of five to eight whorls, varying from evolute to involute; chambers usually squarish or rectangular in median section; planispirally coiled throughout though juvenarium may show axial rotation. Wall relatively thin, composed of granules of calcite bound by calcareous cement, no pores or adventitious material, may be layered and show "secondary" deposits (primitive chomata?); aperture, an elliptical opening.

Distribution: The genus appears for the first time at about the same level in both British and American successions - towards the top of the middle part of the Lower Carboniferous - and rapidly becomes the dominant member of the Endothyrinae.

Remarks: Here again the recognition of this genus is provisional until the completion of Mr.Ovey's work on the type of Endothyra. Should this prove to be planispiral throughout and to have a large number of chambers then Millerella will have to be regarded as a synonym of Endothyra. For the time being, however, the genus Millerella is accepted and defined as above, differing from Endothyra in the larger number of whorls and chambers and the greater development of planispiral coiling.

Dunbar in Cushman (1948) points out that there is serious doubt whether Millerella should be included in the Fusulinidae as Thompson (1942) maintains. In view of the relatively small size, the thin and unspecialized wall-structure, and the presence of an aperture I prefer to include this form in the Endothyrinae and to regard it as an aberrant specialisation along the line linking the Endothyrinae with the Fusulinidae.

<u>Millerella ornata</u> (Brady) (1873 p.99).

Text fig.34.

<u>Endothyra ornata</u> Brady 1873
<u>Endothyra ornata var. tenuis</u> (part) Brady 1876.

<u>Description</u>: Test free, nautiloid, laterally compressed and of moderate size. Coiling almost planispiral and form bilaterally symmetrical. 5-6 whorls present, showing a moderate increase in size and volume, with last completely embracing earlier ones and with a rather narrow, deep umbilicus on both sides. 15 chambers in final whorl, 15 in penultimate. Construction of earlier part of test varies and needs further study. Diameter of proloculum, 0.03mm. and is followed immediately by planispiral coiling in most cases.

Surfaces of chambers appear depressed because of distinctive character of sutures. Latter stout, thick, rounded, radiate costae fusing at the periphery to form a distinct, crenulated keel. Septal details not fully determined but appear as thick and radial lines in median section with a very narrow and low septal aperture. Periphery markedly angular, carinate, and margin crenulated. Sutural costae produce undulating surface which is smooth and glossy. Wall relatively thick and homogeneous, made up of granules of calcite bound by calcareous cement. Details of apertural face unknown due to distortion of type and other specimens.

Dimensions:

| | Max.Diameter. | Min.Diameter. | Thickness. |
|---|---|---|---|
| Figured Spec. Brady Collect. | 0.64mm. | 0.57mm. | 0.28mm. |
| Scottish Specs. Average of 50 specimens. | 0.60mm. (Range 0.43 - 0.67mm) | 0.52mm. (Range 0.34 - 0.54mm) | 0.15mm. (Range 0.12 - 0.27mm). |

Distribution: In the North-Western Province this species appears for the first time in the Productus corrugato-hemisphericus Zone and in Scotland it has been recorded from the Hurlet horizon and the Upper Limestone Group.

Remarks: Probably Brady's Endothyra obliqua is based on specimens of this species crushed at right angles to the plane of coiling (see Text fig.35) and some of the syntypes of Endothyra ornata var.tenuis are laterally crushed forms of M.ornata.

## Millerella tenuis (Brady) 1876.

Text fig. 36.

Endothyra ornata var.tenuis (part) Brady 1876 p.100.
Endothyra radiata var.tateana Howchin 1888.

Description: Test free, nautiloid, large, laterally compressed and angular in apertural view. Coiling planispiral throughout; biumbilicate, with narrow, excavated umbilicus on either side.

Composed of 5-6 whorls with early part very similar

# MILLERELLA

Text Fig. 34

0·5 MM.

MILLERELLA ORNATA (BRADY)
-LATERAL VIEW.

Text Fig. 35

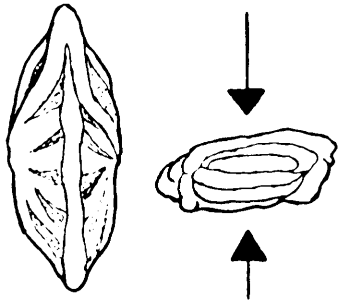
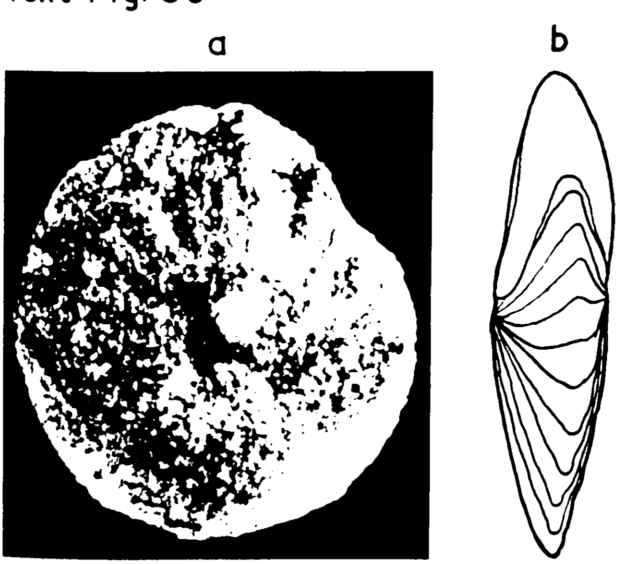



DIAGRAM SHOWING PRODUCTION OF ENDOTHYRA OBLIQUA (BRADY) BY CRUSHING OF MILLERELLA ORNATA.

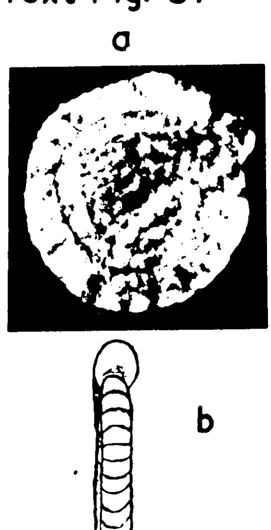
Text Fig. 36




1 MM

MILLERELLA TENUIS (BRADY) – a. LATERAL VIEW;
b APERTURAL VIEW - DIAGRAMMATIC.

Text Fig. 37




0·5 MM

MILLERELLA? AMMONOID-
-ES (BRADY); a. LATERAL
VIEW; b. APERTURAL VIEW
- DIAGRAMMATIC.

to M.ornata but with last 1½-2 whorls showing a distinct alteration, due to marked change in plan of growth. Later whorls have much greater relative height than that of earlier part and test involute. About 23 chambers in final whorl with 18 in penultimate. Externally chambers are long, thin, tapering to umbilici; in median section they have a squarish outline in earlier part and become sub-rectangular in final whorls. Proloculum circular, diameter 0.04mm.

Early sutures single, slightly curved, thin, depressed lines but in final part become thick, broad, limbate, and show as radial costae on surface of test. Change in growth plan has corresponding change in form of septa which becomes relatively much thinner in later part, though radial arrangement and low septal aperture maintained throughout. Periphery sharply angular and margin carinate. Surface smooth. Wall of granules of calcite bound by calcareous cement; no pores or adventitious material. Apertural details not known.

Depositories etc:

Holotype: Brady Collection, British Museum (Nat.Hist.) Slid P.35470, from "Foraminiferal Beds, Leigh Woods, Bristol, England".

Dimensions:

| | Max.Diameter. | Min.Diameter. | Thickness. |
|---|---|---|---|
| Holotype. Figured-Brady Pl.VI.fig.7. | 0.97mm. | 0.74mm. | 0.21mm. |
| Scottish Specs. (Average of 12). | 0.94mm. (Range 0.81 - 1.07mm). | 0.84mm. (Range 0.71 - 0.97mm). | 0.24mm. (Range 0.21 - 0.27mm). |

Distribution: Characteristic of the upper part of the Calciferous Sandstone Series and the Hurlet horizon in Scotland but range in English areas is unknown.

Remarks: The syntypes of M.ornata var.tenuis Brady include crushed specimens of M.ornata (Brady) and representatives of M.tenuis sp.nov. The latter is a very easily distinguished form and bears a resemblance to Fusulinella struvii Moller. Howchin's M.radiata var.tateana is included as a synonym.

Millerella? ammonoides (Brady) (1873 p.63).

Text fig.37.

Endothyra ammonoides Brady 1873.

Description: Test free, relatively small, of a complanate or biconcave form, laterally compressed and discoidal. Coiling planispiral throughout with whorls only slightly embracing; hence test evolute with broad shallow umbilicus on either side and bilaterally symmetrical. Presence of dimorphism suspected for some forms show a degree of axial rotation of coiling in first half whorl after proloculum.

Whorls increase very slowly in height and embrace each other up to about one-quarter of this height; number 10 in adult tests and each contain large number of small, slightly inflated, cuboidal chambers; some 23 chambers in final whorl. In early part sutures thin, depressed lines but in later portion depressed, much broader, and possibly limbate with a sutural curvature away from the apertural region. Septa extend down about three-quarters height of whorl and are about one-quarter width of adjacent chambers in thickness. Peripheral margin smoothly rounded and outline lobulate. Surface smooth. True nature of wall-structure unidentifiable - all sections examined recrystallised. Terminal, apertural face, shield-like and slightly inflated; aperture very low lunate opening at base.

Dimensions:

| | Max. Diameter. | Min. Diameter. | Thickness. |
|---|---|---|---|
| Figured spec. Brady Pl.V., Fig.6. | 0.57mm. | 0.54mm. | 0.11mm. |

The Scottish specimens tend to be smaller than this and there is a definite size change between those of the Lower Limestone Group and those of the Upper Limestone Group, the latter being much smaller.

Distribution: This is a relatively rare form occurring throughout the Limestone Groups of the Scottish Area and the greater part of the English sequence.

Remarks: As Wood (1949) points out the section figured by Brady (Pl.V., fig.6.) is undoubtedly altered and neither Mr.A.G.Davis nor myself have discovered a non-recrystallised specimen. This may indicate a basic difference in wall-structure from the Endothyrinae.

This species does not appear to be closely related to any of the known forms, and, in view of the usual condition of the wall, may belong to an unknown genus possibly representing an aberrant specialization as in the case of *Paraendothyra*. Until accurate details of the wall-structure are known I have tentatively referred the species to *Millerella*.

# CHAPTER XII.

# BRADYININAE.

## The Recognition of the Bradyininae.

I have outlined in the previous chapter the major groups of the Endothyridea and divided the Endothyridae into the Bradyininae and the Endothyrinae. In contrast to members of the latter group the Bradyininae possess a very much thicker perforate wall in which adventitious material is present to a varying degree, together with the normal calcareous material and cement. Other morphological differences include the mode of septation and the prevalence of the cribrate form of aperture in the Bradyininae.

Indeed the differences between the two groups are, in many ways, sufficient to indicate a greater dissimilarity than that usually recognised between sub-families. However the intermediate characters of Endothyranopsis seem to indicate that the Bradyininae are an early specialisation from the endothyrid stock.

## The Systematic Palaeontology of the Bradyininae.

The genera recognised in Britain as forming this sub-family are listed below together with notes on their morphology, ontogeny, and taxonomy. Descriptions of the certain species occurring in the Lower Carboniferous of Britain are included. In addition a large number of specimens of new species of the genera listed below have been found but await further study.

Endothyridea Glaessner.

Endothyridae Glaessner.

Bradyininae nov.

Genus BRADYINA Moller 1878.

Type species: Bradyina nautiliformis Moller (1878 p.78).

Bradyina Moller 1878.
Nonionina (part) Eichwald 1860.
Lituola (part) Brady 1876 (non Lamarck 1804).

Description: Test free, subspherical, close-coiled in a very low trochoid spire, mostly involute, almost bilaterally symmetrical in adult; consisting of few whorls and chambers; wall calcareous, of granules of calcite with much calcareous cement and often including adventitious material, coarsely perforate. (Cushman records chitinous inner lining). Chambers partly divided by interseptal chamberlets or canals formed by septa and one or two converging septal lamellae (pre- and post-septal) or by septal formation as infolding of outer wall; canals communicating with umbilical chamberlets; aperture compound, of a lower and an upper row of rounded pores or slits, or cribrate; supplementary series around septal line communicating with septal chamberlets.

Distribution: This genus is known throughout the Carboniferous and Permian and has a world-wide distribution. In the North-western Province of Britain it appears for the first time in the middle of the Lower Carboniferous and becomes increasingly abundant in the succeeding horizons and in the equivalent beds of the Scottish Area.

Remarks: The ontogeny of Bradyina is somewhat complex and requires further study. The internal structure of the test has been described in detail for various species by Rauser-Chernoussova and Reitlinger 1937, Roth and Skinner 1930, Venukoff 1889 and von Moller 1878.

Two types of growth or septal elaboration are present in the genus (see Text fig.38). The first of these has been described by Venukoff 1889 in Bradyina potanini. During the addition of a new chamber the apertural face is broken down or resorbed to a point short of the upper row of perforations. The new outer wall grows forward for some distance from the foreshortened end of the apertural face and then, with inflation, swings into a convex curve. In this way a double septum is produced by the extension inwards of the walls of the two chambers. Between these two sides of the septum lies a sutural chamberlet or canal connected to the main chambers by perforations and covered exteriorly by a septal flap bearing sutural pores.

The second type of growth has been demonstrated by Roth and Skinner 1930 in Bradyina magna. After the breakdown or resorption of the septal face the outer wall forms in much the same manner as in the Endothyrinae. The development is complicated, however, by the formation of a pre-septal or post-septal lamina or by both which serve to seal off a sutural chamberlet. This is linked to the main chamber by perforations in the lamina and may or may not communicate with the exterior by sutural perforations.

<u>Bradyina rotula</u> (Eichwald) (1860 p.281).

Text fig. 39.

<u>Bradyina rotula</u> (Eichwald) 1860. Moller 1878.
<u>Nonionina rotula</u> Eichwald 1860.
<u>Lituola bennieana</u> Brady 1876.

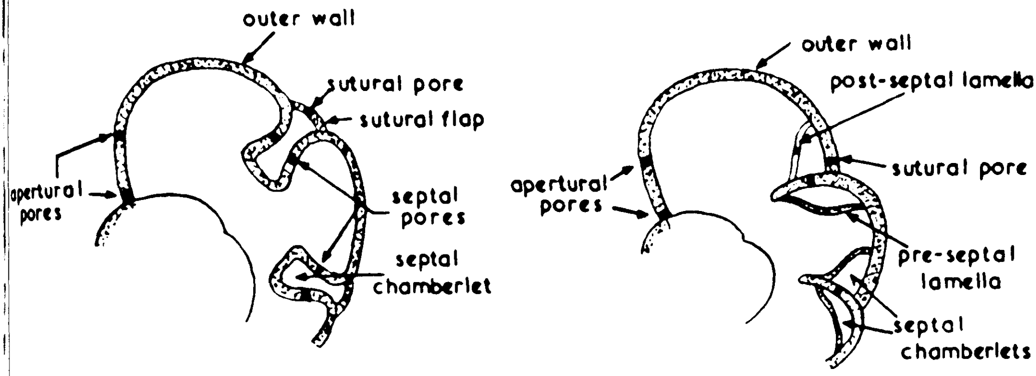
In <u>Lituola bennieana</u> Brady 1876, the feature which Brady regarded as labyrinthic structure is merely the result of the infilling of the interior of the test by secondary percolation. The species is therefore included in <u>Bradyina</u> and regarded as a synonym of <u>Bradyina rotula</u>. Moller (1878) included <u>Lituola bennieana</u> under his <u>Bradyina nautiliformis</u> but there are obvious differences of external form and in the number of chambers in the final whorl.

British specimens of <u>Bradyina rotula</u> are usually highly weathered, casts being common, and it is often difficult to study details.

In Scotland the species has been noted at a number of localities in both the Upper and Lower Limestone Groups. In the North-Western Province it appears for the first time in the Productus corrugato-hemisphericus Zone and is particularly common in the lower part of the Dibunophyllum Zone.

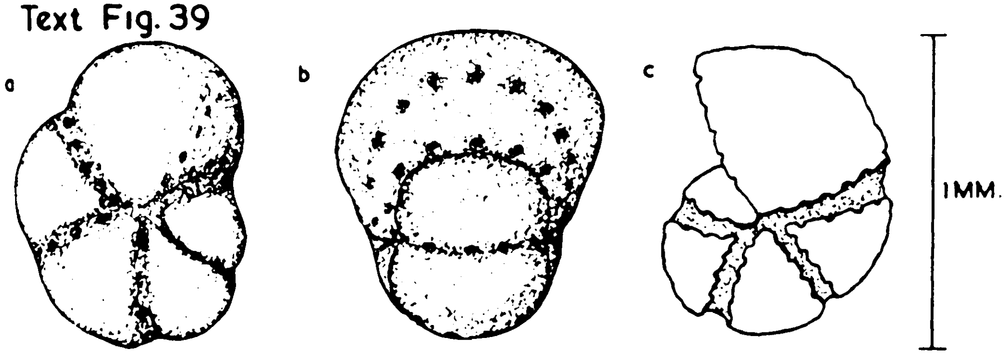
# BRADYININAE

## Text Fig. 38 Modes of Septal Growth in Bradyina



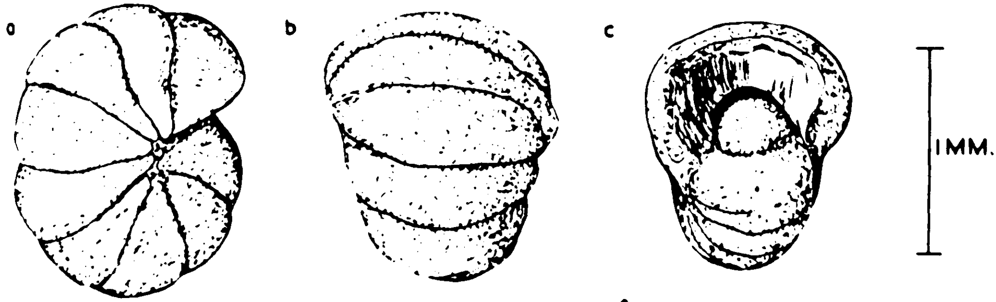

a AS SEEN IN BRADYINA POTANINI    b AS SEEN IN BRADYINA MAGNA

## Text Fig. 39




BRADYINA ROTULA (EICHWALD) a LATERAL VIEW; b APERTURAL VIEW; c DIAGRAM OF INTERNAL CAST

## Text Fig. 40




ENDOTHYRANOPSIS CRASSUS (BRADY) a LATERAL VIEW; b PERIPHERAL VIEW; c APERTURAL VIEW

Genus CRIBROSPIRA Moller 1878.

Type species: Cribrospira panderi Moller (1878 p.86).

Cribrospira Moller 1878
? Lituola Howchin 1888.

Description: Test free, mostly involute, usually bilaterally symmetrical in the adult, wall-structure as in Bradyina but differs from latter in having cribrate aperture of numerous, small, rounded pores scattered over the apertural face.

Distribution: Definite records of Cribrospira are known only from the Lower Carboniferous of Russia since the Cretaceous record by Cushman is open to question.

Remarks: Eimer and Fickert 1899 included Endothyra panderi Moller 1879 under this genus as Cribrospira moelleri. Recently, however, Endothyra panderi has been grouped under the genus Haplophragmella by Rauser-Chernoussova and Reitlinger 1936.

Cribrospira? rotundata (Howchin) 1888.

Lituola rotundata Howchin 1888.

Since the type specimens have not been examined this species can be referred only doubtfully to the genus Cribrospira. It is obvious from Howchin's description and figure that there is no labyrinthic structure in the interior of the test and hence this form cannot be placed in the genus Lituola. On the other hand the general form, the chamberal shape and number, and the position of the compound cribriform aperture indicate a close similarity to Cribrospira.

Genus ENDOTHYRANOPSIS gen.nov.

Type species: Involutina crassa Brady (1869 p.379).

Involutina (part) Brady 1869
Endothyra (part) Brady 1876 and authors.

Description: Test free, large, subglobular; coiled in a low trochoid spire so that test has slightly asymmetrical form. Relatively few whorls and moderate number of chambers. Wall granular calcareous bound by calcareous cement, with perforations and some adventitious material. Aperture low, crescentiform opening at base of apertural face.

Distribution: A characteristic genus of the upper part of the Lower Carboniferous of Britain and occurring at similar levels in Russia.

Remarks: This genus differs from members of the Endothyrinae in several features including the thickness and composition of the wall, the mode of coiling, the number and form of the chambers, and possibly also in septal construction. Its inclusion within the Bradyininae is warranted by its obvious similarity to other members of the sub-family.

Although only the type species is now described, other species of the genus display a wide range of variation which requires further study. The species listed below are included in this genus provisionally until type material can be examined:-

*Endothyra conspicua* Howchin 1888.

*Endothyra crassa var. compressa* Rauser-Chernoussova and Reitlinger 1936.

*Endothyra crassa var. sphaerica* Rauser-Chernoussova and Reitlinger 1936.

*Endothyranopsis crassus* (Brady) (1869 p.379).

Text fig. 40.

*Involutina crassa* Brady 1869
*Endothyra crassa* Brady 1876 and authors.

**Description:** Test free, nautiloid, relatively large, subglobular, and slightly asymmetrical. Coiled in a low trochoid spire, involute on one side and with shallow, indistinct umbilical depression on other.

Three whorls present, increasing moderately in height and almost completely involute. Microspheric form may possess a degree of axial rotation of coiling in initial part but further study required. Proloculum varies in diameter from 0.02 - 0.05mm. Some 28-35 chambers in complete test with ten in final whorl. Chambers crescentiform, with maximum dimensions on peripheral margin and tapering towards umbilical region; in median section have squarish outline; no marked inflation.

Sutures inconspicuous slightly depressed lines which are crenulated in parts and loose identity towards umbilici. Septa vary in shape from periphery to umbilicus, aligned almost radially, extend down some two-thirds height of whorl and have breadth some one third that of adjacent chambers; relatively thinner on peripheral margin than at umbilicus. Septal aperture lunate and does not extend to umbilicus.

Peripheral margin broadly and smoothly rounded and little or no lobulation. Surface roughened. Wall composed of granules of calcite bound by calcareous cement with adventitious material (usually quartz-grains) and perforate. Apertural face, broad, convex, slightly inflated shield with aperture, low, lunate opening at base.

Dimensions:

| | Max.Diameter. | Min.Diameter. | Thickness. |
|---|---|---|---|
| Brady Collection Figured.Pl.V,fig. 16 - 17. | 1.41mm. | 1.29mm. | 0.91mm. |
| Scottish Specs. Average of 20 | 1.34mm. (Range 0.92 - 1.74mm). | 1.14mm. (Range 0.83 - 1.58mm). | 0.83mm. (Range 0.57 - 0.98mm) |

Distribution: In Scotland this species is confined to the Lower Limestone Group. It is very characteristic of the Hockra Limestone in the west of the Midland Valley and of the No.2.Limestone in the east. In the North-Western Province it appears for the first time in the Productus corrugato-hemisphericus Zone and ranges upwards into the lower part of the Dibunophyllum Zone.

# PART C. DISTRIBUTION.

## CHAPTER XIII

## FACIES.

This account of the distribution of the Lower Carboniferous smaller foraminifera is based on results from three areas: Scotland, North-Western England, and the Gower Peninsula.

### OCCURRENCE.

Although much work remains to be done in both systematics and stratigraphy, the results so far obtained afford reasonable grounds for using the foraminifera for correlation by assemblage. The effects of diagenesis have been shown to be a factor in the control of apparent numbers; but of much greater influence on occurrence are the mode of evolution of the group and the environment of deposition. Many previous authors have regarded the distribution of Carboniferous foraminifera as being entirely a reflection of the environment of the containing sediment and hence as being facies fossils of little stratigraphical value. Sufficient evidence has been obtained, however, to show that this view is substantially incorrect. Although foraminifera are absent from many types of Lower Carboniferous sediments, the recognition of three biomes within the facies in which foraminifera are present and the tracing of a time sequence of changing assemblages within these biomes lead to the definition of broad zones which are of major stratigraphical importance.

CARBONIFEROUS FORAMINIFERAL BIOMES

Of the many and varied sedimentary types which are devoid of foraminifera in the Lower Carboniferous the rudaceous, arenaceous, and carbonaceous form the greater part.

It should be stressed that absence of fauna does not necessarily mean inimical environment of sedimentation. Foraminifera are relatively rarely preserved in the Athyris glabristria Zone but this can be shown to be due to destruction of the original fauna by diagenetic processes.

Within the fossiliferous sediments three main types may be recognised, each possessing a distinctive grouping of foraminifera.

(i). The Calcareous Biome.- The limestones and highly calcareous shales contain a fauna in which the Endothyridae are the dominant group.

(ii). The Argillaceous Biome.- The calcareous clays and some of the shales have members of the Tetrataxinae and the archaediscids as the predominant forms.

(iii). The "Carbonaceous" Biome.- Within the marine bands of lagoonal and swamp areas, where the sediment is highly carbonaceous, the clays, shales, and ironstones often contain species of the

Ammodiscidae.

Between the faunas of the argillaceous and calcareous biomes there is a good deal of overlap which assists in stratigraphical correlation. These two biomes cover the greater part of the Avonian sequence in Britain.

The fauna of the "carbonaceous" biome is distinct from the other two and no examples are known where overlap occurs. As might be expected this biome is predominant in coal measures, being recorded from the Pennsylvanian, and from the Upper Carboniferous of Britain and Germany where Bartenstein (1950) regards its presence as indicative of marine incursions.

## CHAPTER XIV

## DISTRIBUTION OF THE LOWER CARBONIFEROUS FORAMINIFERA OF SCOTLAND.

Although it is not possible as yet to present a complete summary of the distribution of the smaller foraminifera in the Lower Carboniferous rocks of Scotland, since much remains to be done in systematic and phylogenetic studies and in the effects of facies control, what is known of the distribution is already of stratigraphical value. This is shown in Table E, based on some 22,000 specimens from 97 localities. Minimising the effect of facies control by incorporating records from a wide range of sedimentary types, I have included consolidated and unconsolidated material.

Although there are indications that an assemblage zoning of the whole sequence may be possible at a later date, the main stratigraphical value of this table lies in its distinction of the lower part of the Lower Limestone Group from the under-lying and overlying formations. To confirm this result a further 12,000 specimens from 45 localities have been used in the comparison of this interval in the west with members of the Lower Limestone Group in the east of the Midland Valley.

### GENERAL DISTRIBUTION.

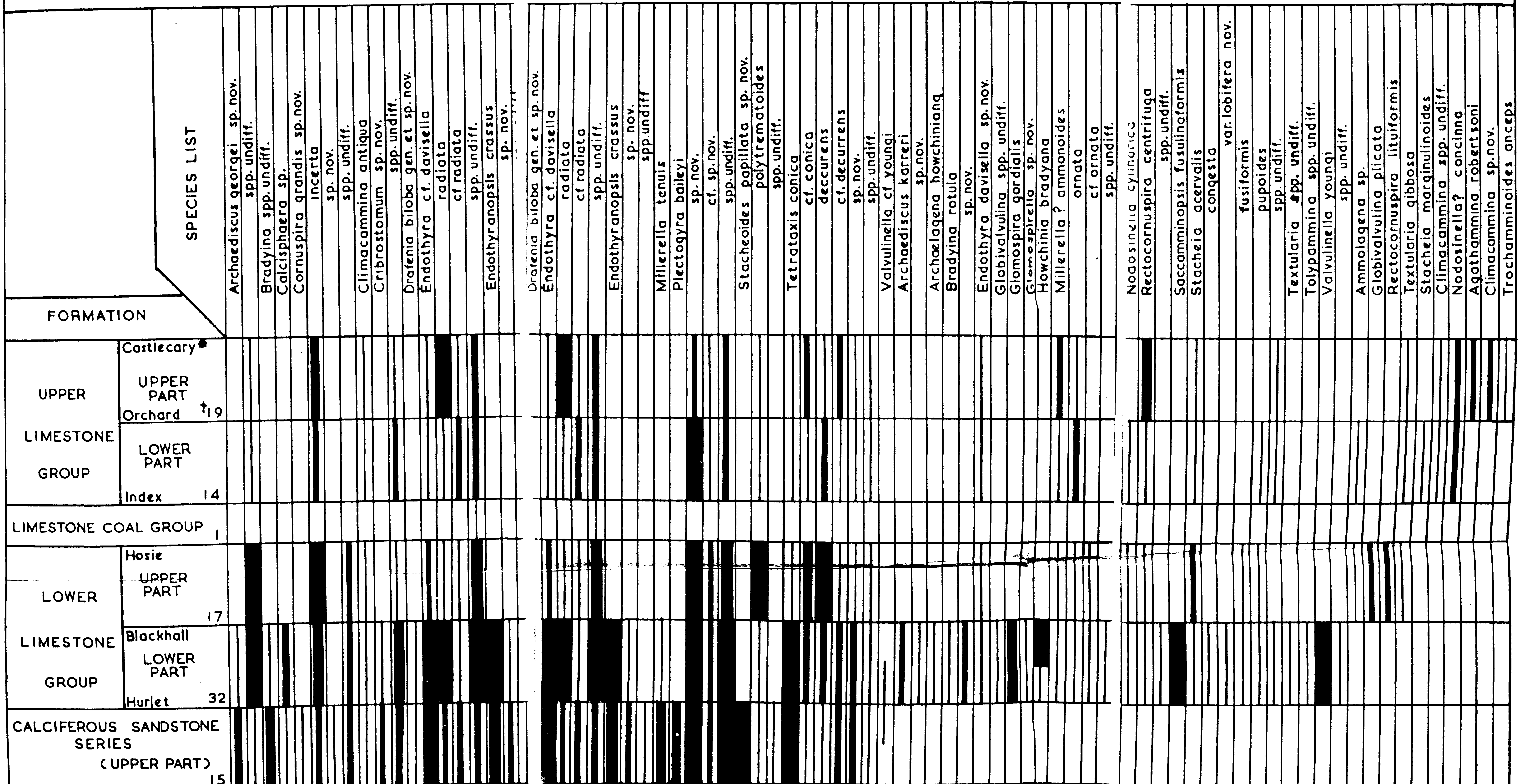
The results shown in Table E are based chiefly on material from localities of known stratigraphical horizon in the sequences of Ayrshire and Lanarkshire. At present it is possible to refer foraminiferal faunas to the upper part of the Calciferous Sandstone Series, to the lower part of the Lower Limestone Group, and to the upper part of the Upper Limestone Group; but it is not possible to distinguish the upper part of the Lower Limestone Group from the lower part of the Upper Limestone Group.

<u>Calciferous Sandstone Series - The Broadstone Assemblage</u>

As yet the greater part of this series has yielded no trace of foraminifera. Thus sampling of the Ballagan Beds at the fossiliferous locality in Auchenreoch Glen, of the Sandersone Limestones of the East Fife succession, and of the Burdiehouse Limestone and marine bands of Midlothian has produced only negative results. The absence of foraminifera is largely due to facies control since almost none of the sequence is truly marine in the sense of the overlying Lower Limestone Group. The carbonaceous biome might be expected however, since it is characteristic of lagoonal and swamp areas and is known from the marine bands of Nottingham and Derbyshire (Edwards and Stubblefield, 1948 p.209).

In the uppermost part of the Calciferous Sandstone Series the true marine horizons lying below the Hurlet Limestone, including the Broadstone Limestone of Ayrshire

TABLE E. General Distribution of F›ution of Foraminifera in the Lower Carboniferous c f Scotland.




* Relative position.

† No. of localitie· lo. of localities examined.

rare; present; common; abundant;

and the Hollybush Limestone of Lanarkshire, yield an abundant and characteristic assemblage - the Broadstone Assemblage. This contains a larger percentage of the Bradyininae and the Textulariidae than those of overlying formations and is outstanding in the large size of many of the species present - a feature not wholly conditioned by environment. Especially characteristic of this assemblage are the following species: Cornuspira grandis, Endothyranopsis sp.nov., Millerella tenuis, Plectogyra baileyi, and Stacheoides papillata. Other species of Bradyina, Cribrostomum, and Climacammina appear to be confined to this assemblage but require further study. Stages of the various phylogenetic lines noted in earlier chapters are present also and assist in fixing the stratigraphical position of faunas of this type. Thus the archaediscids reveal a stage midway between Archaediscus georgei and A.karreri, the latter being characteristic of the lower part of the Lower Limestone Group. Again, in the highest layers of the series, such as the Wee Post Limestone of Ayrshire, Valvulinella cf.youngi is present and is the transitional form between Tetrataxis and Valvulinella, the latter an important member of the over-lying "Hurlet Assemblage".

Lower Limestone Group. This is divisible at present into two parts on the basis of foraminiferal assemblage;

the boundary between the two lying at the top of the Blackhall Limestone in the west.

<u>Lower Part</u> - <u>The Hurlet Assemblage</u>. Within this interval the British foraminifera reach the acme of their development, both numerically and in variety of form, and this distinctive Hurlet Assemblage has been recognised as marking the same stratigraphical horizon throughout Scotland, North-Western England, and parts of South Wales. Although many species are common to both this and the underlying Broadstone Assemblage the distinction between the two is marked by the incoming of a large number of new forms. Many of these are members of the Endothyrinae which dominate the assemblage but there are also present such problematical forms as <u>Archaelagena howchiniana</u>, <u>Calcisphaera sp.</u>, and <u>Brafenia biloba</u>. Amongst the most important species are <u>Archaediscus karreri</u>, <u>Archaediscus</u> sp.nov., <u>Bradyina rotula</u>, <u>Saccamminopsis fusulinaformis</u>, <u>Stacheia congesta</u> var. <u>lobifera</u>, and <u>Valvulinella youngi</u>, all confined to this assemblage, whilst <u>Endothyra daviesella</u> and the various species of <u>Stacheia</u> appear for the first time. Towards the top of the interval <u>Howchinia bradyana</u> rapidly becomes a dominant form in the eastern Scottish areas but is unknown as yet in the west. This last species has been noted by Davis (1945, p.312) as characteristic of the B2 - P2 beds of the Alport boring in Derbyshire.

Upper Part - "The Hosie Assemblage". One of the most outstanding features of the distribution of foraminifera in the Scottish sequence is the rapid impoverishment of assemblage which begins above the Hurlet horizon and continues into the Upper Limestone Group. This impoverishment is reflected in the Hosie Assemblage and may create difficulties in the superficial distinction between it and a poorly developed Hurlet Assemblage. These difficulties are partly overcome by the recognition of new species characteristic of the Upper Part of the Lower Limestone Group, the great majority of which however require further study. Present criteria used in the recognition of the Hosie Assemblage include the presence of such characteristic species as Globivalvulina plicata and Rectocornuspira lituiformis; the phylogenetic stages of the Endothyrinae; and finally the absence of the diagnostic species of the Hurlet assemblage.

Limestone Coal Group. Recently endothyrid foraminifera have been recognised in the Johnstone Shell Bed. This is the only record from the formation, by far the greater part of which has proved unfossiliferous.

Upper Limestone Group. Although this formation may be subdivided into an upper and a lower part on the basis of foraminiferal assemblage the distinction of the fauna of the lower part from the Hosie Assemblage is almost impossible at the present time.

Lower Part - The present inability to recognise differences between the fauna of this interval and that of the upper part of the Lower Limestone Group may be due to inadequate study. The progressive impoverishment of fauna begun at lower horizons continues. The endothyrids are marked by the prevalence of planispirally coiled forms, such as Millerella ornata, and such previously important groups as the archaediscids become very much reduced in numbers, their place being taken by members of the Ammodiscidae.

Upper Part - The Calmy Assemblage. About the level of the Orchard Limestone there occurs a marked change in faunal pattern with the introduction of an entirely new faunistic group in many ways closely similar to that of the American Pennsylvanian. In the underlying formations assemblages display variations in which the Endothyrinae, the Bradyininae and the archaediscids comprise the greater part of the fauna. In the Calmy Assemblage, however, previously important families are absent or very much reduced, while the Ammodiscidae become predominant. Thus such species as Agathammina robertsoni, Hectocornuspira centrifuga, Cornuspira incerta, and Trochamminoides anceps are especially characteristic of the interval. It is possible that this marked change heralds the introduction of the carbonaceous biome of the Coal Measures but it is interesting to note that no similar change occurs below the Limestone Coal Group as might be expected if this were solely due to facies control.

# CHAPTER XV.

## ASPECTS OF FORAMINIFERAL DISTRIBUTION IN THE NORTH-WESTERN PROVINCE

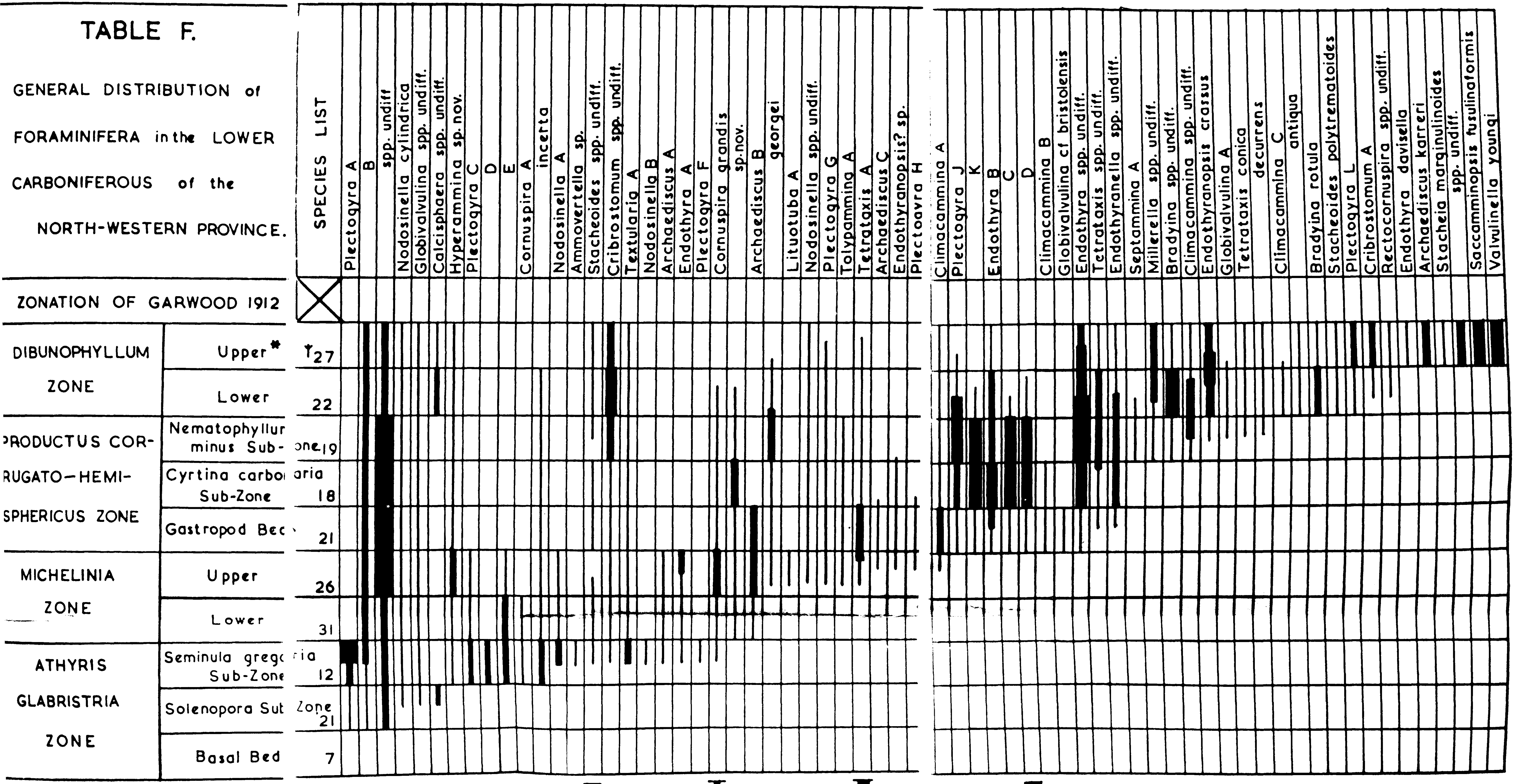
Supplementary to the main study in the Scottish areas, research has been conducted in the Avonian sediments of the North-Western Province with two main objects: to assess the stratigraphical value of the distribution of smaller foraminifera in an area where a considerable part of the Avonian sequence is represented, and to establish a correlation between the Scottish and Northern English areas.

### DISTRIBUTION IN THE NORTH-WESTERN PROVINCE.

A chart of the distribution of the smaller foraminifera in the Avonian sediments of this region is shown in Table F. One of the features of Brady's work is that most of the species he described came from localities in the upper part of the Avonian. Since the systematics of the present study is largely confined to a revision of Brady's work most of the species described in Part B are confined to the upper Avonian. This leads not only to a very common mention of such horizons as the Hurlet Limestone and the Dibunophyllum Zone in the species descriptions of Part B but also limits the systematics description of many of the new forms noted in the lower part of the Avonian

# TABLE F.

GENERAL DISTRIBUTION of FORAMINIFERA in the LOWER CARBONIFEROUS of the NORTH-WESTERN PROVINCE.




No. of samples; * Includes only lowermost beds; rare; present; common; abundant;

sequence of Westmorland; and for the time being these new forms are described as <u>Plectogyra A</u>, <u>Endothyra B</u>, etc. Table F is based on some 8500 specimens from the Shap, Kendal, Kirkby Lonsdale, and Grange-over-Sands areas of the North-Western Province (Garwood, 1912).

The lower part of the Athyris glabristria Zone, comprising the unfossiliferous Basal Beds, the Solenopora Sub-Zone, and the Seminula gregaria Sub-Zone up to the Thysanophyllum Band, contains a very poor fauna frequently destroyed by dolomitisation. This fauna is made up almost entirely of small, primitive species of <u>Plectogyra</u> showing few chambers, a simple wall-structure, and no secondary deposits. The only other foraminifer of note is <u>Nodosinella</u>, though some doubtful forms, tentatively referred to <u>Calcisphaera</u> though they may later prove to belong to the genus <u>Archaesphaera</u>, are also present. A similar fauna to this has been seen in the Caninia Oolite of Gower and in lowermost Main Limestone of Breconshire though no attempt can be made to correlate the areas.

About the level of the Thysanophyllum Band in the North-Western Province a new assemblage may be recognised in the first appearance of a large number of new forms. These include species of <u>Nodosinella</u>, <u>Cribrostomum</u>, and <u>Textularia</u>. The fauna is still on the whole rather poor in numbers; the dominant members are the plectogyrids, which are slightly larger and somewhat more advanced than hitherto. This assemblage continues upwards to almost the top of the Seminula gregaria Sub-Zone.

A well-marked and abundant assemblage of foraminifera occupies the interval ranging from slightly below the base of the Michelinia Zone to slightly below its top. The Endothyrinae are the most common members of the assemblage. The species of Plectogyra become larger and more complicated in structure, and representatives of Endothyra appear for the first time. In this zone the archaediscids become important, and such genera as Bradyina and Tetrataxis make their first appearance as small and very primitive species. Similar assemblages are found in the South-Western Province in sediments of C2S1 age.

The next major faunal break takes place about the level of the Clisiophyllum multiseptatum Band in the uppermost layers of the Michelinia Zone, the new assemblage being present in all horizons throughout the Productus corrugato-hemisphericus Zone except in the upper half of the Nematophyllum minus Sub-Zone. This new assemblage is extremely abundant, over ninety per cent of the forms present belonging to the Endothyrinae and the Bradyininae. Many new species of Plectogyra, Endothyra, Septammina, and Endothyranella occur. The plectogyrids and the endothyrids both become relatively very large and complicated in structure and the supplementary deposits in the wall of the former reach a high degree of development. This assemblage can also be recognised in beds of S2 age in the Gower Peninsula.

The succeeding foraminiferal assemblage appears in the middle part of the Nematophyllum minus Sub-Zone. The dominant forms of this fauna, which ranges up towards the top of the Lower Dibunophyllum Zone, are members of the Bradyininae and Textulariidae, many of which are new species; and it is in this assemblage that specimens of Endothyranopsis become common. Nevertheless there is a wide variety of kinds and such groups as the Tetrataxinae become increasingly important. In its normal development this assemblage is closely similar to the faunas of the Calciferous Sandstone Series recorded from the Closeburn and Penton Linn areas of Dumfriesshire; in the upper beds it becomes almost identical with the Broadstone Assemblage of the Scottish succession.

The final change in fauna recognised occurs at an horizon slightly above the boundary between the Lower and Upper parts of Dibunophyllum Zone, immediately above the base of the Lonsdale floriformis Sub-Zone. Here the "Hurlet Assemblage" appears for the first time, indistinguishable in character from its typical development in the Scottish areas and containing all the diagnostic species including

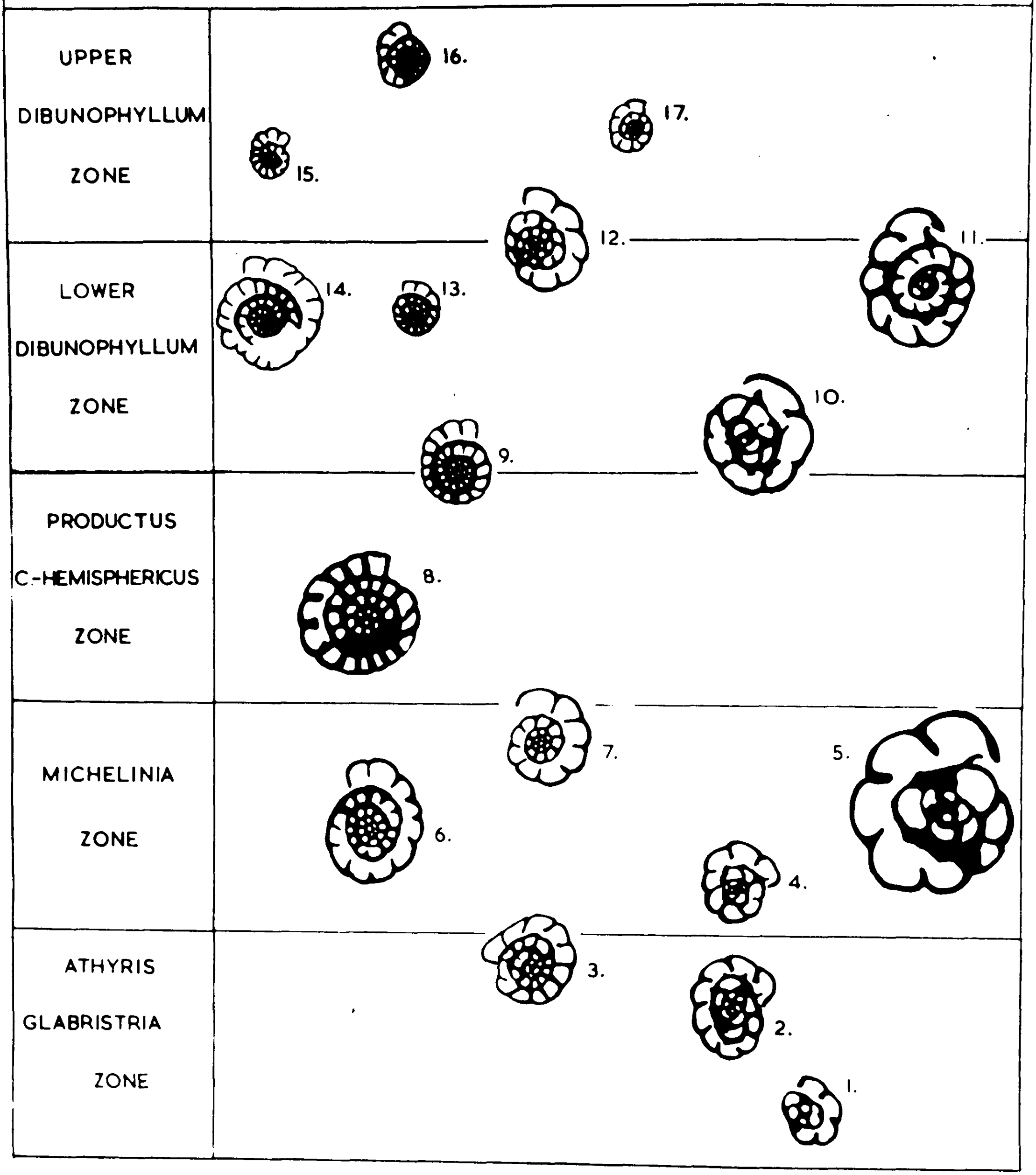
Archaediscus karreri, Brunsia rotula, Valvulinella youngi and Saccammina inopsis fusulinaeformis. The contrasted lithological facies in which this assemblage occurs - of the Yoredale type in the Kirkby Lonsdale area and of a calcareous nature in the Shap, Kendal and western areas - proves it to be not merely of facies significance but a basis for a reliable correlation between the base of the Lower Limestone Group in Scotland and the base of the upper part of the Dibunophyllum Zone.

THE EVOLUTION OF THE ENDOTHYRINAE IN THE AVONIAN.

Morphogenetic changes in the Endothyrinae in the foraminiferal assemblages of the North-Western Province have been noted above. Since the group is present throughout the entire Avonian of all areas examined and exhibits marked morphological and phylogenetic changes it is of great value in stratigraphy.

In Text fig.41 I have summarised the changing characteristics of the Endothyrinae as seen in thin-sections of limestone throughout the North-Western and Scottish Lower Carboniferous. This serves to show the development along the phylogenetic line Plectogyra - Endothyra - Millerella and the variation in size of some groups, a variation which does not appear to reflect simply environmental modification. When this chart is compared with Zeller's (1950, Pl.6) of the evolution of the American Mississippian Endothyrinae

Text Fig. 41 DEVELOPMENT OF THE ENDOTHYRINAE - as seen in thin section.



many close similarities in the pattern of evolution can be observed.

## THE VALUE OF SACCAMMINOPSIS FUSULINAFORMIS.

Frequent reference has been made to *Saccamminopsis fusulinaformis* M'Coy - the *Saccammina carteri* of authors - in the discussion of stratigraphy. This problematical form which can be referred only doubtfully to the foraminifera is recorded from the Ordovician and has been identified in the Silurian by the present author. Previous workers have recognised the Saccammina carteri Band as being of great importance in the correlation of the Avonian sediments of Northern England and Scotland (Garwood, 1912 p.449; Macgregor, 1929). Others have denied the value of the form and have pointed to records of it occurring outside the normal D2 position usually ascribed to it (Hartley, 1936).

In the present study close attention has been paid to the occurrence of this form in the Carboniferous and many earlier records have been checked. The revision has shown that it has been confused in the past on more than one occasion with silicified casts of ostracoda, with another problematical form, *Brafenia biloba* gen.et sp.nov., and with ellipsoidal ironstone nodules. Thus records of it in the Gilmerton Limestone of Whitefield Quarry near Carlops, and of Hillhead Quarry near Penicuick are based on specimens of *Brafenia biloba*. Again the record from the 2nd Dalmy

Limestone of Braidwood (Brady, 1876) is incorrect since the material came from the Main Limestone.

It would appear that _Saccamminopsis fusulinaformis_ is characteristic of the D2 Zone in Northern England and Scotland and is also known at the same horizon in North Wales, the Isle of Man, and Ireland. Davis (1948) records it from P2a beds of the Alport boring in Derbyshire.

The stratigraphical occurrence of this form has been described by a number of previous authors. Ranging over a relatively short time interval it exhibits a maximum development about the middle of that interval. Therefore, whilst often abundant in one limestone band it may be present in several above and below as in the Fourth, Clint's Limestone of the Workington District (Mem. Geol. Surv. Expl. Sheet 28). In relation to the foraminiferal assemblage - the Hurlet Assemblage - it appears to reach its maximum development in the lower half of the interval covered and to appear for the first time after most of the other diagnostic forms.

# CHAPTER XVI

## COMPARISON OF FAUNAL SUCCESSION BETWEEN BRITAIN, THE U.S.A. AND THE U.S.S.R.

### COMPARISON OF FORAMINIFERAL DISTRIBUTION IN AMERICA AND IN BRITAIN.

No direct comparison between Britain and America is possible because of the almost complete absence of American Mississippian faunal studies, on the one hand, and of the British Upper Carboniferous on the other. Further complications arise from the tendency of American research to concentrate on the morphological aspects rather than the time significance of the faunas.

The one major exception is the recent study by Zeller (1950) on the stratigraphical significance of the endothyrid foraminifera of the American Mississippian. There is a marked similarity in the evolutionary pattern of the Endothyrinae illustrated by Zeller (1950, Pl.6) and the development of these forms in the North-Western Province and Scottish areas - as shown in Text fig.41. In both areas the lowermost Lower Carboniferous deposits contain representatives of *Plectogyra* which are small and simple in pattern. In both areas too these are succeeded by much larger forms of *Plectogyra* and by the development of *Endothyra* in the middle part of the Lower Carboniferous.

Finally in the Chesterian of the States and the Upper Avonian of Britain the plectogyrids become reduced in size but retain such features as the basal deposits, whilst the endothyrids give rise to the more primitive species of Millerella. Further study may show this similarity to be of long-range value in correlation for its general pattern is also recognisable in the southern Urals region.

COMPARISON OF DISTRIBUTION IN THE U.S.S.R. AND BRITAIN.

Since the greater part of Soviet research has been concentrated on the Lower Carboniferous a closer comparison with the British sequence of faunas is possible than in the case of America. This comparison is rendered difficult, however, by the inaccessibility of Soviet literature in this country and by the frequent nomina nuda which are employed.

Foraminiferal assemblages have been recognised at all horizons in the Lower Carboniferous of Russia and are being actively employed in a stratigraphical work. Using the results of many authors, including Rauser-Chernoussova (1938, 1939, 1940, 1944), Krestovnikov (1938), Suleimanov (1940), Tolstikhina (1935), Aisenverg (1946), Lee (1937), Mikhailov (1935), Khvorova (1935, 1937), Tchernysheva (1941) Petrenko (1935) and Reitlinger (1939), I have prepared a chart (Table G) of the generalised distribution of what

**TABLE G.** DISTRIBUTION OF IMPORTANT ZONAL FORAMINIFERA IN THE SOVIET LOWER CARBONIFEROUS.

(BASED ON THE WORK OF SEVERAL SOVIET AUTHORS)

| SPECIES LIST / HORIZON | "NAMURIAN" LOWER | "VISEAN" UPPER | "VISEAN" MIDDLE | "VISEAN" LOWER | "TOURNAISIAN" UPPER | "TOURNAISIAN" MIDDLE | "TOURNAISIAN" LOWER | 'ETROEUNGTIAN' |
|---|---|---|---|---|---|---|---|---|
| Archaesphaera magna | | | | | | | X | X |
| minima | | | | | | | X | X |
| Endothyra communis | | | | | | | X | X |
| primaeva | | | | | | | X | X |
| Parathurammina cuchmani | | | | | | | | X |
| dagmarae | | | | | | | | X |
| oldae | | | | | | | | X |
| Bathysiphon minima | | | | | | | X | |
| Hyperammina elegans | | ? | ? | ? | X | X | X | |
| Biseriammina uralica | | | | | | X | | |
| Endothyra glomoformis | | | | | | X | | |
| rjausakensis | | | | | | X | | |
| spinosa | | | | | | X | | |
| Paraendothyra nalivkini | | | | | | X | | |
| Spiroplectammina chernyshinensis | | | | | | X | | |
| parva | | | | | X | | | |
| Forschia subangulata | | | | X | | | | |
| Haplophragmella irregularis | | | | X | | | | |
| tetraloculi | | | | X | | | | |
| Lituotubella glomformis var. magna | | | | X | | | | |
| Hyperammina vulgaris | | X | X | X | | | | |
| Endothyra crassa var compressa | | X | X | X | | | | |
| omphalota var minima | | X | X | X | | | | |
| prisca | | X | X | X | | | | |
| similis | | X | X | X | | | | |
| tschernovi | | X | X | X | | | | |
| Haplophrugmella fallax | | X | X | X | | | | |
| Palaeotextularia dobroljubovae | | X | X | X | | | | |
| oblonga | | X | X | X | | | | |
| Endothyra omphalota | | | X | | | | | |
| Nanicella dainae | | | X | | | | | |
| Samgrina operculata | | | X | | | | | |
| Archaediscus bashkiricus | X | X | | | | | | |
| karreri | | X | | | | | | |
| molleri | | X | | | | | | |
| Bradyina rotula | | X | | | | | | |
| Endothyra crassa | | X | | | | | | |
| var. sphaerica | | X | | | | | | |
| globulus | | X | | | | | | |
| Monotaxis gibba | | X | | | | | | |
| Palaeotextularia lata | X | | | | | | | |

are regarded as the more important zonal fossils of the Russian succession. This covers the regions of the Donetz Basin, the Lwow Trough, Novaya Zemlya, and the very important area of the Southern Urals. I have adopted the Soviet use of the terms "Tournaisian", "Visean", etc., to ensure ease of reference but would point out that these stages may or may not coincide exactly with those in the type areas of Western Europe.

By reference to Table G and the relevant literature it can be shown that, allowing for differences in taxonomy, the foraminiferal faunal succession of the Lower Carboniferous in both countries is remarkably similar. The relatively poor fauna of the lower Avonian of Britain containing the precursors of the endothyrid plexus is closely paralleled in the "Tournaisian" of the U.S.S.R. by faunas largely composed of *Endothyra communis* and *Endothyra primaeva*. In the middle of the British Avonian there occurs the remarkable outburst of the endothyrid plexus and this can be seen in the "Lower and Middle Visean" records of Russia where, in addition to large numbers of species of *Endothyra*, allied genera such as *Haplophragmella*, *Nanicella*, *Staffella* and *Semarina* appear for the first time. In the Russian succession the "Upper Visean" is marked by the incoming of *Archaediscus karreri*, *Endothyra crassa*, *Bradyina rotula* and numerous species of *Climacammina* and *Cribrostomum*.

The parallel to this faunal assemblage in Britain is to be found towards the base of the upper part Dibunophyllum Zone of the North-Western Province and in the Hurlet Assemblage of the Scottish Lower Carboniferous.

# PART D. LIST OF REFERENCES.


1. AIZENVERG, D.E. 1946. "On the Carboniferous Deposits of the Lwow Trough". Comptes.Rendus (Doklady) Acad.Sci.U.R.S.S. Vol.LI. No.1.

2. BAILY, W.F. 1935. "Micropalaeontology and stratigraphy of the Lower Pennsylvanian of Central Missouri". Jour.Pal.Vol.9. pp.485-502.

3. BARTENSTEIN, H. 1950. "Micropalaeontological Research in European Upper Carboniferous Stratigraphy". Geol.Mag.Vol.LXXXVII, No.4.p.253.

4. BRADY, H.B. 1869. "Notes on the Foraminifera of Mineral Veins and the adjacent strata". Brit. Assoc.Report, Exeter Meeting.

5. BRADY, H.B. 1871. "On Saccammina carteri, a new Foraminifer from the Carboniferous Limestone of Northumberland". Ann.Mag.Nat.Hist.,ser.4. vol.VII.

6. BRADY, H.B. 1873. "On Archaediscus karreri, a new Type of Carboniferous Foraminifera". Ann.Mag. Nat.Hist., ser.4, vol.XII.

7. BRADY, H.B. 1874. "On a True Carboniferous Nummulite". Ann.Mag.Nat.Hist., ser.4, vol.XIII.

8. BRADY, H.B. 1876. "A Monograph of Carboniferous and Permian Foraminifera (the genus Fusulina excepted)". Pal.Soc.Monograph, pp.1-166, Pls. I-XII.

9. BROWN, T. 1843. "The Elements of Fossil Conchology". London.

10. BUCKLAND, W. 1841. "Notice of the Discovery of Fossil Foraminifera in the Mountain Limestone of England in 1839 by Messrs.Tennant & Darker". Abstrs.Proc.Ashmolean Society, Vol.1.

11. CHAPMAN, F. 1895. "On Rhaetic Foraminifera from Wedmore, Somerset". Ann.Mag.Nat.Hist., ser.6. Vol.XVI. p.305.

12. CHAPMAN, F. 1901. "On Some Fossils of Wenlock Age from Mulde, near Klintsberg, Gotland". Ann.Mag. Nat.Hist., Ser.7, Vol.V. pp.141-160.

CHEN, S. and CHU, S. - see LEE, J.S.

13. COOPER, CHARLES L. 1947. "Microfossils in Pennsylvanian Correlation". Journ.Geol., Vol.25, pp.241-9.

14. COOPER, CHARLES L. 1947. "Upper Kinkaid (Mississippian) Microfauna from Johnson County, Illinois". Jour.Pal. Vol.21, pp.81-94.

15. CRESPIN, I. 1948. "Foraminifera in Australian Stratigraphy". Int.Geol.Congress, 18th Session, Gt.Britain, Part XV.

16. CUMMINGS, R.H. 1950. "Oriented Thin-sectioning of Microfossils". Cont.Cush.Found.For.Res., Vol.1. pts.3 & 4, pp.66-67.

17. CUSHMAN, J.A. 1929. "The Term 'Arenaceous Foraminifera' and its meaning". Cont.Cush.Lab.For.Res., Vol.5, Pt.2, p.26.

18. CUSHMAN, J.A. 1930. "Some Notes on the Genus Patellina". Cont.Cush.Lab.For.Res., Vol.6, pt.1, p.29.

19. CUSHMAN, J.A. 1935. "Palaeozoic Foraminifera, their relationship to Faunas, and to their Environment". Jour.Pal., Vol.9, pp.284-287.

20. CUSHMAN, J.A. 1948. and earlier editions. "Foraminifera, their Classification and Economic Use". Harvard Univ.Press.

21. CUSHMAN, J.A. and WATERS, J.A. 1927. "Pennsylvanian Foraminifera from Michigan". Cont.Cush.Lab. For.Res., Vol.2, Pt.3, pp.107-110.

22. CUSHMAN, J.A. and WATERS, J.A. 1928. "Upper Palaeozoic Foraminifera from Sutton County, Texas". Jour.Pal.,Vol.2, No.4. p.358.

23. CUSHMAN, J.A. and WATERS, J.A. 1928. "Additional Cisco Foraminifera from Texas". Cont.Cush.Lab.For. Res., Vol.4, p.62.

24. CUSHMAN, J.A. and WATERS, J.A. 1930. "Foraminifera of the Cisco Group of Texas". Univ.Texas.Bull., 3019, pp.22-81.

25. DAVIS, A.G. 1945. "Appendix I. Micro-organisms in the Carboniferous of the Alport Boring", in R.G.S. Hudson and G.Cotton's "The Lower Carboniferous in a Boring at Alport, Derbyshire". Proc.Yorks.Geol.Soc., Vol.25, p.312.

26. [illegible]AVILLE, E. 1936. "Observations et Reflexions sur le genre Nubecularia". Bull.Soc.Geol.France, Ser.5, Vol.6, p.621.

27. EDWARDS, W. and STUBBLEFIELD, C.J. 1948. "Marine Bands and other Faunal Marker Horizons in relation to the Sedimentary Cycles of the Middle Coal Measures of Notts. and Derbyshire". Quart. Journ.Geol.Soc., Vol.CIII, pp.209-260.

28. EHRENBERG, C.G. 1843. "Note of a Communication on Polythalamia from the Mountain Limestone Hornstone of Tula, in Russia". Berichte.Konigl. Preuss.Akad.Wissenich.Berlin, p.79.

29. EHRENBERG, C.G. 1854. "Mikrogeologie; das Wirken des unsichtbaren kleinen Lebens auf der Erde". Leipsig.

30. D'EICHWALD, E. 1860. "Lethaea Rossica ou Paléontologie de la Russie. Vol.1. Ancienne Periode". Stuttgart.

31. EIMER, G.H.T. and FICKERT, C. 1899. "Die Artbildung und Verwandtschaft bei den Foraminiferen". Tubinger Zoo.Arbeiten. Band III, No.6, Leipsig.

32. ELLIS, B.F. and MESSINA, A. 1950 and earlier parts. "Catalogue of Foraminifera". New York.

FICKERT, C. - see EIMER, G.H.T.

33. GALLOWAY, J.J. 1933. "A Manual of Foraminifera". Bloomington, Indiana.

34. GALLOWAY, J.J. and HARLTON, B.H. 1928. "Some Pennsylvanian Foraminifera of Oklahoma, with special reference to the genus Orobias". Jour.Pal.Vol.2, No.4, p.338.

35. GALLOWAY, J.J. and HARLTON, B.H. "Endothyranella, a Genus of Carboniferous Foraminifera". Jour.Pal., Vol.[illegible] p.2[illegible].

36. GARWOOD, E.J. 1912. "The Lower Carboniferous Succession in the North-West of England". Quart.Jour.Geol. Soc., Vol.LXVIII, pp.449-586.

37. GEOL.SURVEY MEMOIR. Explanation of Sheet 28. "The Geology of the Whitehaven and Workington District".

38. GLAESSNER, M.F. 1945. "Principles of Micropalaeontology". Melbourne Univ.Press.

39. HALL, J. 1856. "Description of New Species of Fossils from the Carboniferous Limestone of Indiana and Illinois". Trans.Albany.Institute, Vol.IV.

40. HARLTON, B.H. 1928. "Some Pennsylvanian Foraminifera of the Glenn Formation of Southern Oklahoma". Jour.Pal., Vol.1. p.15.

41. HARLTON, B.H. 1928. "Pennsylvanian Foraminifera of Oklahoma and Texas". Jour.Pal., Vol.1., p.305.

HARLTON, B.H. - see also GALLOWAY, J.J.

42. HARTLEY, J.J. 1936. "On the occurrence of Saccamminopsis fusulinaformis in Northern Ireland". Irish. Nat.Journ.Vol.6, No.4.

43. HENBEST, L.G. 1931. "The Use of Selective Stains in Palaeontology". Jour.Pal., Vol.5, p.355.

44. HENBEST, L.G. 1931. "The species Endothyra baileyi (Hall)". Cont.Cush.Lab.For.Res.,Vol.7, pt.4, p.93.

45. HOWCHIN, W. 1888. "Additions to the Knowledge of Carboniferous Foraminifera". Journ.Roy.Micr.Soc.,Vol.VIII., p.533.

46. KELLY, W.A. 1930. "Lower Pennsylvanian Faunas from Michigan". Jour.Pal., Vol.4, p.129.

47. KHVOROVA, I.V. 1937. "Middle Carboniferous of the Western Slopes of the Urals in Southern Bashkiria and Orenburg Districts". Soc.Nat.Mosc.Bull., vol. 45, sec.geol., vol.15, pp.517-540.

48. KHVOROVA, I.V. 1939. "The Lower Carboniferous of the Western Slope of the Urals within Southern Bashkiria, Chkalov District and North Kazakhstan". Soc. Nat.Mosc.Bull.vol.47, sec.geol., vol.17. pp.53-84.

49. KRESTOVNIKOFF, V.N. and THEODOROVITCH, G.J. 1936. "Une nouvelle espece de foraminiferes du genre Archaediscus du carbonifere de l' Oural meridional". Bull.Soc.Nat.Mosc.,sec.geol. Vol.14, (1) p.86.

50. LEE, J.S. 1937. "Foraminifera of the Donetz Basin and their stratigraphical significance". Bull.Geol. Soc.China, Vol.16, p.57.

51. LEE, J.S., CHEN, S., and CHU, S. 1930. "Huanglung Limestone and its Fauna". Mem.Nat.Research Inst. Geol. (China), No.9, pp.85-144.

52. LE MAITRE, D. 1930. "Sur la presence d' algues et de Foraminiférés du genre Endothyra dans les calcaires d'age Devonian". Compt.Rend. Acad.Sci.Paris, Vol.190, p.763-5.

53. LE MAITRE, D. 1931. "Sur la presence d' Endothyra dans le Famennian de Jeumont (Nord)". Soc.Geol.du Nord, Vol.56, p.213.

54. LIEBUS, A. 1932. "Die Fauna des deutschen Unterkarbons. 3.Teil., Die Foraminiferen". Abh.Preuss. Geol. Landesamt, N.F.141, pp.133-175.

55. MACGREGOR, M. 1929. "Scottish Carboniferous Stratigraphy: An Introduction to the Study of the Carboniferous Rocks of Scotland". Pres. Address.Trans.Geol.Soc.Glasgow, Vol.XVIII, Pt.III. p.319.

56. M'COY, F. 1849. "On some new genera and species of Palaeozoic Corals and Foraminifera". Ann.Nat.Hist.,2nd. Ser., Vol.3, XIII, p.119.

57. MOUNIER, S. 1888. "Examen Paleontologique du calcaire a Saccammina de Cussy -en-Morven". Hist.Nat. Autun.Bull.,Autun, France, No.1.p.236.

58. MEYER, H.L.F. 1914. "Carbonfaunen aus Bolivia und Peru". Neues.Jahrb.Beilage-Bd.XXXVII. p.590.

59. MIKHAILOV, A.1939. "To the characteristics of the genera of Lower Carboniferous Foraminifera on the territory of the Union S.S.R. in, The Lower Carboniferous Deposits of the North-western limb of Moscow Basin". Leningrad Geol. Administration, Symposium No.3, pp.47-69.

60. MOLLER, V.Von. 1877. "Ueber Fusulinen und ähnliche Foraminiferenformen des russischen Kohlenkalks". Neues.Jahrb.f.Min.,etc. pp.138-148.

61. MOLLER, V.von. 1878. "Die spiral-gewundenen Foraminiferen des russischen Kohlenkalkes". Mem. Acad. Imp.Sci.St.Petersburg, Vol.7.No.9, pp.1-147.

62. MOLLER, V.von. 1879. "Die Foraminiferen des Russischen Kohlenkalkes". Mem.Acad.Imp.Sci. St.Petersburg. Vol.7, No.27, pp.1-131.

63. MOREMAN, W.L. 1930. "Arenaceous Foraminifera from the Ordovician and Silurian Limestones of Oklahoma", Jour.Pal.,Vol.4, pp.42-59.

64. PETRENKO, A.1937. "The Novaya Zemlya Excursion". Part Second. Routes.17th.Internat.Geol.Congress, Moscow, pp.60-73.

65. PHILLIPS, J. 1849. "On the Remains of Microscopic Animals in the Rocks of Yorkshire". Aug.8th.1845. Proc.Geol.and Poly.Soc.W.Riding, Yorks., Vol.2. p.274.

66. PLUMMER, H.J. 1945. "Smaller Foraminifera in the Marble Falls, Smithwick and Lower Strawn Strata around the Llano Uplift in Texas". Texas Univ.Pub.4401, p.215.

67. PLUMMER, H.J. 1948. "Morphology of <u>Globivalvulina</u>". Amer.Midland Naturalist, vol.39, p.169-173.

68. RAUSER-CHERNOUSSOVA, D.M. 1936. "On the question of the stratigraphical significance of the Upper Palaeozoic Foraminifera. Bull.Acad.Sci. U.S.S.R. Ser.Geol.1.pp.61-84.

69. RAUSER-CHERNOUSSOVA, D.M. 1938. "The Upper Palaeozoic Foraminifera of the Samara Bend and the Trans Volga Region". Trav.Inst.Geol.Acad. Sci.U.R.S.S.Leningrad. Tome 7, p.95.

70. RAUSER-CHERNOUSSOVA, D.M. AND REITLINGER, E.1936."The Upper Palaeozoic Foraminifera of Petschoraland (western margin of the northern Urals)". Trans.Polar Comm.Acad.Sci.U.S.S.R.Vol.28, pp.159-232.

71. RAUSER-CHERNOUSOVA, D.M. and REITLINGER, E.1940. "On the Carboniferous Foraminifera of the Samara Bend". Trans.Oil.Geol.Instit. Leningrad, n.s., fasc.7.

72. REICHEL, M. 1945. "Sur quelques foraminiferes nouveaux du Permien mediterranean". Eclog.Geol.Helvet., Vol.38, p.524.

73. ROTH, R. and SKINNER, J. 1930. "The Fauna of the McCoy Formation". Jour.Pal.,Vol.4, pp.332-352.

74. ROUILLIER, M. and VOSINSKY, A. 1849. "Etudes progressives sur la Geologie, Quatrieme Etude". Bull. Soc.Imp.Nat.Moscow, Vol.XXII, Moscow.

75. SCHELLWIEN, E. 1897-8. "Die Fauna des karnischen Fusulinenkalks Theil III. Foraminifeera". Palaeontographica, Vol.XLIV. p.237.

76. SCHUBERT, R. 1907. "Beitrage zu einer naturlichen Systematik der Foraminiferen". Jahrb. Neues. Min., Geol.Palaeont., Vol.25, pp.233-260.

77. SCHUBERT, R. 1920. "Palaeontologische Daten zur Stammesgeschichte der Protozoen". Palaeont.Zeit., Vol.3. pp.129-88.

78. SCHWAGER, C. 1883. "Carbonische Foraminiferen aus China und Japan". In Richtofens China - 4to. Berlin, vol.4, Beitr.zur.Palaeont.von.China". pp.106-159.

79. SCOTT, H.W. and ZELLER, E. and D.N. 1947. "The genus Endothyra". Jour.Pal., Vol.21, No.6.p.557.

SKINNER, J. - see ROTH, R.

80. SOLLAS, W.J. 1921. "On Saccammina carteri Brady and the Minute Structure of the Foraminiferal Shell". Quart. Jour.Geol.Soc.Vol.LXXVII, Pt.3. pp.193-212.

STUBBLEFIELD, C.J. - see EDWARDS, W.

81. SULEIMANOV, I.S. 1945. "Some New Species of Small Foraminifera from the Tournaisian of the Ishimbayevo Oil. bearing Region". Comptes.Rendus (Doklady) Acad.Sci.U.R.S.S., Vol.XLVIII, No.2, p.124.

82. TCHERNYSHEVA, N.E. 1941. "A new genus of Foraminifera from the Tournaisian deposits of the Urals". Acad.Sci.U.R.S.S. Comptes Rendus (Doklady) Moscou, n.s. Vol.32, No.1, p.69.

TEODOROVITCH, G.J. - see KRESTOVNIKOV, V.N.

83. THOMPSON, M.L. 1942. "New genera of Pennsylvanian fusulinids". Amer.Journ.Sci., Vol.240, pp.403-420.

84. THOMPSON, M.L. 1948. "Studies of American Fusulinids". Univ.Kansas Publications. Protozoa. Article 1.

85. TOLSTIKHINA, M. 1935. "Carboniferous Deposits of the Central Part of the Ufa Plateau". Trans. Cent. Geol. and Prosp. Inst., Fascc.65, pp. 1-40. Leningrad.

86. VAN DEN BROECK, E. 1898. "La Nummulina pristina du calcaire carbonifère belge". Annal.Soc.Roy.Malac. Belg.Tome XXXIII, p.35.

87. VENUKOFF, P. 1889. "La faune du calcaire carbonifère inférieur du Bardoun en Mongolie". Russ. Kais. Min. Ges.St.Peters.Verh.Ser.2, Bd.25, p.218.

VOSINSKY, M. - see ROUILLIER, M.

88. WARTHIN, A.S. 1930. "Micropaleontology of the Wetumka, Wewoka and Holdenville Formations". Oklahoma Geol.Surv.Bull., No.53.

89. WATERS, J.A. 1928. "A Group of Foraminifera from the Dornick Hills Formation of the Ardmore Basin". Jour.Pal., Vol.1. p.129.

WATERS, J.A. - see also CUSHMAN, J.A.

90. WHITFIELD, R.P. 1881. "On the Fauna of the Lower Carboniferous Limestones of Spergen Hill, Indiana". Amer.Mus.Nat.Hist., Bull I, Art.V.p.39.

91. WILLIAMSON, W.C. 1858. "On the Recent Foraminifera of Great Britain". London.

92. WOOD, A. 1945. "A Rapid Method of Making Accurate Drawings of Small Microscopic Objects". Proc.Geol. Assoc., Vol.56, Pt.1.pp.18-19.

93. WOOD, A. 1949. "The structure of the wall of the test in the Foraminifera; its value in classification". Quart.Journ.Geol.Soc.Vol.CIV, Pt.2, p.229.

94. ZELLER, E. 1950. "Stratigraphic Significance of Mississippian Endothyroid Foraminifera". Univ.Kansas.Pal.Publications, Protozoa, article 4, pp.1-21.

ZELLER, E. and D.N. - see also SCOTT, H.W.