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The Palaeo-ecology and Biostratigraphy of the foraminifera from the Oxfordian of north Dorset.

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Abstract

The Oxfordian rocks of north Dorset are poorly exposed at outcrop. A drilling operation was devised and implemented and the complete sequence of strata from the Weymouth Member of the Oxford Clay Formation through to the Ringstead Waxy Clay Formation was penetrated. Three boreholes were drilled; the Hallett's Farm Borehole, covering the strata from the stratigraphically youngest Ringstead Waxy Clay Formation down to the Cucklington Oolite; the Bowden Farm Borehole, continuing the sequence from the Cucklington Oolite into the lower part of the Hazelbury Bryan Formation and the Hartmoor Hill Borehole which continues downward into the Oxford Clay Formation. A continuous succession of the Corallian rocks from north Dorset was obtained. The fresh borehole material was examined for microfossils, with further samples coming from the BGS East Stour Borehole. A diverse assemblage was extracted. The foraminiferal assemblage was examined and includes representatives of 26 families, comprising 26 genera and 148 species. All species were identified and the taxonomy of each studied and described or confirmed. The assemblage is more diverse than previously recorded Corallian assemblages, partly due to the freshness of the borehole material which is not affected by the weathering processes present at surface outcrops.

The regional lithostratigraphy defined by the British Geological Survey (Bristow *et al.*, 1995) is confirmed and lithological boundaries not visible at outcrop are described.

The distribution and abundance patterns of foraminiferal taxa are analysed and various statistical indices are compared for each borehole. Multivariate methods are employed and in particular non-metric Multidimensional Scaling is used in an attempt to divide the samples into groups which are palaeo-environmentally significant. The authenticity of this method is checked against a Hierarchical Agglomerative Clustering technique. The sample groups are used to define biofacies, fifteen of which are recognised within the studied interval.

The correlation of the four boreholes is achieved using lithological techniques, ammonite zonation, foraminiferal biohorizons and the biofacies defined by multivariate analysis. A total of 21 biohorizons are identified with certain horizons coinciding with lithological boundaries and previously defined unconformities recognised within the Oxfordian of Dorset.

The long ranging nature of the majority of Upper Jurassic foraminifera precludes the definition of a rigorous biostratigraphic zonation. The important biostratigraphic species for the Upper Jurassic are recorded however, and a tentative zonation, based on the concept of interval zones (Salvador, 1995) is proposed. Eleven zones are recognised.

To Maria Harding for being there for me.

"I have picked up a few curious things from the shore of the great ocean of time".

George Mackay Brown, 1994. *Beside the Ocean of Time.*

"Nobody's fault but mine"

Page, J. & Plant, R. 1976.

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Declaration

This is to certify that the work submitted for the Degree of Doctor of Philosophy under the title "The Palaeo-ecology and Biostratigraphy of the foraminifera from the Oxfordian of North Dorset." is the result of original work.

All authors and works consulted are fully acknowledged. No part of this work has been accepted in substance for any other degree and is not being concurrently submitted for any other degree.

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Chapter 1. Introduction.

1.1. Introduction.

The Jurassic System of Britain contains rocks that are some of the most frequently studied strata in the world. The succession exposed on the Dorset Coast is world-renowned and is the site of many of the type-sections for the British Jurassic. Some of the early pioneers in Geology studied these rocks and many of the subsequent published works were instrumental in shaping the modern geologist's view of rock formations and stratigraphic practice; e.g., Buckland (1818), Conybeare and Phillips (1822), Buckman (1893, 1898, 1902), Arkell (1933, 1956). In the "Jurassic Geology of the World", Arkell (1956), commenting on the Jurassic System, says that "for the stratigrapher it is the very well and fountain of his subject".

The Jurassic geology of Dorset provides one of the finest sections of marine Jurassic rocks anywhere in the world. The succession has been studied from the early days of geology and has continued to be the attention of many new studies as recent advances provide new tools for analysis in various disciplines. Previous studies on the Jurassic geology of Dorset have involved many disciplines and covered most aspects of geological research. Some examples are given below.

The geology, sedimentology, facies and depositional environment of the sequence of rocks on the Dorset Coast has been the subject of numerous papers. From the early studies by Arkell (1933, 1935, 1947), Wilson *et al.* (1958) to the studies by Wright (1986a, b), Wilson (1968a, b), Brookfield (1973a, b, 1978) and Talbot (1973, 1974) to the recent studies of Allen and Underhill (1989), Sun (1989, 1990a, b, 1992), Callomon and Cope (1995) and Coe (1995). The interest in the Jurassic geology of the Coast has never waned, as illustrated by the very recent PESGB sponsored, revised and updated edition of House's (1993) field guide to the Dorset Coast. The geological history and nomenclature for the Upper Jurassic of the Dorset Coast is discussed in Section 1.4.5.

The succession of strata in Dorset has attracted the attention from petroleum geologists since the 1930's and oil was first discovered at Kimmeridge Bay in 1959 by British Petroleum (Brunstrom, 1963). The nature of the field is such, that BP have drilled deeper exploratory wells in the vicinity due to speculation regarding other supporting accumulations (Stoneley and Selley, 1991). Many surface oil seepages have been discovered, the most famous being that at Mupe Bay which has become the subject of numerous studies (a recent example is described by Miles *et al.*, 1993). Since the discovery of the Kimmeridge Field modern exploration methods have discovered the Wytch Farm, Wareham and other small oilfields. Wytch Farm, the largest oilfield in the onshore UK, was first discovered in 1973, with a deeper accumulation being found in 1977. This oil field now produces around 4000 b/d and recent drilling by BP has confirmed an offshore extension (Miles *et. al.*, 1993). Potential source rocks sections have been identified as the Lower Lias, the lower part of the Oxford Clay and the Kimmeridge Clay. For further information on the petroleum habitat in south Dorset see Lees and Cox (1937), Selley and Stoneley (1987), Stoneley and Selley (1991) and Miles *et. al.*, (1993).

Not only has the tectonic history and structure of Dorset been of interest to petroleum geologists due to the formation of oil traps and reservoirs but in the context of the Wessex Basin as a whole, the structure and evolution has been the subject of many studies. Intra-Jurassic faulting, tectonic inversion and Mesozoic basin evolution have been the subject of many papers using the geology of the Wessex Basin and Dorset as the centre of research. For a more detailed history of research into the structure and geological evolution of Dorset and the Wessex Basin see Section 1.4.

The excellent preservation, high diversity and abundance of the assemblage in the strata of the Dorset Jurassic has encouraged many palaeontologists to this area from the early days of geology. Many fossil groups have received detailed attention but, in particular, the ammonites are of prime importance. Arkell (1956) in his book "The Jurassic Geology of the World" produces a biostratigraphic zonation scheme combining all of the, then, current knowledge of Jurassic ammonites, which, although outdated, was instrumental in showing the wide area over which time correlations could be made in the Jurassic rocks using fossils. The biostratigraphic role of ammonites has limitations (see Kennedy and Cobban (1977) for a discussion), although they are still extremely useful. The zonal scheme has been refined, and increased, to 75 ammonite zones (Cope, 1995). According to Cope (1993), resolution provided by ammonites, in some cases, is now in the order of 50, 000 years. The subdivision of the Oxfordian Stage using ammonites is discussed in Section 1.4.8.

Other fossil groups preserved in the strata of the Dorset Jurassic have provided interest for many palaeontological studies. Fürsich (1973, 1974, 1975) based his studies of trace fossils on sections from the Dorset Coast. He compared the sections with those in Normandy and proposed new palaeo-ecological and palaeo-environmental models based on trace fossil assemblages. Fürsich notes that the environments indicated by trace fossil associations are primarily related to hydrodynamic conditions and only indirectly related to depth. Fürsich (1973) also suggests an origin for the nodular limestone in the Corallian Beds of the Dorset Coast as being associated with the trace fossil *Thalassinoides*. Fürsich (1976) studied macrofossil assemblages from the Corallian of the Dorset Coast and states that several of the 17 macro-invertebrate assemblages show preferences for particular environments and that the assemblage can often exhibit a clear relationship to 10 types of substrates ranging from clays to oolites (Fürsich, 1976). Wignall (1990) presented an integrated study on the benthic palaeo-ecology of the Kimmeridge Clay, combining sedimentology, biostratigraphy, ecology and taphonomy of the assemblage.

The Kimmeridge Clay in Dorset has received considerable attention, with an array of published material concerning a range of topics, including deposition history (e.g. Fienster, 1989; Hallam and Bradshaw, 1979; Scotchman, 1989; Gallois, 1976; Wignall, 1989; Irwin, 1979; Tyson *et al.*, 1979 and Oschmann, 1988), orbital forcing and Milankovitch cycles (e.g. House, 1985, 1986) and micropalaeontology (e.g. Lloyd, 1959, 1962; Medd, 1979, 1982 and Whatley, 1965).

The Jurassic geology of the Dorset Coast has been well studied but relatively little attention has been paid towards the north Dorset area. In general terms the coastal section has received the most attention from research into the Dorset Jurassic, but many of the pioneering workers on Jurassic geology visited the north Dorset area and, in some cases, published their findings (e.g. Blake and Hudleston, 1877; Arkell, 1933). Obviously, the magnificent coastal sections are more easily studied than the poorly exposed and overgrown outcrops of the north Dorset area, but nonetheless the geology of the north Dorset area is just as important especially in the study of the Wessex Basin as a whole. The history of research into the Upper Jurassic geology of north Dorset and the current lithostratigraphic nomenclature is given in Section 1.4.6.

In recent years, following the advent of sequence stratigraphy, many of the concepts have been applied to onshore strata. The Jurassic strata of the Dorset coast have been the subject of a number sequence stratigraphic studies. Rioult *et al* (1991) and Coe *et al.* (1992) have discussed the coastal succession in terms of sequence stratigraphy and part of the global sea-level curve (Haq *et al.*, 1987) is based on data from the section. Coe (1995) compares the Dorset Coast successions with those of Oxfordshire and Yorkshire for the Oxfordian and 6 major unconformities are recognised (O1 - O6). Coe also indicates that these unconformities are equivalent to sequence boundaries in the sequence stratigraphic model of Vail *et al.* (1991). Sequence stratigraphic implications of the geology of north Dorset are discussed in Chapter 7.

There have been many micropalaeontological studies of the Jurassic of Dorset and many classic papers have been produced (see Section 1.3.1 for the history of research into Jurassic micropalaeontology). However, the micropalaeontological study of the Dorset Jurassic is similar to studies of geology in general, in that the Dorset Coast has been well served and the area of north Dorset has been overlooked. This research is concerned with the Upper Jurassic of the north Dorset area and, in particular, with the Foraminiferida from the Oxfordian Stage. It is hoped that through the study of fresh material (from a number of boreholes drilled within this area) the effects of weathering, present on the Dorset coastal sections, will be avoided and further insight into the biostratigraphy and palaeo-ecology of

Upper Jurassic foraminifera can be achieved.

1.2. AIMS AND OBJECTIVES.

1.2.1. Aims.

The aims of this research are as follows:

1. To sample the complete succession from the Upper Oxford Clay Formation through the Corallian Group and into the base of the Kimmeridge Clay.

2. To examine the Foraminiferida from the same succession.

3. To integrate the foraminiferal data with sedimentological, macrofaunal and other micropalaeontological data.

4. To statistically analyse, as far as the limitations of this project will allow, the foraminiferal database and produce palaeo-environmental, palaeo-ecological and biostratigraphical models for the Upper Jurassic of north Dorset.

5. To compare the results of (4) with the established models for the Jurassic of the Dorset Coast and the Wessex Basin as a whole.

1.2.2 Objectives.

The main objectives are as follows:

1. Collect a complete suite of samples spanning the entire Upper Jurassic sequence from the Upper Oxford Clay Formation through to the Kimmeridge Clay Formation. This sampling programme would be useful in the following ways:

a. Although the above mentioned succession of the Upper Jurassic has been studied previously, a complete sampling programme through this entire succession has not been attempted.

b. The north Dorset area has never been studied micropalaeontologically, and represents a more marginal aspect of the Dorset Coast sections. Information from north Dorset can be used to augment the knowledge of Wessex Basin palaeo-environments in the Dorset area.

c. Where studies analyse longer stratigraphic successions, they often utilise data from a number of scattered and incomplete successions, in this research a continuous succession has been sampled.

2. In order to facilitate the collection of a suite of samples in north Dorset a series of boreholes were drilled. This had the advantages of:

a. providing a complete section through the aforementioned stratigraphic sequence, with overlap between each of the boreholes.

b. providing a suite of samples which had not been subjected to intense subarial weathering that coastal sequences endure.

3. To correlate the boreholes using Foraminiferida.

4. A complete suite of samples from north Dorset will hopefully provide useful data in the following areas:

a. The evolving nature of the foraminiferal assemblage can be analysed statistically over a defined stratigraphic range.

b. The problem of Jurassic foraminiferal facies-specific assemblages can be evaluated and compared with data from other areas.

c. Certain stratigraphic boundaries which prove problematic to recognise in the field may be identified in the boreholes through foraminiferal analysis.

5. Wider geographical correlations will hopefully be possible.

a. If a localised biostratigraphic scheme for north Dorset can be compared with the standard ammonite zonation scheme for the Jurassic it may help in correlation over the Wessex Basin as a whole, particularly when sections are not served with a well preserved ammonite assemblage.

b. If compared to the previous research for the coastal sequences the palaeo-ecological and palaeo-environmental data for north Dorset can provide a synthesised model for the whole area.

1.2.3. Limitations.

The limitations inherent in this project are listed below:

1. The number of samples analysed and their vertical spacing is such that the project is essentially reconnaissance in its nature.

2. The small diameter of the core meant that to achieve a representative sample a longer stratigraphical period was sampled (i.e. greater vertical distance). This has the effect of blurring the biostratigraphic details. However this is a common problem in micropalaeontological studies, and needs to be taken into consideration with (**1.**) above.

3. No lateral sampling or duplicate samples could be utilised. Duplicate samples can provide control on sampling techniques, and lateral sampling provides a more realistic picture of the assemblage given the limitations of (**2.**) above.

4. Comparison with field samples was limited. The poor exposure in north Dorset and the sometimes overgrown nature of the localities precluded detailed field sampling.

5. Correlation between boreholes may blur biostratigraphic resolution. A poor correlation between the boreholes would alter the biostratigraphic accuracy. A single hole would in some cases be preferred.

6. The small number of boreholes and their comparatively close separation precludes a detailed palaeo-geographical reconstruction.

7. Material lost through poor core recovery.

1.3. History of Research.

The Upper Jurassic foraminifera of Britain received little attention prior to the middle of this century when Barnard (1952) published his study on the assemblage of the Oxford Clay from Warboys. From this time onwards, publications have been more frequent, many of which will be discussed below. The history of research into foraminifera from the Jurassic as a whole is naturally more extensive and it is necessary to provide a summary of the earlier works from Europe and elsewhere, in order to bring into context the literature on Upper Jurassic assemblages from Britain. In particular, there are many papers concerned with foraminifera from the Lias, where much of the taxonomic framework for Jurassic foraminifera was established. It is, therefore, necessary to provide a summary of these works as many of the Upper Jurassic studies are based on the taxonomic treatment of Liassic forms.

1.3.1. Pre - 20th Century.

The early pioneering work into Jurassic foraminifera was conducted, in the main, by French and German workers in the latter half of the 19th century. These workers concentrated particularly on the Lias. Some of the more important papers of this time are those by Borneman (1854), Terquem (1855-1886), Berthelin (1879) and Häusler (1881). Borneman (*op. cit.*) studied the Liassic foraminifera from the area around Göttingen and describes a number of new species. According to Barnard (1950b), the illustrations and descriptions given by Borneman provide one of the clearest studies of Liassic foraminifera from the continent and draw attention to the highly variable nature of the assemblage. Terquem's range of Liassic papers span a period from 1855 to 1866; in which Terquem describes a large number of new species. However, the validity of some of Terquem's work has been called into question (*e.g.* Macfadyan, 1941; Barnard, 1950b). Many species are not adequately described and following the "Continental School of thought" at the time, many species are erected on the basis of slight variations from the original type and in some cases without consulting previous literature. Undoubtedly these earlier works are extremely important in the study of Jurassic foraminifera but, unfortunately, they are also responsible for some of the confusion which pervades the literature today. Shipp (1989) mentions that there are problems with some of these earlier works, as often the newly erected species are poorly illustrated and that a number of separate species names are erected for what are probably variations of the same species.

British research into Jurassic foraminifera at this time was also concerned mainly with the Lias. Among the earlier works, four are worthy of mention. These are the papers by Jones and Parker (1860), Brady (1867), Blake (1876) and Crick and Sherborne (1891-92). All of these papers are well illustrated and the foraminiferal descriptions are clear and precise (Barnard, 1950b). Strickland (1846) also published on Liassic foraminifera but the work is not particularly detailed and deals with two species of "microscopic shells".

Following the research into Liassic foraminifera, attention moved to the Upper Jurassic and again the early contributions are by workers from the continent. Three of the most important papers of the time are those by Gümbel (1862), Schwager (1865) and Deecke (1886). These papers deal with foraminifera from the Oxford Clay equivalent of Germany. Although based on the taxonomic framework for Liassic forms laid down by Bornemann (1854), these papers are extremely well illustrated and the descriptions are important for workers on Jurassic foraminifera. Many of the common species described from the British Jurassic by subsequent workers have their original descriptions in these papers. Other useful papers include those by Häusler (1883) on agglutinated foraminifera from Switzerland and the particularly well illustrated papers by Wisniowski (1890, 1891) on the Polish Jurassic.

The research into British Oxford Clay foraminifera at this time is limited and the only papers published were in the form of un-illustrated lists and as appendices to stratigraphic works. In this format they are not particularly useful; *e.g.* Jones and Parker (1875), Whittaker (1886) and Crick (1887). Sherborne (1888) published a short paper on adherent forms from the Oxford Clay and Chapman (1897) published notes on the Microzoa from the Jurassic beds at Hartwell.

1.3.2. Early 20th Century.

During the early part of this century research into Jurassic foraminifera is also limited, but with some useful contributions. Papers published by Paalzow (1917, 1922 and 1932) are useful but not very well illustrated. Macfadyen (1935) published a well-illustrated account of foraminifera from British Somaliland. In this study the samples are said to come from the Argovian Stage, which equates to the Lower Corallian of Britain. This assemblage compares well to the assemblage from the Oxford Clay of Warboys (Barnard, 1952). In this paper Macfadyen was one of the first authors to attempt the task of sorting out some of the difficulties in nomenclature present in the study of Jurassic foraminifera. Franke (1936) published a large paper on the German Lias which is also well illustrated, although suffers from following the Continental School of thought and a large number of species are erected on the basis of slight variations in morphology. Bartenstein and Brand (1937) also produced a large paper in which they attempt to zone the German Lias. The paper is well illustrated and important and, although it follows the previous work of Franke (1936), the taxonomy is based on Cushman's (1927, 1928) scheme rather than that of Rhumbler (1895, 1911, 1923) which Franke (*op. cit.*) had used. Originally deplored by the English School for its proliferation of many new taxa, Cushman's classification and the publication of his book "Foraminifera" (1948) slowly became accepted. By the time that Loeblich and Tappan (1964) published their classification (which practically doubled the number of known genera of the time) followers of the English School of thought had realised that the foraminifera were not a simple plastic group, which was part of their original premise, and the large profusion of new taxa published by Loeblich and Tappan (*op. cit.*) was accepted with little resistance. For an in depth discussion of the history of the classification of foraminifera see Haynes (1990).

The study of British Jurassic foraminifera then received little attention until Macfadyen (1941) published on the foraminifera from the Green Ammonites Beds in Dorset; again this was a study of Liassic foraminifera. As Barnard (1950b) mentions, Macfadyen studied 6 samples from 12 feet of the 111 foot section of the Green Ammonite Beds and drew comparisons from a wide selection of other collections from various localities and horizons around Britain.

1.3.3. Mid-20th Century of Britain.

Barnard (1950-1960) published a number of papers on the Liassic foraminifera from Britain. In these papers Barnard concentrates on the systematic descriptions of the species found in the Lower and Upper Lias and on the variation of certain species of the Lagenidae and Lingulinae. Barnard (1950a) discusses the uses of foraminifera in Lower Jurassic stratigraphy and suggests that, after the elimination of facies-specific forms, the Lias could be divided into broad foraminiferal zones and with more detailed work into finer zones. Barnard (1950b) mentions that the classification put forward for the Lagenidae is based primarily on Recent genera, and, as the family reached its acme in the Jurassic, it is sometime difficult to identify forms occurring in the Jurassic with those present in the clearly defined Recent taxonomy based on relatively few genera. A good example of this is the classification of species of *Lenticulina* Lamarck. Barnard realised that attempting to assign these forms to particular species was fraught with difficulties due to the immense variation exhibited by the group, and the tendency for certain forms to converge. Barnard conducted a systematic study to examine the variation and growth trends exhibited by the whole group at distinct horizons. As a result the Lenticulinae as a whole are treated as an evolving plexus and, as such, the previous trend of creating new species on slight morphological differences is avoided. Barnard also notes that emerging from this study was the fact that in previous works, presumably where insufficient specimens were available, juvenile forms often received a different species name than their adult counterparts. This is one of the serious problems encountered when dealing with the taxonomy of Jurassic foraminifera. Variational trends are plotted and Barnard (*op. cit.*) concludes that a zonal scheme would probably be possible for the Lower Lias. Barnard (1950c) treats the Upper Lias in the same way as the assemblage from the Lower, with perhaps more emphasis on systematic descriptions of the taxa. Barnard provides a number of detailed synonymies and pays particular attention to the evolution of the genus *Pseudoglandulina* Cushman, 1929. He continues to explore the plexus idea in Liassic foraminifera and concentrates on the *Lingulina tenera* Bornemann plexus (Barnard, 1956), and the *Frondicularia brizaeformis* Bornemann plexus for smooth forms and the *Frondicularia sulcata* Bornemann plexus for ornamented forms (Barnard, 1957).

In his next contribution Barnard (1958) departs form the study of the Lagenidae and discusses the relationship between certain Mesozoic species of adherent foraminifera. The evolution of certain species groups is discussed and most of the important Mesozoic adherent forms are well illustrated.

In 1960 Barnard returns to the variation of the different species groups of *Lenticulina* from the Lias. The plexus of evolving forms is studied in greater detail than in his previous work (Barnard, 1950a) and, rather than a purely taxonomic approach, the evolutionary, biological and stratigraphical aspects are given greater importance.

Barnard (1963), in a contribution to the collective volume "Evolutionary trends in foraminifera", combines the salient points of his previous papers and discusses the evolutional aspects of some Jurassic lagenids. Species from four genera, *Rectoglandulina*, *Lingulina*, *Frondicularia* and *Dentalina* are selected to show progressive evolution in certain biocharacters. In some forms the basic test shape occurs in disconnected species groups, which according to Barnard (1963) produces heterochronous homeomorphs which limit stratigraphic usefulness. Other forms show "progressive evolution" of ornament for example which is stratigraphically of value. The differences exhibited between species is highlighted within the Lower, Middle and Upper Jurassic of Britain.

Although mainly concerned with the Lias, Barnard also published on the Upper Jurassic foraminifera of Britain which, up to this point, had received little attention. Barnard (1952) published the first account of foraminifera from the Oxford Clay of England. The assemblage from the Upper Oxford Clay of Warboys, Huntingdonshire was studied and the systematic description of twenty two species presented, of which two species are recorded as new. Barnard (*op. cit.*) concludes that although a few species are restricted in range and may be useful in zonation, the majority of the species are long-ranging. Barnard's second paper on the Oxford Clay (Barnard, 1953) presents the systematic descriptions of twenty-three species of foraminifera from the Upper Oxford Clay of Redcliff Point, near Weymouth, Dorset. This is the first paper published on foraminifera from the Oxford Clay of Dorset; four species are recorded as new. Barnard notes that considerable variation was present in the relative abundance of the assemblage, the bulk of which consisted of the two species, *Ammobaculites suprajurassicum* (Schwager) (*A. coprolithiformis* (Schwager) of this study) and *Lenticulina münsteri* (Roemer). Barnard also indicates that the paucity of some forms, or the complete absence in some cases of *A. suprajurassicum*, may be facies related and not strictly of stratigraphical significance. Both papers by Barnard are adequately illustrated and are useful for their descriptions although the foraminifera are not treated in the same detail as the assemblages from the Lias. Other than systematic descriptions, no attempt is made to simplify any of the nomenclatural problems associated with Upper Jurassic foraminifera nor any examination of morphological variation that Barnard applied to the Liassic assemblages.

Barnard's publications initiated farther studies on Jurassic foraminifera and a continuing stream of publications followed.

Adams (1957) continued the work on Upper Lias foraminifera, concentrating on the morphology of certain species and their variation. His later paper (Adams, 1962) concentrates on the calcareous adherent foraminifera from the British Jurassic and Cretaceous and the French Eocene. Adams (*op. cit*) notes that there is much confusion over the systematic position of these taxa and blames the early workers in the latter part of the 19th century for their failure to provide adequate descriptions of their genera. He notes, however, that at this time it was not realised that the key to relationships between these genera lay in the structure of the test wall. Adams re-describes the genera of calcareous adherent forms reported from the British Jurassic and reviews all the known species.

Ciffelli (1959, 1960) concentrated on the foraminifera from the Bathonian of England, which, as he notes, had received little attention until his study. Ciffelli (1959) describes 104 species, subspecies and varieties and records their stratigraphic range; one species and one subspecies are recorded as new. Ciffelli notes that, like other Jurassic assemblages, the Bathonian assemblage is dominated by the Lagenidae, which are difficult to classify due to the species and genera not having well defined morphological limits. In his later paper Ciffelli (1960) addresses the issue of variation in the Bathonian Lagenidae and comments on the history of their classification. He advises caution in dealing with the variation exhibited by Jurassic lagenids and notes that variation in the evolution of the group should not be overlooked and if variants are masked with new names, then important information to the phylogeny of the group may be obscured. Cifelli chooses a few species to illustrate his discussion and concludes with some comments on the ancestry of the Lagenidae.

Lloyd (1959) describes the agglutinated foraminifera from the Kimmeridgian. Twenty-seven samples were examined from the type section of the Kimmeridge Clay on the Dorset Coast, i.e. the Kimmeridge Bay section. This is a useful study as it concentrates on the agglutinated forms while most of the other papers on the Jurassic deal with the lagenids. He presents systematic descriptions of twenty-five species; three of which are new. Lloyd also studies the type of material utilized by the agglutinated foraminifera in forming their test. In general, Lloyd found that species agglutinate a preferred grain size or even a preferred type of material and these results agree with Hofker's (1953) conclusions. Lloyd (1962) also tackles other groups of foraminifera which have previously received little attention in the Jurassic; in particular the Polymorphinidae, Miliolidae and Rotalidae again from the Type Kimmeridge Clay. In this publication Lloyd discusses variation in the forms referred to *Eoguttulina* and notes the difficulties in applying Cushman and Ozawas' (1928 - 1930) classification of the polymorphinids to Jurassic members of the family.

In 1962, Cordey shifted attention from the English Jurassic and published the first systematic account of the foraminiferal assemblages from the Jurassic of Scotland. He collected samples from the Oxford Clay of Staffin Bay, Isle of Skye. In this paper Cordey discusses the morphological variation of several species, as well as providing systematic descriptions for the calcareous taxa. Two species and one subspecies are considered as new. The internal structure of the epistominids is discussed with reference to Hofker's (1954) classification. Through examination of the dental plates the retention of the generic name *Epistomina* Terquem is advised.

Gordon (1962-1970) continued research into the Upper Jurassic foraminifera and published on assemblages from Scotland and England. Gordon (1962) published the first account of the foraminifera from the Ampthill Clay. He examined two samples of Ampthill Clay from Knapwell and Mepal, Cambridgeshire, and describes seventeen species, including one new one. In this paper, he compares the assemblage to the foraminifera of the sandy-calcareous facies of the Corallian beds seen on the Dorset Coast. Gordon (1965) published the first account on the foraminifera from the Corallian Beds of southern England. Forty-nine species are recorded, four of which are new. Gordon mentions that the most abundant and diverse family is the Lagenidae in keeping with most Jurassic assemblages. The two most abundant species are *Ammobaculites coprolithiformis* (Schwager) and *Lenticulina münsteri* (Roemer) and although the assemblage is dominated by the Laginidae the agglutinated component is quite important. Gordon notes that the assemblage is typically Oxfordian in composition and has more affinity with the preceding Jurassic assemblages than those of the Lower Cretaceous.

Gordon (1967) continued the interest in the Scottish Jurassic and examines the assemblage from the Callovian of Brora. This is equivalent in age to part of the Oxford Clay in England. In this paper the systematic descriptions of fifty species are presented and Gordon also attempts to compare the assemblage with other Jurassic assemblages. The Brora assemblage is comparable with the Oxfordian assemblages described by Barnard (1952, 1953) from the Oxford Clay and to those of Gordon (1962, 1965) from the Corallian Beds of South Dorset. In comparison with the North American assemblages the assemblage from the Lower Vanguard Formation or Rierdon equivalent of Saskatchewan (Wall, 1960) compares best with the Brora assemblage.

In the previously mentioned papers Gordon chiefly describes the assemblage and indicates the stratigraphic position of the species studied. Gordon (1966) discusses the variation of certain nodosariids found in the Middle and Upper Jurassic, stating that, although the Nodosariidae are prolific in most described Jurassic assemblages, their classification is far from satisfactory. He notes that in some instances the morphological variation observed in a single species is wide enough to include individuals that, taken separately, fall within the morphological variation exhibited by up to three commonly accepted genera. Gordon gives an example using specimens referable to *Lenticulina münsteri* from a single rock sample which include individuals showing the characteristics of *Lenticulina* Lamarck, *Marginulinopsis* Silvestri and *Planularia* Defrance. He concludes that the necessary modifications of the classification of the family will best be brought about by grouping together species of proven relationship into larger units, rather than by defining new genera on the basis of a few key characters. This assumption is in keeping with the conclusions of previous authors (*e.g.* Barnard, 1950b, c; Cifelli, 1960).

The contributions by Gordon deal with the taxonomic aspects of Upper Jurassic foraminifera from Britain. Gordon (1970), however, first makes some observations on the palaeogeography and biogeography of Jurassic foraminifera. The biogeography of Jurassic organisms has been of interest to workers since the turn of the century, but apart from the more usual groups receiving attention, (*e.g.* ammonites (Arkell, 1956) and belemnites (Stevens, 1963)), Gordon notes that Jurassic foraminifera have received little attention. In this paper Gordon divides the known Jurassic foraminiferal assemblages into five broad types of assemblages. Three assemblages are typical of shelf regions while the other two are more typical of the Tethyan seaway and its margins. These assemblages are characterised by Gordon as follows:

A. Shelf assemblages.
  1. Nodosariid and nodosariid-mixed assemblages.
  2. Dominantly simple agglutinated assemblages.
  3. Assemblages where calcareous benthonic species are conspicuous (non-nodosariid).
     a. Epistominidae conspicuous.
     b. Ophthalmidiidae conspicuous.
     c. Buliminidae conspicuous.
     d. etc.

B. Tethyan assemblages.
  1. Complex agglutinated species dominant.
  2. Planktonic assemblages.

The Upper Jurassic assemblages are dominated by nodosariids at most levels with, on occasion, large numbers of simple agglutinated foraminifera. Occasional floods of epistominids or *Ophthalmidium* species are present. Gordon concludes that comparatively little is known about the ecology of Jurassic foraminifera and a comparison with present-day assemblages is of limited value. The nodosariids, for instance, occupied a different set of ecological niches in the Jurassic than they do in the present day and were also far more abundant. This highlights the problems inherent in palaeo-environmental studies of Jurassic foraminifera.

1.3.4. Late 20th Century of Britain

In 1981 the "Stratigraphic Atlas of Fossil Foraminifera" was published, the aim of which was to provide a detailed compilation of foraminifera from the Phanerozoic of the British Isles, with the emphasis placed on the most commonly encountered, stratigraphiclly useful species. The chapter on the Jurassic is split into 4 parts (1. Hettangian to Toarcian; 2. Bajocian to Callovian; 3. Callovian to Portlandian and 4. Summary). The atlas provides information on the stratigraphic distribution of the key Jurassic species and reproduces some of the illustrations from previously published literature as well as some new ones. There are brief sections on foraminiferal assemblages and on the palaeo-ecology of Jurassic foraminifera. In this edition of the Atlas the Jurassic is not treated in detail, a point which is rectified in the 2nd edition (see below).

Perhaps the most comprehensive paper on the foraminiferal assemblage from the British Upper Jurassic is by Barnard, Cordey and Shipp (1981). Work carried out on the Upper Jurassic Oxford Clay formation by Cordey and Shipp in their respective PhD theses are published in detail for the first time. The paper is the first comprehensive work on the Callovian and Oxfordian foraminifera from England and provides a taxonomic list of all foraminifera found within the British Oxford Clay (74 species) and provides detailed taxonomic notes on selected species; 5 new species are also recorded. Detailed stratigraphic notes are provided for selected species and species range charts are given. The morphological variation of selected taxa is discussed in detail. The palaeo-ecology is discussed for various foraminiferal assemblages and some palaeo-environments are suggested. A number of palaeo-geographic maps are also included. This paper has become the standard reference work for researchers on the Upper Jurassic foraminifera of Britain.

Barnard and Shipp (1981) also published on the Kimmeridgian foraminifera from the Boulonnais. Twenty-seven species are recorded and described. The assemblage consists solely of agglutinated forms and species from the nodosariid, vaginulinid and polymorphinid families. One unusual aspect of the assemblage is the absence of miliolids, ophthalminids and epistominids, which are a common constituent in contemporaneous assemblages from

Britain and the rest of Europe. An ecological interpretation is presented for the dominant species of foraminifera and the assemblage is compared with other Kimmeridgian assemblages.

Lord and Bown (1987) published the field guide for the 20th European Micropalaeontological Colloquium entitled "Mesozoic and Cenozoic stratigraphical Micropalaeontology of the Dorset Coast and Isle of Wight, southern England". This is a useful publication as it lists certain principal species of foraminifera found in the Mesozoic strata on the Dorset coast. The Jurassic chapter is subdivided into Lower, Middle and Upper sections. Each section also lists the ostracods, calcareous nannofossils and palynomorphs. A good reference volume it however is only a listing of spot samples from each given horizon on the Dorset coast, and therefore gives little information on abundance or stratigraphic usefulness of the foraminifera.

A palaeo-environmental interpretation is provided by Gregory (1989) for the Lower Kimmeridgian foraminifera from the Helmsdale-Brora Outlier in northeast Scotland. The assemblage is characterised by low diversity and abundance; 24 species are illustrated. Gregory describes the assemblage present as consisting of a high abundance of spirillinids and nodosariids with simple agglutinated foraminifera. He suggests that this may be taken to represent a shallow-water, well-oxygenated, shelf environment. This is in contrast with the deep water sediments found associated with this area. Gregory suggests that the assemblage has been transported, perhaps caused by siesmic activity or by climatic or tidal factors.

The 2nd edition of the stratigraphic atlas of fossil foraminifera (Jenkins and Murray, 1989) follows the same format as the original and uses many of the same illustrations. New sections were added as research had progressed in some areas, and the Jurassic chapter is considerably altered as a consequence. Sections on depositional history, palaeo-ecology, environmental significance and faunal associations (mainly taken from Barnard, Cordey and Shipp (1981)) were added. The taxonomy is revised in keeping with recent developments, as is the biostratigraphy. There is a comprehensive reference list and data is used from most of the published works on British Jurassic foraminifera as well as from unpublished PhD and MSc theses. A figure showing the chronostratigraphy of British Upper Jurassic sections analysed for foraminifera is included, which utilises the Geological Society's correlation scheme for the Upper Jurassic rocks in the British Isles (Cope *et al.* 1980).

1.3.5. Mid to Late 20th Century of the Continent.

Research into Upper Jurassic foraminifera by continental workers during the latter half of the century are quite well represented and there are some important contributions to the taxonomy.

Seibold and Seibold (1953, 1960) have published on the lower Malm (Upper Jurassic) from southern Germany. These papers include useful descriptions and synonymies and are adequately illustrated with text-figures and SEM photomicrographs. Two other papers (Seibold and Seibold, 1955 and 1956) are of a different nature and deal with the taxonomic revision of the earlier papers by Gümbel (1862) and Schwager (1865) respectively. The importance of these papers is that they update the taxonomy of these classic works in Upper Jurassic micropalaeontology and provide relatively current synonymies for the more important species.

Lutze (1960) published work on the Callovian and Oxfordian foraminifera and ostracods from northwest Germany. The paper has excellent illustrations and Lutze describes important new species from the Callovian and Oxfordian as well as new variants of established species. He provides extensive synonymies for some of the more important species.

Other work of this time is published by Bizon (1958) who describes the foraminifera and ostracoda from the lower Oxfordian and part of the Upper Oxfordian from Villers-sur-Mer, Calvados. Bizon describes 39 species of foraminifera, with two new species being introduced. He provides distribution charts of some of the more important species which may be useful in the Anglo-Paris Basin and for north-west Germany. A contribution by Wernli (1971) deals with the taxonomy of about 50 species of foraminifera from the Dogger

(Aalenian-Callovian) of the southern area of the Jura Mountains in the east of France. The porcellaneous foraminifera are excluded in this paper, the descriptions being mainly of nodosariids, discorbids, spirillinids and lituolids.

Important contributions from Polish workers include Bielecka and Pozaryski (1954) on the Upper Malm from central Poland and Bielecka (1960) on the Lower Malm from southern Poland. Both of these papers are well illustrated with good descriptions; some important new species are introduced. Bielecka and Pozaryski (1954) describe 16 new species and have divide the Polish Malm into 12 local zones on the basis of short-lived foraminifera. The Polish Lower Malm is also zoned locally using foraminifera (Bielecka, 1960), in this case index species have been distinguished for individual foraminiferal zones and are correlated with the known ammonite zones.

From southern Sweden, Norling (1972) has published on the stratigraphy of the Jurassic of Western Scania. This paper is very well illustrated with detailed descriptions and lengthy synonymies for some of the more important species. This is the first work to be published on the foraminifera from the Jurassic of Sweden. The sections investigated are Lower Lias outcrop samples and boreholes covering strata of Early, Middle and Late Jurassic age. Norling notes that the foraminiferal assemblages are comparable with other assemblages of the same age from other basins in Europe. Around 50 species are described with 4 species described as new. The author presents a zonal scheme based on foraminifera for the Jurassic of western Scania.

Scandanavian studies of the Jurassic continued with more recently published papers from Norway and from the Norwegian area of the North sea. Nagy (1980) discusses the foraminiferal stratigraphy of Jurassic deposits on Kongsoya, Svalbard. This covers strata from the Lower Jurassic to the Callovian and Oxfordian. The assemblage consists mainly of agglutinated foraminifera. The depositional environment for the Lower Jurassic is considered to be lagoonal and the environment for the Upper Jurassic is suggested to be inner shelf, with slightly stagnant bottom conditions. The interest continues with agglutinated foraminifera and Nagy, Lofaldi and Bomstad (1983) record the Bajocian assemblage from the Yons Nab Beds of the Yorkshire coast, where the foraminiferal sequence is subdivided into a basal *Citharina* assemblage and an overlying, more extensive, *Ammodiscus* assemblage. Lofaldi and Nagy (1983) discuss the low diversity assemblage from the Jurassic and Cretaceous dark shales in southern Spitsbergen; the assemblage is agglutinated, with lesser numbers of *Lenticulina* spp., being dominated by the genus *Haplophragmoides*. Nagy (1985a, b) discusses the foraminiferal facies from the Statfjord area, northern North sea. He expands Gordon's (1970) theme of five principle types of foraminiferal assemblage, in particular utilising the shelf group of assemblages. This group is used to try and elucidate the palaeo-environment of a succession of foraminiferal assemblages developed under marine deltaic conditions, Nagy uses a combination of quantitative faunal analysis on the genus level with major faunal parameters of ecological value. This study is an extension of an earlier study (Nagy *et al.*, 1984). Nagy, Lofaldi and Bäckström (1988) record the foraminiferal distribution and depositional conditions in the Middle Jurassic to Lower Cretaceous (Bathonian-Hauterivian) shales in eastern Spitsbergen; again the assemblage is mainly agglutinated. Nagy, Pilskog and Wilhelmsen (1990), in their paper on the distribution of foraminifera in the Jurassic North Sea Basin, try to relate the composition of foraminiferal assemblages to aspects of their depositional environments. They note that although the application of quantitative faunal distribution data to the elucidation of palaeo-environments has been successfully applied to Cenozoic deposits, the usage in the Jurassic is only in its beginning due to the compositional differences between Jurassic and Recent assemblages. Continuing the study of foraminiferal distribution in Spitsbergen, Nagy, Lofaldi, Bäckström and Johansen (1990) published on the middle Jurassic to basal Cretaceous shales from Central Spitsbergen. Nagy (1992) published on the application of morphogroup analysis on foraminifera from Jurassic North Sea deltas. This is the first time that the morphogroup concept has been applied to Jurassic assemblages.

1.3.6. Non-European Literature

From outside Europe papers include Said and Barakat (1958) from Egypt and Subbotina, Datta and Srivastava (1960) form the Upper Jurassic deposits of Rajasthan and Kutch, India, although the illustrations are not of particularly good quality.

There are a number of publications by Russian authors which are worthy of note and they are very useful for the identification of Upper Jurassic taxa, especially the agglutinated foraminifera. One of the difficulties with the Russian work is that the nomenclature is different, and has been built up independently to the taxonomy prevalent in Europe. One important work entitled "Foraminifera of Upper Jurassic deposits of western Siberia" edited by Dain (1972) is very well illustrated and useful, especially for comparison of agglutinated assemblages. It is obvious that the agglutinated portion of the assemblage is well preserved and facilitated the ease of identification which is often difficult in European assemblages. This is probably a factor with most of the European publications which tend to concentrate on the calcareous taxa. Another contribution edited by Azbel and Grigyalis (1991), entitled "Practical Manual of Micropalaeontology of the SSSR. Volume 5.", is concerned with Mesozoic foraminifera. The book is also well illustrated in parts and covers the Upper Jurassic assemblages from the European part of the USSR; the Caucasus; Crimea and Middle Asia and Siberia and is useful for comparison with European illustrations of species, although the text is in Russian.

The study of Jurassic foraminifera from North America has received attention in recent years. Loeblich and Tappan (1950) describe the assemblage from the Oxfordian of South Dakota. The Redwater Shale Member produces a assemblage of 56 species of foraminifera with over two thirds of the assemblage belonging to the Lagenidae. Although 80% of the taxa are calcareous the few species of agglutinated foraminifera make up a large portion of the total assemblage due to the abundance of certain species. Tappan (1955) describes the Jurassic foraminifera from the Arctic slope of Alaska. Around 110 species are described from the Sinemurian equivalent through to the Kimmeridgian. Tappan notes that this is the first Lower Jurassic assemblage to be described from the western hemisphere and it correlates closely with the Liassic assemblages from Germany, France and England. The most fossiliferous portion of the Jurassic system in Alaska is the Middle to Upper Lias. Tappan mentions that work in England has been concentrated on the Lower Lias and, as such, only 18 species of foraminifera are common between the two areas.

Gradstein (1976, 1978) presents a biozonation scheme using foraminifera and some palynological data from eight exploratory wells from the Grand Banks ranging from the Pliensbachian through to the Tithonian. Gradstein describes 8 biostratigraphic zones. The assemblage bears little relevance to coeval North American or Alaskan assemblages but has similarities with those of Europe and northern Africa. This can be explained by the proximity of the Grand Banks with these regions during the Jurassic. Gradstein (1978) notes that the number of wells involved in his study, coupled with their small area of coverage, are inadequate to provide a comprehensive multiple biozonation for the Jurassic rocks of the Canadian and United States Atlantic margin.

Wall (1983a, b) records the biostratigraphy of foraminifera from the Eastern Sverdrup Basin, Canadian Arctic Archipelago. The assemblages are dominated by agglutinated foraminifera. Eleven foraminiferal assemblages are recognised with stratotypes selected for each assemblage. The age covered, ranges from the Toarcian (Early Jurassic) to the Campanian (Late Cretaceous).

Ascoli (1976) records the foraminiferal and ostracod biostratigraphy of the Mesozoic-Cenozoic, Scotian shelf, Atlantic Canada. Data from nine deep exploratory wells provide a detailed biozonation for the Upper Mesozoic and Cenozoic for the Scotian Shelf and southwestern Grand Banks using the four microfossil groups; planktonic foraminifera, calcareous benthonic foraminifera, agglutinated foraminifera and ostracods. Ascoli (1981) refines the previous biozonation scheme and produces another, solely for the Late Jurassic of the Scotian Shelf, using foraminifera and ostracoda. Ascoli (1984) produces a biostratigraphic scheme based on the epistominids. This is utilised across the Jurassic Cretaceous boundary on the northwestern Atlantic Shelf.

According to Shipp (1989) work from offshore areas is either not well documented or not available; some examples are Colin *et al.* (1981) and Ainsworth *et al.* (1987) who published work from the Jurassic to Cretaceous of the North Celtic Sea Basin, offshore southern Ireland, and the North Celtic Sea and Fastnet basins respectively.

1.3.7. Recent Research.

Recent work on Upper Jurassic foraminifera has come from a variety of different areas. Nagy *et al.*, (1995a) published on the foraminiferal stratigraphy from the Upper Jurassic to Lower Cretaceous deposits in Thakkhola, Nepal. The assemblage from the Oxfordian consists of highly diversified agglutinated taxa which is split by the authors into three assemblages. The assemblage, as a whole, resembles assemblages from Western Siberia, Svalbard and the Canadian Arctic Archipeligo. Nagy *et al.* (1995b), continuing this study, have applied the morphogroup scheme proposed by Nagy (1992) to interpret the environments of deposition. There is also a good correlation with the morphogroup patterns of the Jurassic assemblages from the North Sea Basin. Neagu and Neagu (1995) have published the first account agglutinated foraminifera from Upper Jurassic (Kimmeridgian) limestones from the Eastern Carpathians, Romania, from which they have been extracted using a weak acid treatment. Based on the wall structure, Neagu and Neagu (*op. cit.*) recognise four new genera and describe a assemblage composed of smaller agglutinated foraminifera.

1.4. GEOLOGICAL HISTORY.

1.4.1. Introduction.

The geological deposits preserved within Dorset range from the Devonian and Carboniferous basement rocks, comprising of either platform carbonates or phyllites, through to the periglacial deposits of the Quaternary (Figures 1.1 and 1.2). In the north Dorset area in particular, the oldest strata to appear at outcrop are the Jurassic Bridport Sands (Figure 1.2). The youngest rocks exposed are those of the Upper Greensand and Chalk from the Cretaceous. Older formations (Jurassic, Triassic, Permian and Palaeozoic) have been proved at depth by boreholes drilled for hydrocarbon exploration and BGS exploratory boreholes (e.g. The Winterborne Kingston Borehole) (Bristow *et al.*, 1995). The geology of the north

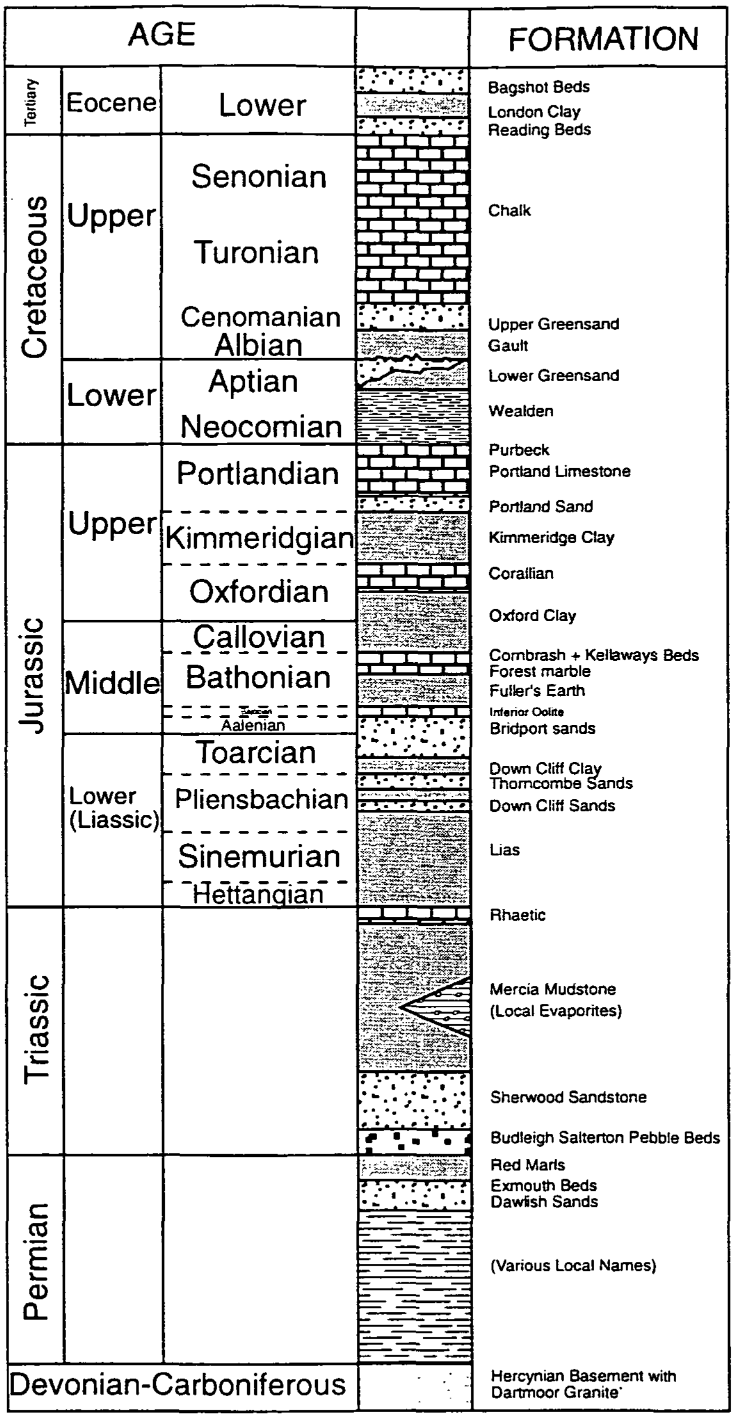


Figure 1.1. Simplified Stratigraphical Column for the Wessex Basin. (After Stoneley and Selley, 1991). Not to scale.

	Group	Formation	Member	Thickness (m)
Quaternary	Alluvium, River Terrace Deposits, Older Head, Head, Clay-with-flints			
Createaceous	Chalk Group	Upper Chalk	Spetisbury Chalk Tarrant Chalk Blandford Chalk	c.220
		Middle Chalk	Lewes Chalk New Pit Chalk Holywell Chalk	
		Lower Chalk	Zig Zag Chalk West Melbury Chalk	25-65
		Upper Greensand	Melbury Sandstone Boyne Hollow Chert Shaftesbury Sandstone Cann Sand	16-57
		Gault	sandy clay Fontmell Magna Sand sandy clay	12-25
		Lower Greensand	Bedchester Sands Child Okeford Sands	0-c.10
Jurassic		Kimmeridge Clay		42-270
	Corallian Group	Ringstead Waxy Clay		0-9
		Sandsfoot Formation	Sandsfoot Grit Sandsfoot Clay	1.8-c.12
		Clavellata Beds	Eccliffe Clavellata Beds	3-12
		Coral Rag		0-2.7
		Stour	Todber Freestone Newton Clay Sturminster Pisolite Hinton St. Mary Clay Cucklington Oolite Woodrow Clay	17-28
		Hazelbury Bryan Formation		10-52
		Oxford Clay	Stewartby and Weymouth Members Peterborough Member Mohuns Park Member	120-145
		Kellaways		20-37
	Great Oolite Group	Cornbrash	Upper Cornbrash Lower Cornbrash	6-12
		Forest Marble		30-55
		Frome Clay	Frome Clay Wattonensis Beds	45-65
		Fuller's Earth	Upper Fuller's Earth Fuller's Earth Rock Lower Fuller's Earth	66-110
		Inferior Oolite	Crackment Limestones Rubbly Beds Sherbourne Building stone Miller's Hill Beds Corton Denham Beds	25-44
	Lias Group	Upper Lias	Bridport Sands Down Cliff Clay	121-171
		Middle Lias	Marlstone Rock Bed Pennard Sands Middle Lias Silts	112-116
		Lower Lias	Green Ammonite Beds Belemnite Marls Black Ven Marls Shales-with-Beef Blue Lias	158-369
Triassic	Penarth Group	Lilstock Formation	Langport Member Cotham Member	10-28
		Westbury Formation		
	Mercia Mudstone Group			162-657
	Sherwood sandstone Group			115-209
	Aylesbeare Mudstone Group			0-350
Permian	Witch Farm Breccias			0-16
Carboniferous	Carboniferous Limestone			0-352
Devonian	?Shirehampton Beds			5+
	Phyllites			49+

Figure 1.2. Geological Succession in north Dorset. (After Bristow *et al.*, 1995). (Some informal names used).

Dorset area, which lies to the western edge of the Wessex Basin, is best described in conjunction with the history and formation of the basin, and the sequence of deposits that lie within the basin as a whole.

1.4.2. The Wessex Basin.

The following is a general account of the regional geology of the Wessex Basin. More detailed accounts of the Jurassic geology of Dorset are presented in Sections 1.4.5 and 1.4.6.

The term "Wessex Basin" was first introduced by Kent (1949) for the downwarped area of southern England "in which a broad deep basin extending from the Cotswolds southwards to Dorset and eastwards to Kent, has been modified by Tertiary folding". It is called the Wessex Basin after the ancient name for the region. Kent (1949) used this term to encompass the regions of west Kent, Sussex, Hampshire, Wiltshire and Dorset, that at the time, were believed to be underlain by a single depositional basin of Permian and Mesozoic age. Smith (1985) suggests that the term "Wessex Basin" be retained for convenience, and used to describe the same geographical area, but with the realisation that the broad Wessex Basin as defined by Kent (1949) contains a number of smaller sub-basins (Figure 1.3). It is worth noting that the terms Wessex Sub-basin or Wessex-Weald Basin are used by some authors (e.g. Brooks and Glennie, 1987), but are used to describe only the western portion of the Wessex Basin as defined by Kent (1949). The author agrees with Smith (1985) in retaining the definition as proposed by Kent (1949). This definition is the most frequently used and accepted term. The Wessex Basin as a whole, is divided into a number of smaller sub-basins and highs and has a complex tectonic history. The interesting structure, sedimentology and as a site for on-going petroleum exploration, both onshore and offshore, has made the Wessex Basin the subject of numerous papers (e.g. Kent, 1949; Hallam and Sellwood, 1976; Hudson, 1976; Ziegler, 1981; Stoneley, 1982; Lake, 1985; Smith, 1985; Sellwood *et. al.*, 1985; Whittaker, 1985, 1986; Chadwick, 1986; Sellwood *et al.*, 1986; Karner *et. al.*, 1987; Lake and Karner, 1987; Selley and Stoneley, 1987; Ruffell and Wignall, 1990; Jenkyns and Senior, 1991; Stoneley and Selley, 1991; Bradshaw *et. al.*,

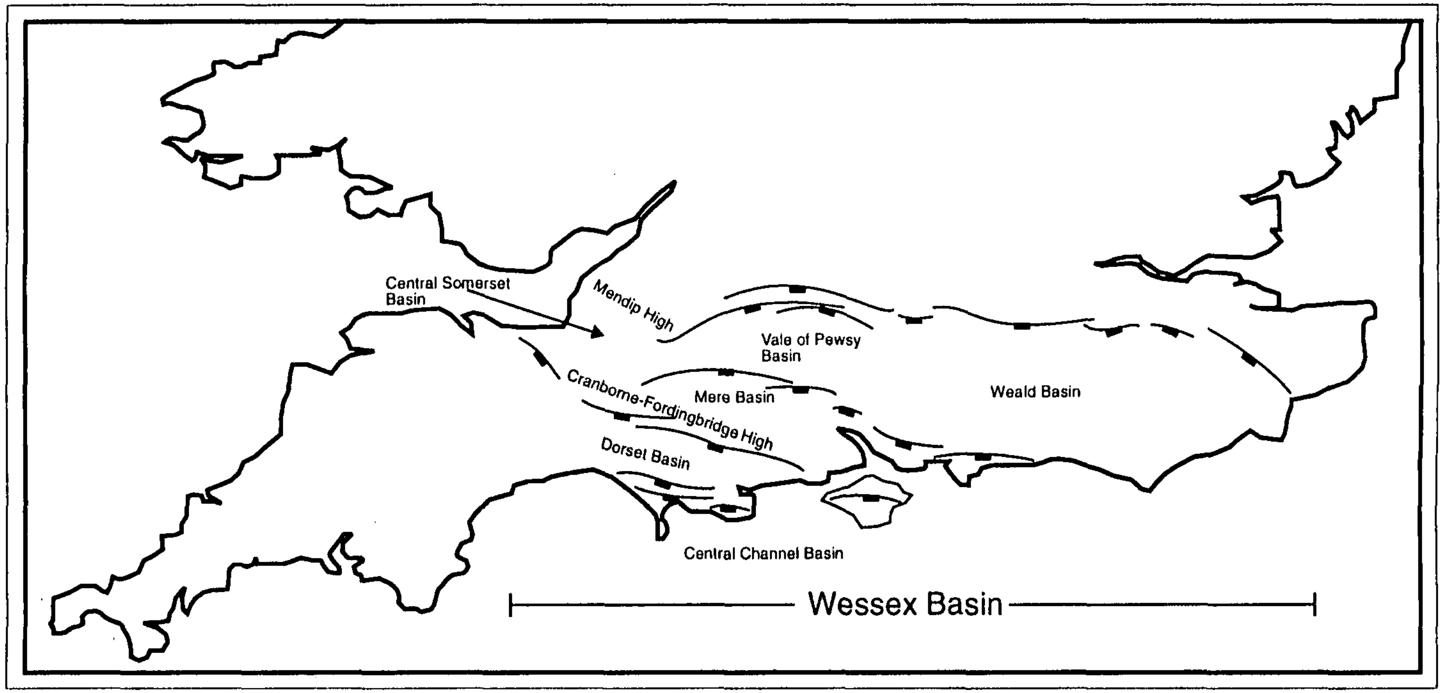


Figure 1.3. Simplified map of southern Britain showing areal extent of the Wesex Basin and component Sub-Basins. (After Smith, 1985).

1992; Melnyk *et. al.*, 1992; Miles *et. al.*, 1993; Hesselbo and Jenkyns, 1995).

For a more detailed account of the various structural and depositional aspects of the Wessex Basin the reader is referred to the above list of authors as it is beyond the scope of the present study. A generalised account of the formation, structure, tectonic framework and geological history is summarised from the above authors, and is presented below.

1.4.3. Geological History of the Wessex Basin.

A simplified stratigraphical log for the Wessex Basin is shown in Figure 1.1.

The basement rocks within the Wessex Basin are represented by a variety of Palaeozoic deposits. These beds are strongly folded and weakly metaphormosed: the argillaceous sediments show a slatey cleavage whilst the carbonate rocks are strongly fractured (Stoneley and Selley, 1991). The formation of the Wessex Basin was initiated in the Early Permian, by a period of crustal subsidence, which continued with only minor interruptions, until the end of the Cretaceous (Chadwick, 1985). This was part of the widespread post-Carboniferous subsidence of the northwestern European continental area (Ziegler, 1981). Permian deposits consist of reddened breccias and sandstones (Fig. 1.1) deposited in an alluvial or aeolian environment but with some fluvial input. These fluvial and aeolian sands alternate with often thick, red, mudstones of probable playa-lake origin. Continental red-bed, fluvial or alluvial conditions continued into and throughout most of the Triassic Period. The Lower Triassic is predominantly arenaceous as indicated by the deposition of the Sherwood Sandstone Group (Fig. 1.1). During the Late Triassic the environment changed to being fluvially dominated with aeolian influences with the deposition of the argillaceous Mercia Mudstone Group. The close of the Triassic is marked in the north Dorset area by the deposition of the shales of the Westbury Formation of the Penarth Group (Figure 1.2), which indicate the first truly marine phase. A fully marine environment prevailed throughout most of the following Jurassic Period, although the early Jurassic seas were partly stagnant and as a consequence the bottom sediments almost anoxic. The presence of bivalve and brachiopod assemblages indicate that pure anoxic conditions did not prevail. These sediments of the Lower Lias produced one of the major source-rock formations of the basin. Throughout the Lias, deposition was nearly continuous and by the late Liassic the sediment cyclicity of clay-sandstone-limestone had become established. The cyclical nature of the sedimentation is * present throughout the Jurassic (Hallam, 1975). For a summary of Jurassic sedimentary cycles see Section 1.4.7.

Mudstones are particularly prominent within the Jurassic System. Stoneley and Selley (1991) note that they occur as two distinct facies:

1. Organic-rich black laminated shales with potential as source rocks, notably in the Lower Lias (e.g. Blue Lias, and Black Ven Marls of north Dorset, Fig. 1.2), in the Callovian Oxford Clay (e.g. the Peterborough Member) and in the Upper Jurassic Kimmeridge Clay;
2. Massive grey mudstones with benthonic fossils. This type of facies occur in the Upper Lias, the Bathonian, the Upper Oxford Clay (Weymouth Member) (Figure 1.2) and the overlying Corallian Group.

Sandstones are also a prominent lithology within the Wessex Basin. In the Upper Lias the Thorncombe Sands, Downcliff Sands and Bridport Sands are well developed (Figure 1.1), while in overlying strata the sandstones tend to be more thinly developed. A shallow marine environment is suggested for their origin (e.g. the Kellaways Formation of north Dorset (Figure 1.2)).

Limestone sequences within the Wessex Basin are generally high-energy deposits, and include the condensed sequences of the Junction Bed (Upper Lias) and the Inferior Oolite (Bajocian) (Figure 1.2). The Cornbrash is a widespread marine limestone divisible into lower (Bajocian) and upper (Callovian) units, generally with a non-sequence separating the two (Bristow *et al.*, 1995). The sequence of clastic/carbonate shallowing-up cycles of the Corallian are topped by limestone deposits (e.g. Members of the Osmington Oolite Formation of the Dorset Coast and the Cucklington Oolite and Todber Freestone Members in north Dorset Fig. 1.2). The Portland Stone is a prominent sequence deposited near to the close of the Jurassic Period on the Dorset Coast. Towards the end of the Kimmeridgian, the

Jurassic seas shallowed, and, with the near emergence of the entire region, shallower-marine deposits were deposited during the Portlandian. Further shallowing, accompanied by a probable north-eastward retreat of the sea during the late Portlandian and early Cretaceous (Berriasian), led to the establishment of lagoonal environments and the sabkha and fresh water deposits of the Purbeck Beds (Bristow *et. al.*, 1995). These environments, are transitional with the Lower Cretaceous continental Wealden Beds, Figure 1.2 (Stoneley and Selley, 1991).

Following the deposition of the Wealden Beds there was uplift and erosion in the western part of the Wessex Basin. In the north Dorset area the erosion was not uniform, but was most severe over the southern part of the Cranborne-Fordingbridge High (Fig. 1.3). Here the Berriasian and Portlandian deposits and most of the Kimmeridge Clay were removed. This period of erosion manifests itself in the "late-Cimmerian Unconformity", which was a series of widespread stratigraphical breaks in the Upper Jurassic and Lower Cretaceous throughout north-west Europe (Bristow *et al.*, 1995). The deposits of the Lower Cretaceous are almost entirely composed of fresh-water, variegated clays, sands and gravels, with rare sandy limestones (Stoneley and Selley, 1991).

A series of transgressions began in the Aptian and part of the Lower Greensand was deposited during the first pulse (the Child Okeford Sands Member of north Dorset (Figure 1.2) and the Atherfield Clay Formation in south Dorset). The successive transgressions succeeded in overstepping westwards onto the eroded Jurassic surface. In north Dorset the Lower Greensand (Lower Albian Bedchester Sands Member) overlaps the Child Okeford Sands Member and is overlapped itself by the Middle Albian Gault (Bristow *et al.* 1995). Hancock (1969) notes that during the Middle Albian, marine deposition advanced around 60km westwards out of the basin on to the Cornubian Massif. Complex facies relationships exist between the overlying Gault and the Upper Greensand. The Gault was the first lithology of the Cretaceous Formations to uniformly extend across the north Dorset area. This uniformity, however, was interrupted by an important north-west-trending high, the Mid-Dorset Swell. The Mid-Dorset Swell was first described by Drummond (1970) and subsequently discussed (amongst others) by Kennedy (1970), Carter and Hart (1977) and Hart (1994) and is primarily used to explain the thinning of the Upper Greensand in north Dorset and the variation in thickness and nature of sedimentation in the Upper Albian and Cenomanian. The Cenomanian gave rise to the establishment of pure chalk seas, and clastic sedimentation ceased. Close to the end of the Cretaceous, there is marked uplift and subsequent erosion. In some areas localised vertical movements have removed the entire Cenomanian (Hart, 1982). Towards the close of the Cretaceous, Chalk sedimentation becomes more uniform, but at the close of the Cretaceous Period uplift and minor folding is followed by erosion (Bristow *et al.* 1995).

After the Cretaceous, a wide spread hiatus and unconformity follow the Chalk, preceding the Tertiary inversion movements. The majority of the Tertiary succession, extending up to the Oligocene is present on the Isle of Wight. This consists of variegated sands and clays. At the end of the Palaeogene Sub-Period, the Alpine Orogeny culminated in the inversion of the major Mesozoic basins and highs. Within the Wessex Basin the Cranborne-Fordingbridge High inverted to form the syncline underlying the Hampshire "Basin" (Bristow *et al.*, 1995).

The region of the Wessex Basin lay beyond the Pleistocene ice-sheets, but the superficial deposits show a wide range of periglacial phenomena (Stoneley and Selley, 1991). The Clay-with-flints of the north Dorset district probably formed during this period. Head deposits were also deposited during the Pleistocene and the deposition of Alluvium continued through the Holocene to the present day (Bristow *et. al.* 1995).

1.4.4. Structure And Development Of The Wessex Basin.

The Wessex Basin of southern England (Kent, 1949) (Figure 1.3), covers an onshore area of greater than 20,000 km^2 and occupies an area beneath the English Channel to the south. In total the area occupied is some 80,000 km^2. The basin is bounded in the north and east by the London-Brabant Platform, to the south by the Amorican Massif and to the west by the Cornubian Massif. It lies upon a basement consisting of predominantly Cambrian to Carboniferous deposits (Smith, 1985). The basement has been deformed by thrust related structures during the Carboniferous Variscan Orogeny. Within the basin, as discussed above, sediments of mostly Permian to Tertiary age are deposited with an average total thickness of 1500 m, and locally, exceeding 3500 m. The basin is an extensional basin, formed during the widespread post-Carboniferous subsidence of the northwestern European continental shelf area (Ziegler, 1981; Whittaker, 1985; Bradshaw, 1992).

The basin is subdivided into a number of sub-basins (Figure 1.3), these are:

- the Central Somerset Basin,
- the Vale of Pewsey Basin,
- the Weald Basin,
- the Mere Basin,
- the Dorset Basin (called the Winterbourne Kingston Trough by Lake and Karner, (1987)) and
- the Central Channel Basin (Smith, 1985; Lake and Karner, 1987).

The Wessex Basin displays two major trending tectonic lineaments. The first major structure is a series of deep seated normal faults trending east-west (Stoneley, 1982). These structures form the northern boundary of the Wessex Basin and its northern sub-basins, which developed as half grabens. The second set of faults are developed in a north-south to northwest-southeast direction, and have a sinistral strike-slip motion (Lake and Karner, 1987). Two fundamentally different interpretations have been given to explain the formation of the Wessex Basin, depending on the importance given to either the east-west or northeast-southwest trending fault systems (Karner *et al.*, 1987). In essence, the mechanism of rift basin formation can be divided into two types; those resulting from lithospheric stretching (McKenzie, 1978) and those resulting from crustal/upper crustal extension (Royden *et. al.*, 1983; Karner and Dewey, 1986; Karner *et. al.*, 1987). Recent papers outlining models for the formation of the Wessex Basin have also followed one of the two mechanisms mentioned above. Chadwick (1986) favours McKenzie's (1978) model and discusses the Wessex basin in terms of lithospheric extension, whereas Karner *et. al.* (1987) propose a model which consists of a smoothly varying subsidence, punctuated with a number of rapid, but smaller, subsidence events. This is a modification of the Royden *et. al.* (1983) and Karner and Dewey (1986) models.

During the Late Cretaceous-Early Tertiary, major inversion of the Wessex Basin was initiated which culminated in the Oligocene-Miocene (Late Alpine "Helvetic phase") and terminated the development of the Wessex Basin (Karner *et. al.*, 1987). This inversion principally manifested itself in the uplift of Mesozoic basins and subsidence of Mesozoic highs. The amount of uplift is greater in the southern part of the Wessex Basin (Lake and Karner, 1987).

At the surface, the Wessex Basin comprises wide areas of gently dipping strata in a classic layer-cake geological structure, separated by narrow belts of monoclinic flexuring. The importance of the inversion of the Wessex Basin is in the formation of localised monoclinic flexures, which influence the subsequent accumulation of sediment. The Purbeck-Isle of Wight Flexure is an example of this and dominates the geology of southern Dorset (Stoneley and Selley, 1991) and, in turn, influences the accumulation of early Cretaceous deposits.

1.4.5. Lithostratigraphy of the Dorset coast.

The Jurassic geology of Dorset is magnificently exposed in the cliffs between Lyme Regis and Swanage on the Dorset Coast. The complete succession from the Corallian Group, (including the type sections), into the Kimmeridge Clay Formation is exposed here. The type section for the Lower Kimmeridgian, as designated by Ziegler (1962), is also exposed at Black Head. The Weymouth Member of the Oxford Clay (formally the Upper Oxford Clay) is exposed and the sections at Furzy (or Jordan) Cliff and Ham Cliff have recently been designated as reference sections by Cox *et. al.* (1992). The junction between the Oxford Clay Formation and the Corallian Group is also located at Furzy Cliff. This coastal area has been the subject of intense sedimentological, stratigraphic, palaeo-environmental, palaeogeographic, palaeontological and recently sequence stratigraphic studies. As such, this succession represents a very important section in the study of the Upper Jurassic and therefore a summary of the lithologies is given below.

1.4.5.1. Dorset Coast Nomenclature.

During the late 18th century the sub-division of the British Upper Jurassic first appeared as an unpublished stratigraphical table by William Smith. This table was designed to accompany the first geological map ever made which illustrated the geology in a 5 mile radius around Bath. This list (referred to as the manuscript table of William Smith, 1799) was not published but subsequently appeared in the literature as friends of Smith began to publish his ideas. However, as Arkell (1933) mentions Townsend (1813) published a stratal list based on Smiths findings but "at the same time paying a handsome tribute to his teacher". This table of Jurassic Strata was clarified and published by Smith (1815-16) and Buckland (1818). This classification has changed little, and the commonly accepted divisions were published by Arkell (1933, 1947). The stratigraphic nomenclature was revised by Cope *et al.*, (1980) and subsequently by Wright (1986b), which is the nomenclature currently used today (Figure 1.4).

	Stage	**Group**	**Formation**	**Member**
Upper Jurassic	Kimmeridgian		Kimmeridge Clay	
	Upper Oxfordian	Corallian Group	Ringstead	Ironstone / Coralbed
				Waxy Clay
			Sandsfoot	Sandsfoot Grit
				Sandfoot Clay
			Clavellata Beds	Red Beds
				Clay Band
				Chief shell Beds
				Sandy Block
	Middle Oxfordian		Osmington Oolite	Nodular Rubble
				Shortlake
				Upton
			Red Cliff	Bencliff Grit
				Nothe Clay
				Preston Grit
	Lower Oxfordian		Nothe grit	
			Oxford Clay (Weymouth Member)	Bowleaze Clays "Bed"
				Jordan Cliff Clays "Bed"
				Furzedown Clay "Bed"

Figure 1.4. Lithostratigraphic nomenclature for the Corallian Group and Oxford Clay Formation (*pars.*) of the Dorset Coast.

1.4.5.2. Summary of lithologies.

The Oxfordian and Kimmeridgian Periods are represented on the Dorset Coast by a complex series of carbonate and siliciclastic rocks, generally of shallow marine origin. The Oxfordian and Kimmeridgian strata for the Dorset Coast is presented in Fig. 1.4. Lithological descriptions are synthesised from Allen and Underhill (1989), Arkell (1933, 1936, 1947), Brookfield (1973, 1978), Callomon and Cope (1995), Coe (1995), Cope (1995), Fürsich (1973, 1974, 1975, 1976), House (1985, 1993), Sun (1989, 1990a, b), Talbot (1973) and Wright (1986a, b)

Oxford Clay Formation.

The Weymouth Member of the Oxford Clay Formation is exposed at Furzy Cliff [SY 700 818]. It is currently the only good exposure of this member in the Wessex Basin (Coe, 1995). The division of the Weymouth Member follows Buckman (1925) who was the first to note the three-fold subdivision. This was subsequently revised by Arkell (1947) and is commonly used at present with minor alterations. The three units comprising the Weymouth Member will be informally referred to as Beds in the following synthesis, following the recent re-classification of the Oxford Clay as a Formation by Cox *et al.* (1992), previously these units were referred to as members of the Upper Oxford Clay Formation. The division, from the lowest stratigraphic position, to the highest, is as follows: Furzedown Clay Bed, Jordan Cliff Clays Bed and Bowleaze Clays Bed. The lowermost bed is not exposed on the Dorset Coast. The Weymouth Member of the Dorset coast was deposited in a more marginal marine environment than that of the Midlands, and clastic sedimentation occurs at various horizons (Wright, 1986b).

Jordan Cliff Clays "Bed".

This bed comprises of grey claystones with fine sand and silt and tough blocky silty clay. The percentage of fine sand increases to 5% then decreases towards the top of this bed (Wright, 1986b). The assemblage consists of numerous *Gryphaea dilitata* and also *Isognomon*, *Lopha* and *Modiolus* (Coe, 1995).

Bowleaze Clays "Bed".

These clays are predominantly very fine grained, but with frequent incursions of sandy clay (Wright, 1986b). The base is marked by a layer of tabular limestones nodules. The following clay comprises interbedded pale and dark clays and carbonaceous dark clays. These clays are overlain by the Red Nodule Beds (Wright, 1986b), which comprise a mudstone with two layers of red-stained sideritic concretions. The top of this bed is composed of pale grey, very fine clay with infrequent smaller nodules.

CORALLIAN GROUP.

The Corallian Group is divided into 6 formations, the Nothe, Redcliff, Osmington Oolite, Trigonia Clavellata Beds, Sandsfoot and Ringstead Formations (Wright, 1986b).

Nothe Grit Formation.

This is a fine-grained, sub-rounded and fairly well-sorted sand with the frequent development of calcareous concretions (Wright, 1986b). Coe (1995) however, refers to carbonate-cemented units, one of which is a prominently cemented with abundant sponge spicules near the middle of the formation. Fossils include an abundant bivalve assemblage (Wright, 1986b), including *Lopha*, *Chlamys* and *Gryphaea*. Some beds are highly bioturbated. The environment of deposition is thought to be an open marine near shore.

Redcliff Formation.

This formation consists of the Preston Grit, Nothe Clay and Bencliff Grit Members.

Preston Grit Member.

This member consists of one massive bed although split into two parts; the lower consisting of soft, argillaceous fine-grained sandstones and the upper consisting of medium-grained, shelly, calcareous sandstone. It is sometimes pebbly and immature ooliths are visible in thin section (Wright, 1986b). Coe (1995) suggests that the pebbles are of Triassic mudstone and quartz. Arkell (1936, 1947) records a list of fossils dominated by *Chlamys* and *Pleuromya* and Fürsich (1976) records a macroassemblage referred to his *Pleuromya uniformis*

Association. This Association includes the trace fossils *Spongeliomorpha suevica*, *Teichichnus rectus* and *Chondrites*.

Nothe Clay Member.

The Nothe Clay Member consists of a grey mudstone with 8 limestone bands of differing composition (Coe, 1995). Bivalves are common, as are brachiopods, gastropods and echinoderm fragments, sponge spicules and intraclasts of bioclastic sandstone are present in the interbedded limestones (Sun, 1989). There is a gradual increase in fine sand towards the top of the Nothe Clay Member. The environment of deposition is interpreted as an offshore shelfal deposit which accumulated under quiet water conditions (Coe, 1995).

Bencliff Grit Member.

According to Allen and Underhill (1989) three separate lithofacies can be recognised within the Bencliff Grit Member. These are a sandstone facies, a heterolithic facies and a mudstone facies; the sandstone facies forming 85-90% of the lithology. Allen and Underhill (1989) conclude, that the Bencliff Grit Member contains unusual bedforms, analogous to swaley cross-stratification or amalgamated hummocky cross-stratification. These bedforms are thought to have formed by primarily unidirectional currents carrying large amounts of fine sand in suspension. The intervening heterolithics contain climbing and non-climbing ripples and mudstone drapes giving a flaser bedded appearance. Allen and Underhill (1989) envisage a mechanism of deposition for each facies. The sandstone facies formed by erosional and depositional processes, primarily by unidirectional currents; the heterolithic facies indicates reversing flows of tidal or gravity wave frequency and the mudstone facies represents a quieter-water period with fall-out from suspension.

The macroassemblage recovered from the Bencliff Grit Member do not provide any additional palaeo-environmental indications (Allen and Underhill, 1989). Fresh-water tolerant ostracods however, have been reported (Whatley, 1965). The ichnoassemblage is dominated by *Diplocraterion parallelum*, *D. habichi*, *Spongeliomorpha suevica* and *Planolites*, all of which are indicative of a high energy environment (Fürsich, 1975).

The evidence suggests that the Bencliff Grit Member was deposited under high energy conditions, close to land and with occasional tidal influences, possibly near the mouth of an estuary (Coe, 1995).

Osmington Oolite Formation.

The term Osmington Oolite was first used informally by Blake and Hudleston (1877). Arkell (1933, 1936, 1947) applied the name to a section of the Dorset coastal succession and divided the formation into a series of informal beds. Wright (1980) classed the unit as a formation and proposed the formal introduction of three members; the Upton Member; the Shortlake Member and the Nodular Rubble Member (Wright, 1986b).

Upton Member.

The Upton Member is composed of several thin argillaceous limestones separated by mudstones (Coe, 1995). Wright (1986b) notes that individual units can be traced over several kilometers. The limestones vary in composition from sparsely oolitic, containing sand and clay to oncolitic/pisolitc (with ooids) to nodular and micritic, interbedded with clays. All limestone beds contain shelly material. The intervening mudstones are sandy with scattered ooliths and form coarsening-up sequences with the limestones (Coe, 1995).

The assemblage is diverse including ammonites, bivalves and gastropods. The oyster *Nanogyra nana* and *Chlamys qualicostata* are very abundant (Bed 2 of the Osmington Oolite is named the *C. qualicostata* Bed (Arkell, 1936)). Ichnoassemblage are well represented with an assemblage including *Thalassinoides*, *Diplocraterion*, *Gyrochortye*, and *Rhizocorallium* (Fürsich, 1975). According to Fürsich (1973) the trace fossil *Thalassinoides* contributes to the origin of the nodular limestones; organic material or the lining of the burrow serves as a nucleus for $CaCO_3$ precipitation.

The Upton Member represents a transgressive succession as the lower boundary represents a minor unconformity (Coe, 1995).

Shortlake Member.

This member is composed of cross-bedded oolitic grainstones, bioturbated oolitic packestones and wackestones, clays and nodular wackestones, interbedded with calcareous claystones and mudstones. Flaser bedding is also present in the cross-bedded oolites (Sun, 1989).

This member represents an oolitic shoal environment progressively smothered by clays (Coe, 1995).

Nodular Rubble Member.

The Nodular Rubble Member consists of cream coloured nodular limestone, alternating with thin calcareous clay (Sun, 1989). Coe (1995) noted that the nodules consisted of *Rhaxella* biomicrites and that the surrounding clay laminae were deformed around the nodules. The trace fossils are characterised by *Thalassinoides* and *Teichichnus*. According to Sun (1989) the associated assemblage is indicative of a restricted environment including gastropods, foraminifera, euryhaline bivalves, ostracods and abundant sponge spicules (Sun, 1989). As with the limestones within the Upton Member the nodular limestone is thought to have been formed through the precipitation of $CaCO_3$ within *Thalassinoides* burrows (Fürsich, 1973).

According to Wright (1986b) the Nodular Rubble Member was deposited in a quiet deep water marine environment, favouring the growth of the sponge *Rhaxella.*

Trigonia Clavellata Formation.

Originally this formation was named the "Trigonia-beds" of Weymouth by Blake and Hudleston (1877). Arkell (1936, 1935-48, 1947) designated the type-section at Bran Point [SY 743 813], and produced detailed measured sections and his 4-fold division of this formation has been followed by most subsequent workers (Wright, 1986b). The Trigonia Clavellata Formation is divided into the Sandy Block Member, the Chief Shell Beds Member, the Clay Band Member and the Red Beds Member. The faunal diversity within this formation is the highest in the Corallian (Fürsich, 1976).

Sandy Block Member.

This member consists of a sandy, sparsely oolitic micritic limestone, divisible into 4 beds separated by thin argillaceous beds (Coe, 1995). Sand-filled burrows extend down into the Nodular Rubble Member (Wright, 1986b). The sand content of this member can be as high as 35% (Sun, 1989). The assemblage is dominated by bivalve and echinoid fragments. Ammonites, gastropods and bivalve body fossils are also present.

A distinct biostratigraphical hiatus separates the Sandy Block Member and the preceding Nodular Rubble Member (Wright, 1968b) and, according to Coe (1995), this unconformity is present throughout the Wessex Basin interpreted by Coe as the start of a transgressive phase.

Chief Shell Beds Member.

The Chief Shell Beds Member is a sandy, bioclastic, peloidal packstone, so named because of the abundance of the bivalve *Myophorella clavellata*, formally *Trigonia*. Sun (1989) notes that the quartz sand content is significantly less than the other members in this Formation and comprises less than 25%. Peloids and bioclastic fragments are common. This member can be divided into 5 beds at Black Head [SY 728 819] the 4th bed from the base being a very distinctive red-coloured shelly, siderite-cemented limestone (Coe, 1995).

Clay Band Member.

The third member of the Trigonia Clavellata Beds Formation is a mudstone with occasional ooids (Coe, 1995), described by Sun (1989) as an argillaceous, bioclastic, intraclastic packestone. Fossils include echinoderm and bivalve fragments. Sun (1989) also describes common intraclasts with a composition reflecting the lower Chief Shell Beds Member.

Red Beds Member.

The upper member of this formation, the Red Beds Member, comprises alternations of oolite with sideritic micrite, capped by shelly impure limestone (Wright, 1986b). Sun (1989) describes this member as a bioclastic wackestone and packstone and notes that bivalve fragments are common. The trace fossils are characterised by *Thalassinoides* (Sun, 1989).

Coe(1995) interprets the Trigonia Clavellata Beds Formation as a transgressive deposit with each of the members representing a different phase within the transgression.

Sandsfoot Formation.

Sandsfoot Clay Member.

This member was first described by Blake and Hudlestone (1877) who designated the type section at Castle Cove, south of Weymouth. This section is now grassed over, but around 4 m of the Sandsfoot Clay is exposed at Black Head, close to Osmington Mills, on the Dorset Coast (Coe, 1995).

The Sandsfoot Clay Member comprises a soft calcareous, silty clay with occasional lenses of sandstone and some light and dark banding (Coe, 1995).

The assemblage is impoverished with occasional *Deltoideum delta*, and other small bivalves. Belemnites are also present (Brookfield, 1978).

Brookfield (1978) studied coarse fractions from the Sandsfoot Clay and noted that it can be compared with the marginal low-salinity bay and open lagoonal environments of the Gulf of Mexico. This is consistent with Talbot's (1973) model of change from the offshore shelf environment of the Red Beds Member into the barrier sands of the Sandsfoot Grit.

Sandsfoot Grit Member.

According to Coe (1995) the Sandsfoot Grit member is stratigraphically complex. Wright (1968b) measured 11.3 m of this member and divided it into 5 units. This differs from Brookfield (1978) who divided the member into 3 units. Wright (1968b) notes that Brookfield (1978) had previously confused beds IV and V of Wright (*op. cit.*) as the recurrence of his units I-III. Coe (1995) mentions that only beds I-III are present at Black Head. The first unit consists of poorly cemented red sand, with phosphate nodules and fossil lag at the base. Unit II is a soft un-cemented clayey sand. The 3rd unit is a prominent red band consisting of medium grained sand with some clay. This upper unit is intensely bioturbated, with a rich bivalve assemblage, common ooids and scattered black quartz pebbles (Coe, 1995).

The Sandsfoot Grit Member is interpreted as having been deposited in a shallow water environment, generally above wave base. It also resembles the sub-tidal environment of a beach bar complex Brookfield (1978).

Ringstead Formation.

The Ringstead Formation sharply overlies the Sandsfoot Grit Member and is divided into the Ringstead Waxy Clay Member and the Osmington Mills Ironstone Member.

Ringstead Waxy Clay Member.

This member is a light-grey calcareous clay about 3.75 m thick (Coe, 1995). Brookfield (1978) records a thinly bedded blue silty clay, interbedded towards its top with thinly bedded, orange-weathering, ferruginous calcareous silty clays. A line of carbonate concretions is commonly developed at the top of this member.

Brookfield (1978) states that the sand fraction and macroassemblage resemble the deeper areas of open, high-salinity bays of the Gulf of Mexico. He disagrees with Talbot's (1973) model of a lagoonal environment.

Osmington Mills Ironstone Member.

Following Brookfield (1978), the Ringstead Coral Bed of Arkell (1929-37) is regarded as a facies of the much more widespread Osmington Mills Ironstone (Wright, 1968b). The ironstone consists of a thin, very varied, limonite-oolite marl, occasionally well enough cemented to form an impure limestone (Wright, 1968b). Coe (1995) notes that the member shows many features indicative of condensation including an abundant and diverse assemblage, evidence of boring, encrustation and the formation of phosphate nodules and iron ooids. This member also includes the Ringstead Coral Bed (Arkell, 1936, 1947).

Kimmeridge Clay Formation.

The Kimmeridge Clay Formation is one of the thickest formations of clay in the British Jurassic. Conventionally it is divided into the Lower Kimmeridge Clay and the Upper Kimmeridge Clay although, lithologically, it can be divided into 4 distinct informal units (Callomon and Cope, 1995).

The Kimmeridge Clay varies from bioturbated shelly clays with highly bituminous layers, to laminated sapropelic shales and thin dolomitized stone beds, to less shelly, silty clays with few bituminous layer (Callomon and Cope, 1995). The Kimmeridge Clay consist of a sedimentary cyclicity consisting of clay, bituminous clay, oil shale, and coccolith limestone. Cox and Gallois (1981) have traced these sedimentary cycles widely over southern Britain.

The depositional models for the cyclic sediments of Kimmeridge Clay have been the subject of many papers (e.g. Hallam, 1975; Tyson *et. al.*, 1979; House, 1985, 1987; Oschmann, 1988; Wignall, 1989; Hart and Fitzpatrick, 1995). In general the formation was deposited in a complex setting encompassing a range of dysaerobic or anaerobic environments.

1.4.6. Lithostratigraphy of north Dorset.

The Upper Jurassic succession of north Dorset has, until recently, remained one of the least studied areas in the British Jurassic. Prior to the work of Wright (1981), the only published maps for the area were the original 1-inch maps for Shaftesbury and Wincanton, first mapped in the 1850s (published as Memoirs of the Geological Survey of England and Wales). These maps underwent only limited subsequent corrections. Following an extensive field-mapping programme (1986-1990) the British Geological Survey (BGS) have now re-mapped and re-issued the maps for Shaftesbury (Sheet 313) and Wincanton (Sheet 297) along with the accompanying memoirs (Bristow *et al.*, 1995).

1.4.6.1. North Dorset Nomenclature.

Oxford Clay Formation.

Within the north Dorset area very little is known of the stratigraphy at outcrop of the Oxford Clay. As part of the field mapping of this area the BGS have gained more information and Bristow, Cox and Wilkinson (1989) published results in a paper on the stratigraphy. Few exposures of the Oxford Clay exist within this area and most information was from a sewerage pipe-line trench. This trench was dug during 1986 and was visited by the authors. Museum material deposited by Woodward (1895) was also re-examined. As a result the stratigraphy of the Oxford Clay for the north Dorset area is presented in Bristow *et. al.* (1995). Following Cox, Hudson and Martill (1992), the BGS classify the Oxford Clay as a Formation. Within the Oxford Clay Formation the three basic subdivisions are given the status of Members by the BGS and are renamed the Peterborough Member (for the Lower Oxford Clay), the Stewartby Member (for the Middle Oxford Clay) and the Weymouth Member (for the Upper Oxford Clay). The division between the Stewartby Member and the Weymouth Member is delineated by the Lamberti Limestone in the type area of Oxfordshire. In north Dorset the marker limestone is absent and, as a result, the clays above the Peterborough Member are recorded as a single unit (Stewartby and Weymouth Members (undivided)) by the BGS (Bristow *et al.*, 1995).

Corallian Group.

The earliest published account of the Corallian rocks of north Dorset is included in the work by Blake and Hudleston (1877), entitled "On the Corallian rocks of England". In "Part II, The north Dorset District", Blake and Hudleston examined a number of sections within the area. Some of the best exposures were those in the Gillingham railway cutting and in the quarries at Cucklington, Todber and Langham. Perhaps the most important section was that recorded in the Sturminster Newton railway cutting which, in the words of Blake and Hudleston, "affords a magnificent section, which to a large extent serves as a key to the whole district, the other developments being best understood by their relation to the rocks here exposed". This section was seen by Blake and Hudleston to be around 77ft (~ 23.5 m) in thickness and almost the entire Corallian section above the Hazelbury Bryan Formation was formerly exposed here. In Part I of that study Blake and Hudleston examined the Corallian rocks around Weymouth on the Dorset Coast, and introduced many of the names for lithologies which have persisted in the literature and were accepted as standard, *e.g.* the Nothe Grit, Nothe Clay and Osmington Oolite. Although much of the succession in north Dorset was described in detail, no new names were introduced for the lithologies. The section at the Sturminster Newton railway cutting encompasses most of the strata encountered in the north Dorset area and as this section has subsequently been referred to by various authors, it has become accepted as the standard for the Corallian of the north Dorset area. The following section from the Sturminster Newton Railway-cutting is summarised from Blake and Hudleston (1877) in descending order:

No. 1. Yellow argillaceous sands ("Foxy sands"). 14' 0".

No. 2. Blue marl and clay, with numerous small oysters. 8' 6".

No. 3. Calcareous sandstone graduating downwards into rubbly limestone bands with marly partings. 8' 9".

No. 3a. Light-blue marl, with light rubbly limestone concretions at the top. 4' 6"

No. 3b. Rough limestone, shelly and hardened towards the upper part, thin bed of blue clay below. This contains a few oolitic grains of all sizes up to that of a pea. Fossils include: *Trigonia clavellata.* 2' 3".

(Nos. 3-3b collectively known as "Upper Calcareous Series").

No. 4. Rubbly limestone ("*Florigemma* limestone"). Fossiliferous with reworked and transported fossils. 9' 0".

No. 5. False-bedded series, shell limestones of varying hardness. 15-18'

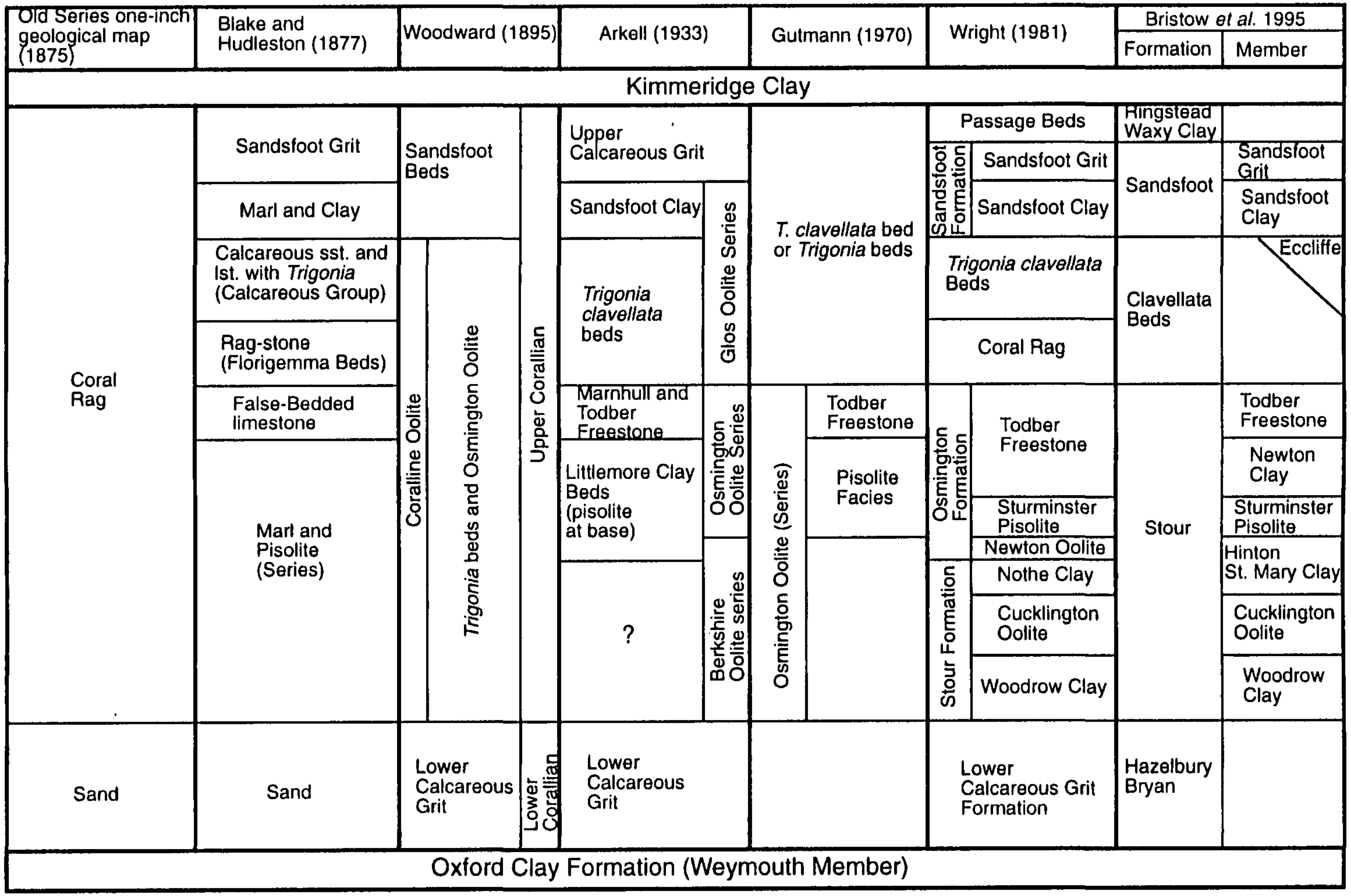
No. 6. Black and white rubbly marl. 8' 0"

No. 6a. Loose Pisolite of large flattened concretions. 1' 0"

No. 6b. Oolitic marl with large grains. 3' seen.

The lithostratigraphy is summarised in Fig. 1.5.

Following on from the work by Blake and Hudleston, two Memoirs of the Geological



<table>
<tr><th rowspan="2">Old Series one-inch geological map (1875)</th><th rowspan="2">Blake and Hudleston (1877)</th><th rowspan="2" colspan="3">Woodward (1895)</th><th rowspan="2" colspan="2">Arkell (1933)</th><th rowspan="2" colspan="2">Gutmann (1970)</th><th rowspan="2" colspan="2">Wright (1981)</th><th colspan="2">Bristow <i>et al.</i> 1995</th></tr>
<tr><th>Formation</th><th>Member</th></tr>
<tr><td colspan="13">Kimmeridge Clay</td></tr>
<tr><td rowspan="12">Coral Rag</td><td rowspan="2">Sandsfoot Grit</td><td rowspan="3" colspan="2">Sandsfoot Beds</td><td rowspan="12">Upper Corallian</td><td rowspan="2" colspan="2">Upper Calcareous Grit</td><td rowspan="5" colspan="2"><i>T. clavellata</i> bed or <i>Trigonia</i> beds</td><td colspan="2">Passage Beds</td><td>Ringstead Waxy Clay</td><td></td></tr>
<tr><td rowspan="2">Sandsfoot Formation</td><td>Sandsfoot Grit</td><td rowspan="2">Sandsfoot</td><td>Sandsfoot Grit</td></tr>
<tr><td>Marl and Clay</td><td>Sandsfoot Clay</td><td rowspan="3">Glos Oolite Series</td><td>Sandsfoot Clay</td><td>Sandsfoot Clay</td></tr>
<tr><td>Calcareous sst. and lst. with <i>Trigonia</i> (Calcareous Group)</td><td rowspan="9">Coralline Oolite</td><td rowspan="9"><i>Trigonia</i> beds and Osmington Oolite</td><td rowspan="2"><i>Trigonia clavellata</i> beds</td><td colspan="2"><i>Trigonia clavellata</i> Beds</td><td rowspan="2">Clavellata Beds</td><td rowspan="2">Eccliffe</td></tr>
<tr><td>Rag-stone (Florigemma Beds)</td><td colspan="2">Coral Rag</td></tr>
<tr><td>False-Bedded limestone</td><td>Marnhull and Todber Freestone</td><td rowspan="3">Osmington Oolite Series</td><td rowspan="7">Osmington Oolite (Series)</td><td>Todber Freestone</td><td rowspan="3">Osmington Formation</td><td rowspan="2">Todber Freestone</td><td rowspan="7">Stour</td><td>Todber Freestone</td></tr>
<tr><td rowspan="6">Marl and Pisolite (Series)</td><td rowspan="3">Littlemore Clay Beds (pisolite at base)</td><td rowspan="2">Pisolite Facies</td><td>Newton Clay</td></tr>
<tr><td>Sturminster Pisolite</td><td>Sturminster Pisolite</td></tr>
<tr><td rowspan="4">Berkshire Oolite series</td><td rowspan="4"></td><td colspan="2">Newton Oolite</td><td rowspan="2">Hinton St. Mary Clay</td></tr>
<tr><td rowspan="3">?</td><td rowspan="3">Stour Formation</td><td>Nothe Clay</td></tr>
<tr><td>Cucklington Oolite</td><td>Cucklington Oolite</td></tr>
<tr><td>Woodrow Clay</td><td>Woodrow Clay</td></tr>
<tr><td>Sand</td><td>Sand</td><td colspan="2">Lower Calcareous Grit</td><td>Lower Corallian</td><td colspan="2">Lower Calcareous Grit</td><td colspan="2"></td><td colspan="2">Lower Calcareous Grit Formation</td><td>Hazelbury Bryan</td><td></td></tr>
<tr><td colspan="13">Oxford Clay Formation (Weymouth Member)</td></tr>
</table>

Figure. 1.5. Evoultion of the lithostratigraphic nomenclature of the Corallian Group in north Dorset. (After Bristow *et al.*, 1995).

Survey were published. The first by H W Woodward entitled "The Jurassic rocks of Britain, Vol. 5, The Middle and Upper Oolitic rocks of England (Yorkshire excepted)" was published in 1895. In this account Woodward describes the sections recorded by Blake and Hudleston and mentions some new ones. Woodward re-interprets the lithologies in the Sturminster Newton railway cutting and also attributes some of Blake and Hudlestons' south Dorset names to the strata observed in the north Dorset succession (Fig. 1.5). In particular he groups Beds 1-4 of Blake and Hudleston as the "Trigonia Beds and Osmington Oolite" and Beds 5 and 6 as the "Sandsfoot Beds". Woodward also lists all the macrofossils found in the limestone beds at Sturminster Newton.

In 1923 the other relevant Geological Society Memoir was published by White. This was entitled "The Geology of the country south and west of Shaftesbury". White re-describes sections visited by previous authors, but records no new sections. White modifies Blake and Hudlestons' figure of the Sturminster Newton railway cutting and a generalised section of the Corallian beds near Sturminster Newton and Marnhull is produced. This section comprises of 7 divisions. These are, in descending order:

G: Ferruginous sands and Sandy Clays
F: Marl and Clay
E: Calcareous Sandstones and Limestones with *Trigoniae*
D: Rag-Stones (Florigemma Beds)
C: False-Bedded Limestones.
B: Marls and Pisolites.
A: Clays and Sands ("Lower Calcareous Grit")

White also attempted the first correlation of the north Dorset strata with the succession of the Dorset Coast, which is shown below.

G-F: Sandsfoot Grit Member and Clay Member.
E-B: Trigonia Beds Formation and Osmington Oolite Formation.
A: Bencliff Grit Member and "Nothe Beds".

This correlation has subsequently been accepted by most authors. A minor difference is that White included the Bencliff Grit, Nothe Clay and Nothe Grit of the coastal succession as correlatable with the Lower Calcareous Grit (Hazelbury Bryan Formation of this thesis). Subsequent authors omit the Bencliff Grit from this correlation. Arkell (1947) correlates only the Nothe Grit with the Hazelbury Bryan Formation.

Arkell (1927) includes north Dorset in a correlation table and introduces the name "?Limestone of Langham and Cucklington". Other than this Arkell's only published account of the geology of north Dorset is a small section of his 1933 publication. Arkell (1933) includes only brief descriptions of the various lithologies and the introduces the name "Marnhull and Todber Freestone" for the "false bedded limestone" of Blake and Hudleston. In a later publication Gutman (1970) mentions that Arkell had in fact surveyed the area with an intention of publishing his work in a Dorset Archaeological and Natural History Society publication, to follow on from his first paper on the Dorset Coast. His premature death, however, precluded this and thus the completion of his project of mapping the Corallian Beds from Oxford to the south coast was prevented (Wright, 1981). Arkell frequently mentions the north Dorset area in his monograph on Corallian bivalves (1929-1937).

Mottram (1956), reporting on a field meeting during which a few localities in north Dorset were visited, presents some useful stratigraphic information. The first locality visited was the Vale of Wardour, where the Gault and Lower Greensand was examined. Mottram also describes some of the exposures of the Corallian rocks and records details of the ammonites found in the Clavellata Beds and Todber Freestone. No new sections are described.

Gutman (1970) details two quarries from the centre of the area. Although working on a small area, he concludes that there is a close correlation with the inland Corallian Beds exposed at Lisieux and Glos (Normandy), and a similarity in the assemblage with the widespread occurrence of the gastropod *Pseudonerinea clytia*. A list of macroassemblage is also provided for the north Dorset Corallian beds and some of the more important taxa are illustrated in 3 plates, (Gutman, 1970, pl. 3, figs 1-11; pl. 4, figs 1-5; pl. 5, figs 1-3).

According to Wright (1981) the problems associated with the stratigraphic succession in north Dorset had, until that point, not been addressed in any great detail. During 1978-1979, Wright conducted a mapping project on the scale of 1:25,000, taking advantage of many temporary exposures (gas trenches, road cuts, pits etc.). Over 300 hand specimens were taken for laboratory analysis with attention being paid to the bivalve, ammonite and echinoderm assemblages. The results were published in 1981. Wright examined many new sections and re-interpreted some of the previous sections. He elaborated the stratigraphic sequence described by Blake and Hudleston (1877) and introduced new formations and members. These are compared in Fig. 1.5. Following Brookfield (1978), Wright uses the lithological names defined in south Dorset for the north Dorset area. These are the Passage Bed Formation, the Sandsfoot Formation and the Trigonia Clavellata Formation. The Coral Rag and Osmington Oolite of Blake and Hudleston (1877) are regarded by Wright as being of formational status. The Osmington Oolite Formation in north Dorset is divided into 3 members by Wright (1981): the Todber Freestone Member as used by Arkell (1933); the Sturminster Pisolite Member, informally used by White (1923) and a new name introduced by Wright, the Newton Oolite Member. A new formation name introduced was the Stour Formation which includes the alternating lithologies of clay/limestone/clay between the Lower Calcareous Grit Formation and Osmington Oolite Formation. The Stour Formation includes the Nothe Clay Member which Wright correlated with the same clay on the Dorset coast. The Cucklington Oolite Member is named after Arkell's (1927) "? Limestone of Langham and Cucklington". Wright also introduced the Woodrow Clay Member for the persistent band of clay lying between the Cucklington Oolite Member and the Lower Calcareous Grit Formation. The Lower Calcareous Grit Formation was introduced by Talbot (1973). Wright (1981) comments that the Stour Formation had not been recognised by previous authors (Blake and Hudleston, 1877; White, 1923) and that they had confused the Oxford Clay Formation and the Nothe Clay Member in places. Where oolite was seen to be resting on clay, these authors considered it to be the Osmington Oolite, which had overstepped the Lower Calcareous Grit Formation to rest on the Oxford Clay Formation. Wright (1981) points out that earlier authors also failed to distinguish the Osmington Oolite when it lay unconformably on the Cucklington Oolite Member, treating the two separate lithologies as a complete succession. Wright (1981) constructed maps for the whole Corallian outcrop in north Dorset and correlated the sequences with those of the Dorset Coast.

The next revision of the terminology was during 1989-1990 when the British Geological Survey (BGS) implemented an extensive mapping programme of the Shaftesbury and Wincanton areas. The results were published as a series of Technical Reports (Onshore Geology Series) culminating in the printing of the new Shaftesbury Geological Map (313) and its accompanying memoir (Bristow *et al*, 1995).

As a result of this re-survey by the BGS the stratigraphic nomenclature for the north Dorset Corallian has altered considerably from that of previous authors and a number of new formation and member names have been introduced. The new terminology is, in part, based on the work of Wright (1981), but with some modifications (Fig. 1.5). According to Bristow (1989b), the BGS geologists noticed mistakes on the field slips and overlays obtained from J. K. Wright of the north Dorset Corallian, which led to a revision of his terminology. Bristow (*op. cit*) notes that Wright's maps were not, strictly, geological maps derived from the following of outcrops in the field, but were constructed by joining similar outcrops with straight lines which paid little or no attention to the topography. This led to some mis-correlations. The main error was the introduction by Wright (1981) of the Newton Oolite as a new Member. Certain outcrops of oolitic clay and oolites were described as the Newton Oolite Member by Wright (1981). This, in turn, affected the interpretation of the clays underlying the Newton Oolite Member which Wright describes as the Nothe Clay. Some, if not all, of this clay is now described as the Woodrow Clay according to the BGS. The Newton Oolite Member of Wright is in fact part of the Cucklington Oolite Member. The clay which overlies the Cucklington Oolite, which Wright (1981) describes as the Nothe Clay, is present throughout most of the district. As this clay cannot be correlated with any certainty to the Nothe Clay of the Dorset coast, the BGS have introduced a new name for this member, the Hinton St. Mary Clay. This clay is named after the village in which its thickest outcrop appears. The Lower Calcareous Grit Formation is now renamed Hazelbury Bryan

Formation.

1.4.6.2. Summary Of Lithologies.

The following lithological descriptions have been summarised from Wright (1981) Bristow (1989a, b, 1990), Freshney (1989) and Bristow *et al.* (1995). For detailed descriptions of lithologies encountered within the studied boreholes see Chapter 3.

Oxford Clay Formation.

The Oxford Clay from the Stewartby and Weymouth Members in the north Dorset area comprises medium grey, variably silty mudstones, with some very fine-grained sand. Small cementstone nodules, up to 0.3 m in diameter, occur sporadically. It is very shelly with common *Gryphaea lituola* characterising the lower part and *G. dilitata* characterising the upper part.

The type locality of the Stewartby Member is at present yet to be designated but according to Cox *et. al.* (1992) one of the brickpits or sections at Stewartby, Bedfordshire will be nominated. The Weymouth Member reference sections are the sections at Furzy (or Jordon) Cliff [SY 700818] and Ham Cliff [SY 712 817] on the Dorset Coast.

CORALLIAN GROUP.

The Corallian Group in north Dorset comprises a siliciclastic lower sequence with very sandy, shelly limestones (Hazelbury Bryan Formation). An interval of oolitic, calcareous clays and oolitic, pisolitic and bioclastic limestones (Stour Formation, Clavellata beds and Coral Rag) comprise the overlying sequence and an upper part consisting of sandy and argillaceous lithologies (Sandsfoot Formation and Ringstead Waxy Clay). This tripartite division is maintained throughout Dorset although, in the area of the studied boreholes, the middle section is more sandy. The Group outcrops from West Stour in the north of the district, southwards towards Sturminster Newton and then south-westward towards Hazelbury Bryan. Southwards of this the outcrop is disturbed by the major east-west trending Merriott-Hardington Fault. The outcrop continues westward towards Glanvilles

Wooton and Lyons Gate, where the upper units are progressively cut out by the overstep of Cretaceous strata. The group varies in thickness from 100 m at its thickest to 40 m. It is around 90 m thick in the studied boreholes.

Hazelbury Bryan Formation.

The Corallian Group commences with the Hazelbury Bryan Formation (formally the Lower Calcareous Grit Formation). The Lower Calcareous Grit was formally visible in the Gillingham Railway cutting and described in detail by Blake and Hudleston (1877). Wright (1981) re-describes this section and comments that there is no good section available within the district. The formation consists of clays, clayey sands and sands, mostly in coarsening-upward sequences, topped locally by thin sandy limestones. Where thickest, the Hazelbury Bryan Formation consists of four sand units (A-D). It varies in thickness from 10 m to 52 m, being approximately 35 m thick in the studied boreholes.

The assemblage is dominated by bivalves including *Chlamys*, *Gervillella*, *Isognomon*, *Lopha*, *Modiolus*, *Myophorella*, *Pinna* and *Thracia*. Rare cardioceratid ammonites have also been recorded (Bristow *et al.* 1995).

Stour Formation.

The overlying Stour Formation (Bristow, 1989a) is a modification of Wright's (1981) Formation of the same name. The change was necessitated following the recognition of the new Hinton St. Mary Clay Member and the elimination of Wright's (1981) Newton Oolite Member (which equates to the Cucklington Oolite Member (Bristow, 1989b)). The Formation now consists of six members, forming a unified sequence of alternating calcareous, commonly oolitic and locally sandy clays and oolitic and pisolitic limestones (Bristow, *et. al.* 1995).

Woodrow Clay Member.

The formation commences with the Woodrow Clay Member which was introduced by Wright (1981) for the 3-4 m of grey clay that lies between the Lower Calcareous Grit

Formation (Hazelbury Bryan Formation) and the Cucklington Oolite Member. The type locality is in the hamlet of Woodrow [ST 759 108]. The member consists of up to 5m of grey, generally sand-free, calcareous, locally oolitic clay. At some localities the clay is extremely shelly, slightly sandy with scattered ooids with a shelly micrite towards its base. In the Bowden Farm Borehole it is around 2.5 m thick.

Cucklington Oolite Member.

The overlying Cucklington Oolite Member was introduced by Wright (1981) for the oolitic limestones that outcrop at the village of Cucklington [SY 7575 2740] and were referred to by Arkell (1927) as "?Limestones of Langham and Cucklington". The member is dominantly a flaggy, coarse-grained, shelly oolite or oobiosparite to oomicrite.

Fossils are frequent, but often broken. The echinoid *Nucleolites scutatus* (Lamarck) is usually well preserved. Bivalves are common including *Camptonectes*, *Grammatodon*, *Nanogyra nana*, *Pleuromya uniformis*, *Pseudolimea* and *Thracia* (Bristow *et al.*, 1995). Wright (1982) recorded ammonites indicative of the Vertebrale Subzone. Its maximum thickness is 5 m, which is recorded in the Bowden Farm Borehole.

Hinton St. Mary Clay Member.

Overlying the Cucklington Oolite Member is the highly variable Hinton St. Mary Clay Member, which varies from oolitic clay to marl with some oolite, to mainly oolitic limestone; it only occurs in the southern half of the district. It varies in thickness from less than 1 m to 5 m, but is not present in the studied boreholes. This Member was introduced by Bristow (1989b) as a replacement for the Nothe Clay Member as used by Wright (1981) in north Dorset. A new name was suggested for the clays which overlie the Cucklington Oolite Member in north Dorset as correlation with the Dorset coast Nothe Clay Member is at best tenuous.

Sturminster Pisolite Member.

The Sturminster Pisolite Member varies between a grain-supported pisolith concentrate to a matrix-supported pisolite in a clayey oolitic matrix. It is the most distinctive member of the north Dorset Corallian. In places the pisoliths can be up to 8 mm across when grain supported and can be up to 20 mm across when matrix supported (Bristow *et. al.*, 1995). The member varies in thickness from 0.6 m to around 3 m when a pisolitic, oolitic clay. The type locality of this member is at Sturminster Newton [ST 7830 1348] and comprises 1.2 m of grey sandy pisolitic marl with harder areas of coarse, pisolitic, oomicrite (Wright, 1981). The member is 0.6 m thick in the Hallet's Farm Borehole. The Sturminster Pisolite Member is generally not very fossiliferous.

Newton Clay Member.

The Newton Clay Member is the north Dorset equivalent of Arkell's (1933) Littlemore Clay and is dominated by an oolitic, grey calcareous, commonly sandy, clay. In the northern part of the district sand and sandstone are also present. Here, the member consists of a clay/sand sequence which increases in sand content upwards allowing distinct sand body to be mapped. The member varies from 5-15 m in thickness and is approximately 12 m thick in the Hallett's Farm Borehole. The name was introduced by Bristow (1989b) and the type locality is the road cutting [ST 7825 1347] at Newton.

The assemblage consists almost exclusively of bivalves and includes non-diagnostic species of *Camptonectes*, *Isognomon*, *Pseudolimea*, *Chlamys*, *Nanogyra*, *Pholadomya* and *Thracia* (Bristow *et al.* 1995).

Todber Freestone Member.

The uppermost member of the Stour Formation consists of up to 5m of cross-bedded, fine-grained oosparite with some pelmicrite. The Todber Freestone includes the famous "False-bedded Limestone" described by Blake and Hudleston (1877). This member is called the Todber Freestone Member following Mottram (1957) and was formally introduced by Wright (1981) as a modification of Arkell's (1933) "Marnhull and Todber Freestone". It is 3 m thick in the Hallett's Farm Borehole.

The type sections are situated at Todber and consist of a number of small quarries [ST 7949 1980, ST 796 199, ST 7975 1990, ST 7970 1973 and ST 7940 1976]. *Nucleolites scutatus* (Lamarck) and *Camptonectes* are common fossils (Wright, 1981).

Clavellata Beds Formation.

The overlying formation is the Clavellata Beds Formation, typically consisting of tough, coarsely bioclastic oolitic limestone. Beds of fine- to medium-grained oolite, in units of up to 0.3m thick, and shelly, sporadically oolitic, spicular micrite also occur. The formation varies from 3-12 m across the district. In places beds of sandy marl are common. The limestones range from biosparites and oobiosparites to pelmicrites and biopelmicrites. The Coral Rag, which Wright (1981) distinguishes at the base of the Clavellata Beds, is not sufficiently distinctive to be mapped as a separate unit (Bristow *et. al.*, 1995). It has, therefore, been included in the Clavellata Beds Formation by the BGS. This formation is approximately 11 m thick in the Hallett's Farm Borehole.

Although *Myophorella clavellata* is present within this Formation it is not as abundant as in the type localities on the Dorset coast. Other fossils present are *Liostrea*, *Phasianella*, *Mytilus*, *Gervillia* and *Nerinea* (Wright, 1981).

Sandsfoot Formation.

The Sandsfoot Formation is locally divided into two members; the Sandsfoot Clay Member which is grey, oolitic, locally sandy and ferruginous clay, and the Sandsfoot Grit Member which varies from a fine-grained sand, commonly ferruginous, to a fine-grained clay.

Sandsfoot Clay Member.

Only locally developed, the Sandsfoot Clay Member in the south of the district varies from 0.1 m of oolitic clay to 3 m of medium grey, locally oolitic, sand-free clay. In the north of the district up to 3 m of fine-grained sandy, shelly clay at the base of the Sandsfoot Formation is regarded as the Sandsfoot Clay.

Sandsfoot Grit Member.

The Sandsfoot Grit Member typically consists of fine-grained sandy clay and clayey fine-grained sand. Fine-grained sandstone, ferruginous, fossiliferous sand and sandstone and ferruginous oolite occur locally. It ranges from around 3-12 m thick. Wright (1981) recorded *Liostrea* as the only fossil encountered

Ringstead Waxy Clay Formation.

The Ringstead Waxy Clay is mapped with the Kimmeridge Clay in north Dorset by the BGS due to the fact that a distinction between the two is not easily made in the field. For details of this Formation in the studied boreholes see Chapter 3.

1.4.7. Jurassic Cyclicity.

Jurassic sediments have long been noted to exhibit cyclicity. Arkell (1933, 1936) was the first to recognise cyclicity in his study of the Corallian, and this group exhibits the best examples of cyclicity.

Two cycles are present in the Lias (Eype Clay, Downcliff-Thorncombe Sands, Junction and Downcliff Clay, Bridport Sands, Inferior Oolite). Three, and locally four, cycles are present in the Corallian and it is this Group on the Dorset Coast that has been the subject of detailed study (Arkell, 1933, 1936, 1947; Whatley, 1965; Wilson, 1968a, 1968b, 1975, 1991; Talbot, 1973, 1974; Fürsich, 1973, 1975; Brookfield, 1978; Wright, 1986a, 1968b; Sun, 1989; Rioult *et. al*, 1991 and Coe, 1992, 1995).

Arkell (1933, 1936) first attributed the cycles to shallowing up sequences, beginning with a deep water clay, overlain by a sandstone and topped by a shallow water carbonate deposit. Each cycle began with an abrupt deepening but is subsequently related to a shallowing of sea-level, with renewed transgressions at the limestone clay contacts (Stoneley and Selley, 1991).

The cycles of Arkell were re-interpreted by Wilson (1968a, 1968b), and were attributed to the rate of siliciclastic sediment deposition. Wilson indicates that the overall driving force for production of the cyclical sedimentation is linked to "events in the source area and not to sea-level changes".

Talbot (1973) interprets the sequence as resulting from four asymmetric, upward shallowing cycles. The cycles consist of limestone-clay-sandstone succession and are separated by non-sequences usually erosional surfaces which relate to marine transgressions caused by a rapid sea-level rise. Talbot placed these sequence boundaries at the sandstone limestone contacts, at abrupt changes in lithology and noted evidence of truncation of structures in the underlying sediments. The control is envisaged as being eustatic.

Wright (1986) identifies four cycles from shelly siliciclastic sand to silty clay/lime mud to shallow water marine sandstones or limestones. Wright believes that tectonic, rather than eustatic changes, control the cyclicity. Previously Wright (1981) in his study of the rocks from north Dorset noted that the previous models of four major cycles recognised by Talbot (1973), later accepted by Fürsich (1976) and Hallam (1976), did not hold true when compared to the succession present in north Dorset. Wright recognised nine cycles where the basic tenant of sediments laid down in less energetic sedimentary environments gradually being succeeded by those laid down in more energetic, often oolitic environments, holds true. However the first episode of marine clay is not always deposited immediately and in some cases shallow water, sometimes bioclastic sediments are deposited above each erosion surface. The final transition of each cycle to supratidal silts and sands, according to Wright, although important to the more marginal areas studied by Talbot (1973), is of little significance to the north Dorset area.

In a more recent study Sun (1989) interprets the Corallian Group as representing four regressive-transgressive cycles which contrasts to the previous interpretations of four asymmetric regressive cycles. Each regressive sequence is separated at the top from the following transgressive sequence by a sharp erosional contact. Sun concludes that the sedimentary cycles are produced by eustatic sea-level rises and compares the sequences to the global eustatic sea-level curves by Hallam (1978) and Haq *et al.* (1987).

With the advent of Sequence Stratigraphy recent interpretations have been presented by Wilson (1991), Rioult *et al.* (1991) and Coe (1992, 1995).

Wilson (1991) interprets the Corallian Group as containing three cycles, bounded by a type-1 sequence boundary. Transgressive surfaces are proposed to occur at the base of units showing the most diverse marine assemblage.

Rioult *et al.* (1991) divide the Corallian into four sequences, separated from the next by sequence boundary, which is interpreted as forming as a result of a relative sea-level fall.

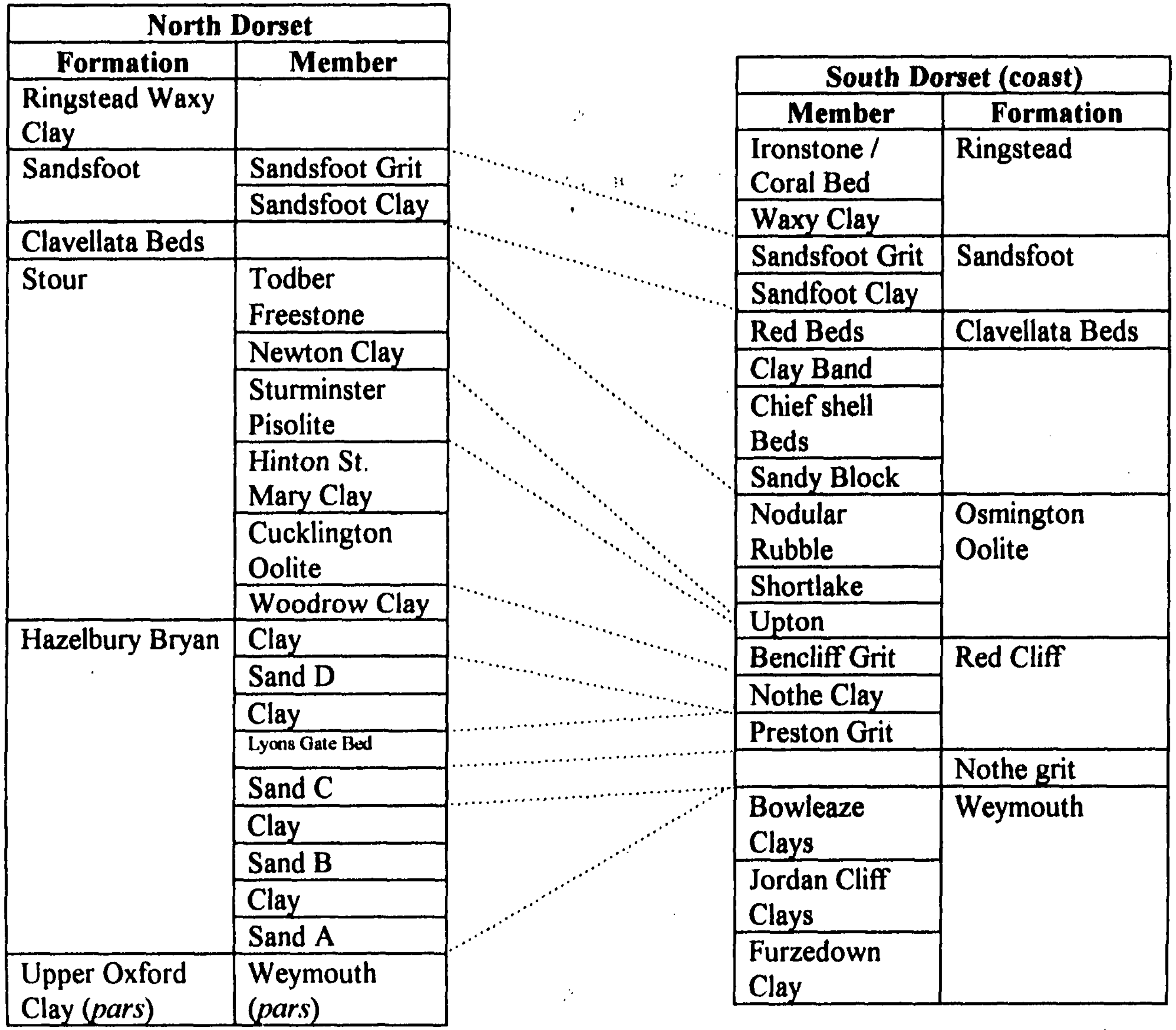
Coe (1992, 1995) studies the Oxfordian as a whole and subdivides it into six packages of sediment separated by major unconformities O1 to O6. These packages are interpreted as representing cycles of sea-level change.

1.4.8. Comparison between north and south Dorset lithostratigraphy.

The correlation provided by Cope *et al.* (1980), which is based on the work of Wright (1981), is slightly inaccurate due to the subsequent alteration of the lithostratigraphy following the BGS mapping of the area. See Section 1.4.6.1, Fig. 1.5. and Bristow *et al.* (1995) for more details. Although some of the lithologies prove difficult to correlate over distance, especially the clay beds, a brief summary is provided below and shown on Figure 1.6.

Certain Formations and Beds are present in both the coastal and north Dorset successions and they are almost certainly correlatable. These are the Ringstead Waxy Clay Formation, the Sandsfoot Formation, the Clavellata Beds Formation (Trigonia Clavellata Formation of the coast).

There is no direct equivalent in north Dorset for the Osmington Oolite and Redcliff



North Dorset	
Formation	**Member**
Ringstead Waxy Clay	
Sandsfoot	Sandsfoot Grit
	Sandsfoot Clay
Clavellata Beds	
Stour	Todber Freestone
	Newton Clay
	Sturminster Pisolite
	Hinton St. Mary Clay
	Cucklington Oolite
	Woodrow Clay
Hazelbury Bryan	Clay
	Sand D
	Clay
	Lyons Gate Bed
	Sand C
	Clay
	Sand B
	Clay
	Sand A
Upper Oxford Clay (*pars*)	Weymouth (*pars*)

South Dorset (coast)	
Member	**Formation**
Ironstone / Coral Bed	Ringstead
Waxy Clay	
Sandsfoot Grit	Sandsfoot
Sandfoot Clay	
Red Beds	Clavellata Beds
Clay Band	
Chief shell Beds	
Sandy Block	
Nodular Rubble	Osmington Oolite
Shortlake	
Upton	
Bencliff Grit	Red Cliff
Nothe Clay	
Preston Grit	
	Nothe grit
Bowleaze Clays	Weymouth
Jordan Cliff Clays	
Furzedown Clay	

Fig. 1.6. A possible correlation of the rocks of north and south Dorset. (After Bristow *et al.*,(1995) and Wright (1986a, b).

Formations on the coast, although certain lithologies are similar. Below the Trigonia Clavellata Formation on the coast part of the clay and cross-bedded oolite sequences of the Shortlake and Upton Members are possibly equivalent to the Newton Clay and Todber Freestone Members in north Dorset. The distinctive Sturminster Pisolite Member in north Dorset probably corresponds to the Pisolitic Bed towards the base of the Upton Member on the coast. The Bencliff Grit on the coast has no direct equivalent in north Dorset although it occupies the same stratigraphical position as the Cucklington Oolite and Woodrow Clay.

The Nothe Clay Member on the coast is equivalent to the Woodrow Clay Member and the clay from the top of the Hazelbury Bryan Formation down to the first sand unit.

The Preston Grit Member correlates with the Lyons Gate Member (Bristow *et al.*, 1995). which is found above the second sand unit of the Hazelbury Bryan Formation in some areas of north Dorset. Wright (1981), however, correlates the Preston Grit Member with Cucklington Oolite of north Dorset.

The Nothe Grit Formation is equivalent to the second sand unit from the top of the Hazelbury Bryan Formation (Bristow *et al.*, 1995).

1.4.9. Chronostratigraphy.

The Jurassic System is named after the succession of rocks of this age in the Jura Mountains of France and Switzerland. Alexandre Brongniart (1829) introduced the term "Terrains Jurassiques" but restricted it in meaning to the Lower Oolitic series of Conybeare and Phillips (1822) and excluded the Lias.

In Britain the use of the term Jurassic quickly followed but also excluded the Lias (Lyell, 1833). The adoption of the term Jurassic was eventually accepted, stimulated by the publication of Wright's (1872) paper, entitled, "On the correlation of the Jurassic rocks in the Department of the Cote d'Or, France, with the Oolitic Formations in the counties of Gloucester and Wiltshire", (see Cope *et al.*, 1980 for more detailed information).

1.4.8.1. The Definition of the Upper Jurassic.

According to Cope *et. al.* (1980) the division of the Jurassic in Germany into Lower, Middle and Upper by Buch (1839) forms the basis for the currently accepted subdivisions of the Jurassic System. Arkell (1946), closely following the concept of Buch (1839) chose the base of the Oxfordian as the base of the Upper Jurassic. It is commonly accepted now that the Upper Jurassic should begin with the Oxfordian Stage (Callomon, 1965; Maubeuge, 1970; Hallam, 1975).

1.4.8.2. Ammonite Zonation Scheme.

The palaeolatitude of Britain during the Jurassic place it within the envisaged extent of both the Tethyan and Boreal Realms. This, in turn, affects the ammonite assemblages which reflect the interplay between the Tethyan carbonate platforms and the siliciclastic sequences of the Boreal Realm (Cope, 1995). During mid- and late Oxfordian times ammonite provincialism became so acute that different standard zonations have been developed for each province. In Europe three separate zonal schemes have been developed for the Boreal Realm, the North West European Realm and the Sub-Mediterranean Realm (see Sykes and Callomon, 1979). The zonation traditionally applied to the Corallian Group of Dorset is a predominantly perisphinctid zonation (the N. W. European scheme of Sykes and Callomon (1979)). The zonation scheme based on Cardioceratids (the Boreal - sub-Boreal scheme of Sykes and Callomon, (1979)) used elsewhere in England, can also be applied to the north Dorset area in part (Fig. 1.7). Cope *et. al.* (1990) note that only one zonation scheme can be used in a correlation chart as the number of subzones determines the vertical spacing. They have chosen the Boreal Zonation scheme of Sykes and Callomon (1979) as the standard scheme for the Middle and Upper Jurassic and use this scheme in the correlation of the Jurassic rocks of the British Isles. They define the Upper Oxfordian as the first appearance of *Amoeboceras*. The zonation schemes applicable for the Upper Jurassic of north Dorset are shown in Fig. 1.7 (after Sykes and Callomon (1979), *emend.* Birkelund and Callomon (1985)). The lithostratigraphy for north Dorset and the Dorset coast are shown in relationship to the zonation schemes.

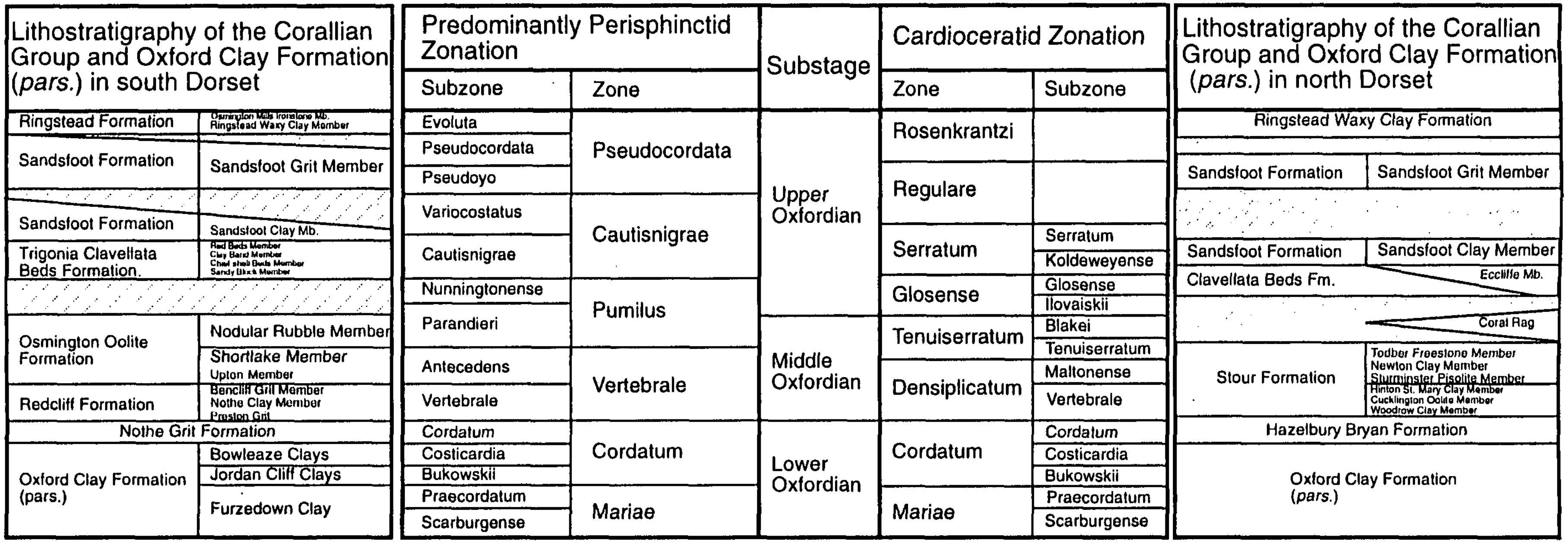


Figure 1.7. Chronostratigraphic subdivision of the Oxfordian Stage showing the different Ammonite Zonation Schemes used and the comparison with the Lithostratigraphy of the Corallian Group and Oxford Clay Formation (*pars.*) of north and south Dorset. (After Sykes and Callomon, 1979, *emend.*, Birkelund and Callomon, 1985; Bristow *et al.*, 1995 and Coe, 1995.)

Chapter 2. Materials and Methods

2.1. Introduction.

During the initial stages of the research extensive field work was undertaken to examine the strata from the Upper Jurassic throughout the Wessex Basin. Fieldwork was conducted on the Dorset Coast over the course of two Summer field seasons, and the outcrops of the Oxford Clay Formation, Corallian Group and Kimmeridge Clay Formation exposed on the coastal sections) were visited. Certain exposures inland were also examined (e.g. Chickerell Brick Pits, near Weymouth) The sections were logged in detail and over two hundred samples were recovered for analysis (both for thin section and micropalaeontological analysis). Fieldwork was also conducted at the Coastal exposures in Normandy. The sections exposed at the Vaches-Noires and Roches-Noires Cliffs were also logged in detail and over 100 samples were collected for analysis.

Other samples were obtained from boreholes from the Oxfordian and Callovian of north Dorset. The borehole material was supplied by the British Geological Survey (BGS). Further samples were obtained from field work in north Dorset from the limited exposures (mainly quarries and road cuttings).

At this stage in the research the samples were intended to form the basis of two separate integrated projects. The material from the Dorset coastal sections and the Normandy coastal sections were allocated as one project and the north Dorset samples allocated as the second project. This thesis is concerned with the samples from north Dorset.

It was realised that the samples provided by the BGS did not cover a sufficiently diverse stratigraphic sequence on which to base a complete project. It was decided that further samples were to be obtained and that due to the poor exposure in the north Dorset area fresh borehole material was needed.

Unfortunately the research worker involved with the south Dorset and Normandy samples abandoned the project part-way through for personal reasons.

2.2. Drilling Project.

2.2.1. Introduction.

The mid-Upper Jurassic succession of north Dorset is poorly exposed but has become better known as a result of recent BGS mapping (Bristow, 1989, 1990; Freshney, 1990; Bristow *et al.* 1995). Many of the classic road and railway cuttings where much of the north Dorset Jurassic geology used to be exposed are overgrown and to some extent weathered. In order to facilitate the recovery of a fresh set of samples, 3 boreholes were drilled by the author in the north Dorset area. In consultation with the BGS Regional Office in Exeter and utilizing the extensive data from the re-mapping of the Shaftesbury and Wincanton sheets (field slips, bore hole data, auger data etc.) a series of five boreholes were planned. The sites were positioned to provide a stratigraphic overlap between the boreholes thereby allowing recovery of a complete suite of samples from the Lower Oxford Clay through to the Kimmeridge Clay. A secondary objective was the sampling of the junctions between the Oxfordian Stage and the Kimmeridgian above and the Callovian below. Between August and mid-October 1994 three of the boreholes were drilled by the author in the north Dorset area. Due to the extreme difficulties encountered in drilling through the clays of the Oxfordian (see below) two of the boreholes were abandoned and the Middle and Lower Oxford Clays were not sampled.

2.2.2. Methodology.

The boreholes were drilled using a trailer-mounted B24 Mobile Surveyor Drilling Rig. This is a medium-sized drill and was towed behind a Land Rover (see Fig.2.1). Two different core barrels were used throughout the operation; a T2-56 mm diamond core barrel and a TT-56 mm triple barrel diamond core barrel which uses a plastic liner system. Both of these barrels were around 1.5m long. Ideally a split core-barrel would have best suited the drilling conditions and would have eased collection of the core, as most lithologies encountered were soft friable sediments or clays. However, the small diameter of the core barrel precluded the

Figure 2.1. The B24 Mobile Surveyor Drilling Rig in operation on the site of the Hartmoor Hill Borehole, north Dorset.

use of such a barrel and the TT-56 was used instead. This barrel has an inner plastic liner which can be removed from the core barrel with the core still intact. In industry the cores are transported within the plastic liner and are extracted at a later date by cutting the plastic. Cost precluded this method and the cores were extruded from the liner into core boxes on site. This method was, however, not without its problems. The vast majority of strata penetrated were clay, which were very plastic and adhered to the inside of the liner. This made the extrusion of the core on site very difficult and time consuming. Because of the nature of the lithologies water loss was severe, which made some aspects of the drilling more difficult. Polymer additives were used on occasions but failed to rectify the problems. Water loss is explained by the nature of the sediments of the Hazelbury Bryan Formation which consists of clays, clayey sands and sands in coarsening-up sequences. This formation was encountered in all three boreholes and is around 30-50 m thick in north Dorset. Most of the sands within this formation have pronounced spring lines at their bases (Bristow *et al.*, 1995). This meant that water use was not easily controlled, resulting in some of the sandier units being washed away. The use of a diamond core barrel in the clayey sediments proved quite problematic. Rather than cutting, it tended to compact the clay and force its way through the lithologies. Ideally, a tungsten -carbide saw-tooth bit would have been more useful, but again the small diameter of the core barrel precluded its use.

2.2.3. Borehole Details.

The three holes drilled at Bowden Farm, Hartmoor Hill Farm and Hallett's Farm cover the interval from the Upper Oxford Clay through the entire Corallian Group to the Ringstead Waxy clay member and part of the local equivalent of the "Ampthill Clay". The boreholes were drilled in an area approximately 8 km west of Shaftesbury, between East Stour in the east and Buckhorn Weston in the west; see Fig. 2.2. The core recovery was good, with an average of 75%.

The details of each of the boreholes, and a brief summary of the lithologies penetrated, are given below. For a general summary of north Dorset geology see Chapter 1 (Section 1.4.6.). For a detailed description of the lithologies of each borehole see Chapter 3.

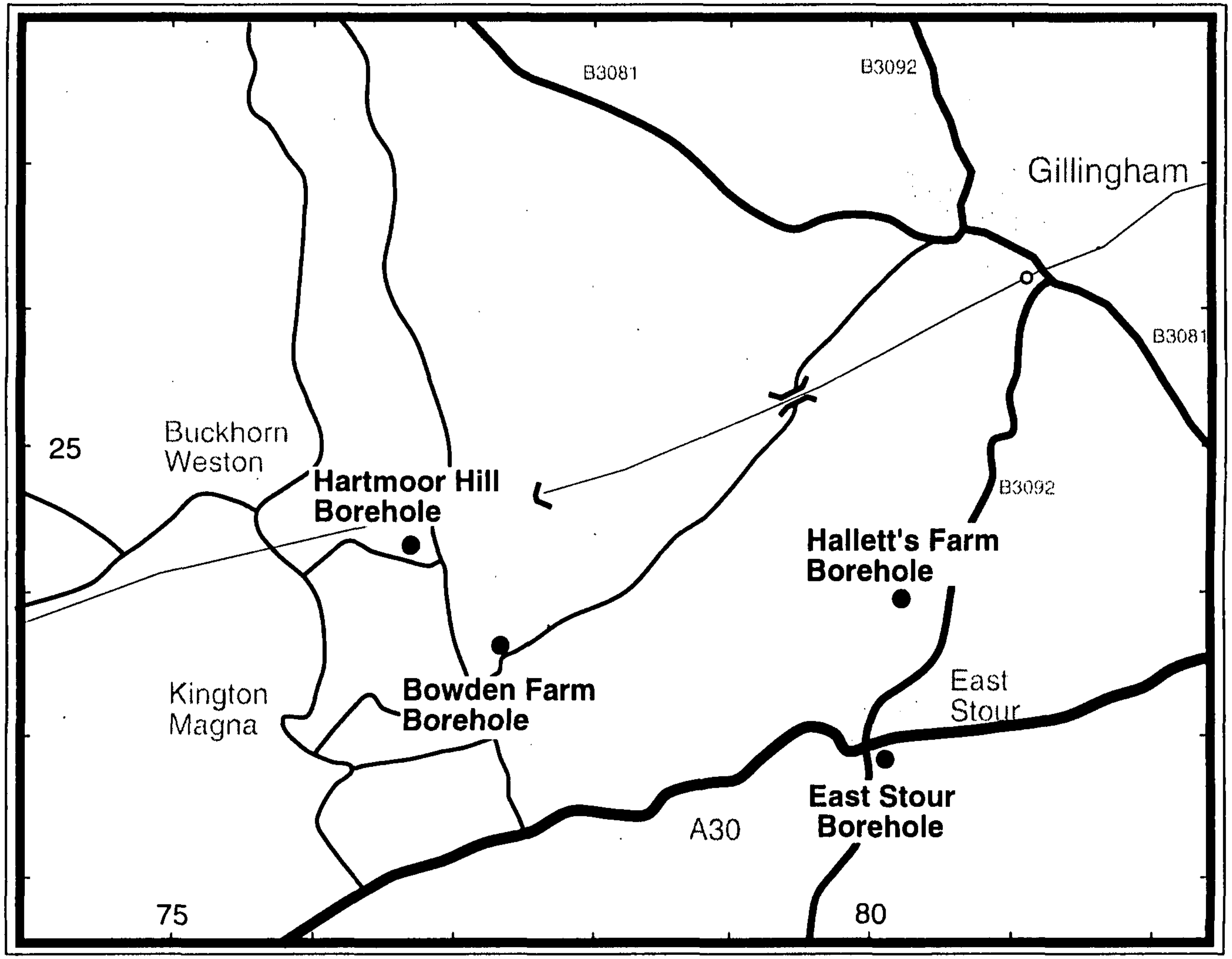


Figure 2.2. Location map showing the position of the Hallett's Farm, East Stour, Bowden Farm and Hartmoor Hill Boreholes in north Dorset.

Hallett's Farm Borehole [ST 8023 2393], located approximately 700m NNE of the village of East Stour, spans the sequence from the Ringstead Waxy Clay Formation through the Sandsfoot Grit Member, Sandsfoot Clay Member, Clavellata Beds Formation, Todber Freestone Member, Newton Clay Member to the Sturminster Pisolite Member and part of the Cucklington Oolite Member at the base; both of which are distinctive lithostratigraphic units. Hallett's Farm Borehole began at 1.30m below ground and penetrated to a depth of 44.65m. The core loss was approximately 13%.

Bowden Farm Borehole [ST 7741 2364], located approximately 1.1km NE of the village Kington Magna, overlapped with that at Hallett's Farm and recorded the succession below the Sturminster Pisolite Member. The sequence includes the Cucklington Oolite Member and the Woodrow Clay Member and terminated within the Hazelbury Bryan Formation. Bowden Farm borehole commenced at 1.28m below ground and penetrated to a depth of 48.53m. The core loss was approximately 25%.

Hartmoor Hill Borehole [ST 7659 2438], located approximately 1 km ESE of the village of Buckhorn Weston began within the Hazelbury Bryan Formation and continued down into the Oxford Clay Weymouth Member. Hartmoor Hill Borehole commenced at a depth of 1.17m below ground and penetrated to 40.95m depth. The core loss was approximately 37%. In this borehole the upper 7m yielded a very poor recovery due to the unconsolidated nature of the sand units at this level. This was rectified by re-sampling using a hollow-stem auger.

Each core was logged briefly on site and deposited into temporary core boxes. All cores were transported to the Department of Geological Sciences Core Store, University of Plymouth and transferred into 1m long core boxes, in which they were examined in detail. Dr. Bristow and Dr. Freshney from the BGS Regional Office at Exeter visited the Core Store and helped in the initial identification of the lithologies.

2.3. BGS BOREHOLES.

Material from two British Geological Survey (BGS) boreholes were obtained. The boreholes are East Stour and Cannings Court and are situated within the village of East Stour [ST 8013 2297] and approximately 2.5 km WSW from the village of Hazelbury Bryan [ST 7189 0734] respectively. The East Stour Borehole began within the Clavellata Beds Formation and spans the entire Stour Formation (Todber Freestone, Newton Clay, Sturminster Pisolite, Cucklington Oolite and Woodrow Clay Members) and terminates within the Hazelbury Bryan Formation. It penetrates to a depth of approximately 58m. The Cannings Court Borehole essentially covers the same strata. It commences within the Clavellata Beds Formation and also spans the entire Stour Formation and terminates within the Hazelbury Bryan Formation. The total depth is 52m.

2.4. Material.

A total of 182 samples were obtained from the three department boreholes. Hartmoor Hill, Bowden Farm and Hallett's Farm provided 58, 75 and 49 samples respectively, with an additional 8 samples being provided by the Hartmoor Hill hollow-stem auger. Samples were taken from the three boreholes at approximately 50 cm intervals, each weighing approximately 150 g. Each sample was then sub-sampled; 100 g for micropalaeontological analysis, 25 g each for nannofossil and palynological analysis. The micropalaeontological processing and analysis was undertaken by the author, the nannofossil samples were analysed by Patrick Quinn and formed the basis of his MSc project at the University College London, under the supervision of Dr. Paul Bown (see Quinn, 1995). Some of his conclusions are discussed in Section 8.3.

The samples obtained from the BGS had already been processed with the <63μm fraction removed. From the East Stour Borehole and Cannings Court Borehole 40 samples and 49 samples were provided respectively.

2.5. METHODOLOGY.

2.5.1. Processing.

A standard processing technique was applied to all 100g micropalaeontological samples. The technique is summarised below:

Each 100 g sample was carefully crushed into roughly 1 cm^3 blocks and dried in an oven before being placed in a fume-cupboard and soaked overnight in white spirit. The white spirit was then decanted off and the sediment immersed in distilled water until disintegration occurred. At this stage, if complete disintegration had not been obtained, the above process was repeated. The samples were then wet sieved over a 63 µm sieve to remove the clay and fine silt fractions. The residue was dried in an oven at 40° C.

Certain samples were selected from the three departmental boreholes and from one of the BGS boreholes to provide an even sampling spread over the entire Upper Jurassic sequence encountered. Sample locations within the boreholes are illustrated in Chapter 3. These samples (BGS and departmental) were then dry-sieved over a nest of sieves sized 1000 µm, 500 µm, 250 µm and 150 µm. All sieve fractions, including the collecting tray (>63 µm), were examined under a binocular microscope (Olympus S211) and the microfossils extracted. For statistical purposes 301 foraminifera were picked from each fraction of each sample. The rationale behind this picking format is outlined below.

2.5.2. Picking methods/philosophy.

Material received from the BGS was already processed, with the <63 µm fraction removed. The complete sample had been processed as opposed to a uniform weight sub-sample. Ideally a known sample weight would have been chosen for each sample and all microfossils picked after processing (either from the total residue or from a known fraction of the residue). This method would have facilitated the use of all statistical techniques, *e.g.* absolute abundance and number of foraminifera per gram. As a comparison between the boreholes was desired a standard picking technique had to be applied for all samples, across all boreholes. The author decided to pick a certain number of foraminifera from each sample, which is a standard technique applied in industrial micropalaeontology. Usually, a "statistically meaningful" number is picked from each sample. Based on Dryden (1931), who derived an equation for counting heavy mineral grains, Phleger (1960) first applied this counting method to foraminiferal studies and suggested the figure of around 300 specimens per sample. This figure of 300 was arrived at through Phleger's own experience with foraminiferal studies and through the application of Dryden's (1931) equations and provides sufficient accuracy for most quantitative analysis. Counting >300 individuals per sample is not generally necessary as the accuracy of percentage determinations becomes asymptotic (Dryden, 1931; Phleger, 1960; Martin and Liddell, 1989; Murray, 1991, p. 316). However, there are some dissenters to this method. Pielou (1979) disputes that a sample of 300 counts is adequate (Murray, 1991). The normal method for the counting of foraminifera is to choose a size fraction (usually between 63 µm and 125 µm) and count approximately 300 specimens from the residue greater than that chosen fraction. This statistical method has evolved to fulfil the needs of biostratigraphers, where a reasonable accurate method was needed to guarantee that a certain species which made up x% of the total assemblage would be encountered y% of the time. Paul (1992) illustrates this with an example; for a species present as 1% of a sample, counts would be needed of 299 and 459 identified specimens per sample to be 95% and 99% certain, respectively, of not overlooking this taxon. This method is obviously not ideal for palaeo-ecological studies. The use of the standard count method takes no account of foraminiferal species-specific size distributions (Martin and Liddell, 1989), which may reflect important palaeo-ecological information (Schröder *et al.*, 1987; Sen Gupta *et al.*, 1987). In another study Patterson and Fishbein (1989) re-examine the previous literature in order to re-evaluate the statistical base utilized in determining the number of counts required. Some of their conclusions are as follows; to accurately determine species abundance percentages, they suggest 300 counts for species comprising 10%, 500-1000 counts for species comprising 5% and several thousand counts for species comprising 1% of a sample, respectively. These results vary to the those of Paul (1992) discussed above. The author decided upon the method of counting 300 specimens from each fraction. Although still limited by the preclusion of absolute values and the reliance of relative abundance figures, it was felt that this method would at least be better than the standard counting method. In addition, Martin and Liddell (1989) conclude that certain factors can affect the enumeration of species abundances in foraminiferal sediment assemblages using standard counting methods, *e. g.* the size of the test and colouration. They suggest that by picking 300 from each fraction more subtle changes in ecological and taphonomic gradients can be elucidated.

The benefits of counting 300 specimens per fraction can be summarised as follows:

i. A larger total number of specimens per sample, around 1,200 is obtained. Although certain authors (Dryden, 1931; Phleger, 1960; Murray, 1991) believe that counts above 300 do not provide any gain in accuracy in the relative proportions of an assemblage, a higher specimen count does concur with the findings of Patterson and Fishbein (1989). They advocate counts of between 500 and 1000 to provide reliable statistics for a species which comprises 5% of the total assemblage.

ii. The bias towards picking larger specimens or more visually prominent specimens is removed; see Martin and Liddell (1989) for complete discussion. This bias can also be removed by using random-number tables in conjunction with a numbered picking tray. The table would indicate a certain square, in which all foraminifera would be picked, regardless of size.

iii. Picking 300 specimens from all fractions greatly increases the probability of recording the rarer/smaller species which could be overlooked if a fewer number of specimens are picked.

The disadvantage of this method is that if a particular fraction does not contain 300 specimens and the total assemblage in this fraction is extracted, the species present will be over-estimated in the final percentage abundance.

2.5.3. Relative and absolute abundance.

As mentioned in the previous section there is a difference in information given by relative and absolute abundance. The definitions are as follows. Absolute abundance is the precise number of individuals of a taxon in a given area, volume, population or community while relative abundance is defined as the total number of individuals of one taxon compared to the total number of all other taxa combined, per unit area, volume or community (Lincoln *et. al.*, 1982). As Murray (1991) states, it is important to realise that these two measurements give different information, and that peaks of abundance recorded by one method may not correspond with those of the other method. Paul (1992) points out that relative abundance is ideal for biostratigraphic use but suffers when applied to palaeo-ecology. Some of the problems of using relative abundance are that abundance for all taxa are inter-dependent, inappropriate or misleading conclusions may result and that data on absolute abundance is obscured (Paul, 1992). Murray (1991) concludes that, despite these difficulties, both methods (relative and absolute abundance) are useful. He goes on to say that most dead assemblages are considered in terms of relative abundance. Although Murray is discussing Recent assemblages, his observations can equally apply to the fossil record.

It must be noted that all data within this thesis are presented in the form of relative abundance. Every conclusion is therefore be in the light of this information and every care is taken to avoid any unsubstantiated assumptions.

2.5.4. Other methods.

Following picking, specimens were mounted on micropalaeontological slides and sorted into species. Selected specimens were examined under the Scanning Electron Microscope (JEOL 5300/5200) and illustrated by the means of photomicrographs. Certain specimens were also illustrated by means of the Camera Lucida

All three departmental boreholes were photographed and logged in detail prior to the removal of samples (Chapter 3). Each borehole was photographed, and a series of colour slides and black and white prints were made for future illustration, these photographs are illustrated in Chapter 3. The harder lithologies were thin-sectioned and examined under a petrological microscope. The argillaceous samples were processed as described in Section 2.5.1.

In addition to the previously mentioned sub-samples, a small amount of material (approximately 5g) was removed from each sample and used for grain-size analysis. During the processing of the micropalaeontological samples all of the sediment fraction <63 µm was washed away. The author was concerned that information on grain-size within this very fine fraction was lost. Grain-size analysis of the >63 μm fraction could easily be obtained by standard weighing methods. As a consequence small sub-samples were prepared for analysis by a Malvern Instruments Mastersizer, which analyses the grain-size of sediments optically. Approximately 5g of each sample was crushed gently using a mortar and pestle. The sample was then immersed in 6% Hydrogen peroxide (H_2O_2) and heated in a water bath for around 2 hours to destroy the organic material. The samples were then immersed in Calgon, a solution of Sodium hexametaphosphate and Sodium carbonate, which deflocculates the sample. They were finally placed in an ultrasonic bath to aid dispersal of the sediment, before being injected into the analyser as a solution. The results of grain-size analysis are then produced in a variety of formats.

The data for <63 μm fraction provided by the Mastersizer were added to the >63 μm fraction data produced by simple weighing. The combined data provide a complete grain-size analysis for each sample. Although not technically compatible the two sets of data provide adequate information for the desired purpose, which was to assess the selectivity of certain grain-sizes by different species of foraminifera.

Chapter 3. Sedimentological description of the Boreholes.

3.1 *Introduction.*

The three boreholes drilled by the author were used primarily to obtain a complete suite of samples from the Upper Jurassic succession of north Dorset. They cover part of the Weymouth Member from the Oxford Clay Formation and span the Corallian Group to the Ringstead Waxy Clay Formation.

Each borehole was drilled using a B24 Mobile Surveyor Drilling Rig, with a 56mm diameter core barrel with a length of 1.5m. Each core was extracted and stored in 1m lengths. The diameter of the core is 40mm. For details see Section 2.2. The boreholes are numbered 1 to 3, in the order that they were drilled and each core length is also numbered. The boreholes are logged and a summary is presented below.

All core sections have been photographed (Figs 3.2-3.5, 3.7-3.11, 3.13-3.16). Core loss is shown in the borehole logs, but is not indicated on the actual photographs of the cores.The lithologies of each borehole are described below, in stratigraphic order, starting with the youngest member of each borehole.An attempt to correlate the boreholes based solely on lithological information is illustrated at the end of the chapter. A legend for all figures is presented in Figure 3.1a.

3.2 Hallett's Farm Borehole (Borehole number 3).

The Hallett's Farm Borehole [ST 8023 2393] is situated approximately 700m NNE of the village of East Stour (see Fig. 2.2). It spans the sequence from the Ringstead Waxy Clay Formation through to the Sturminster Pisolite Member of the Stour Formation. The Borehole commences 1.30m below ground and penetrates to a depth of 44.65m. It consists of cores 3.1 to 3.31. See Figures 3.1 to 3.5.

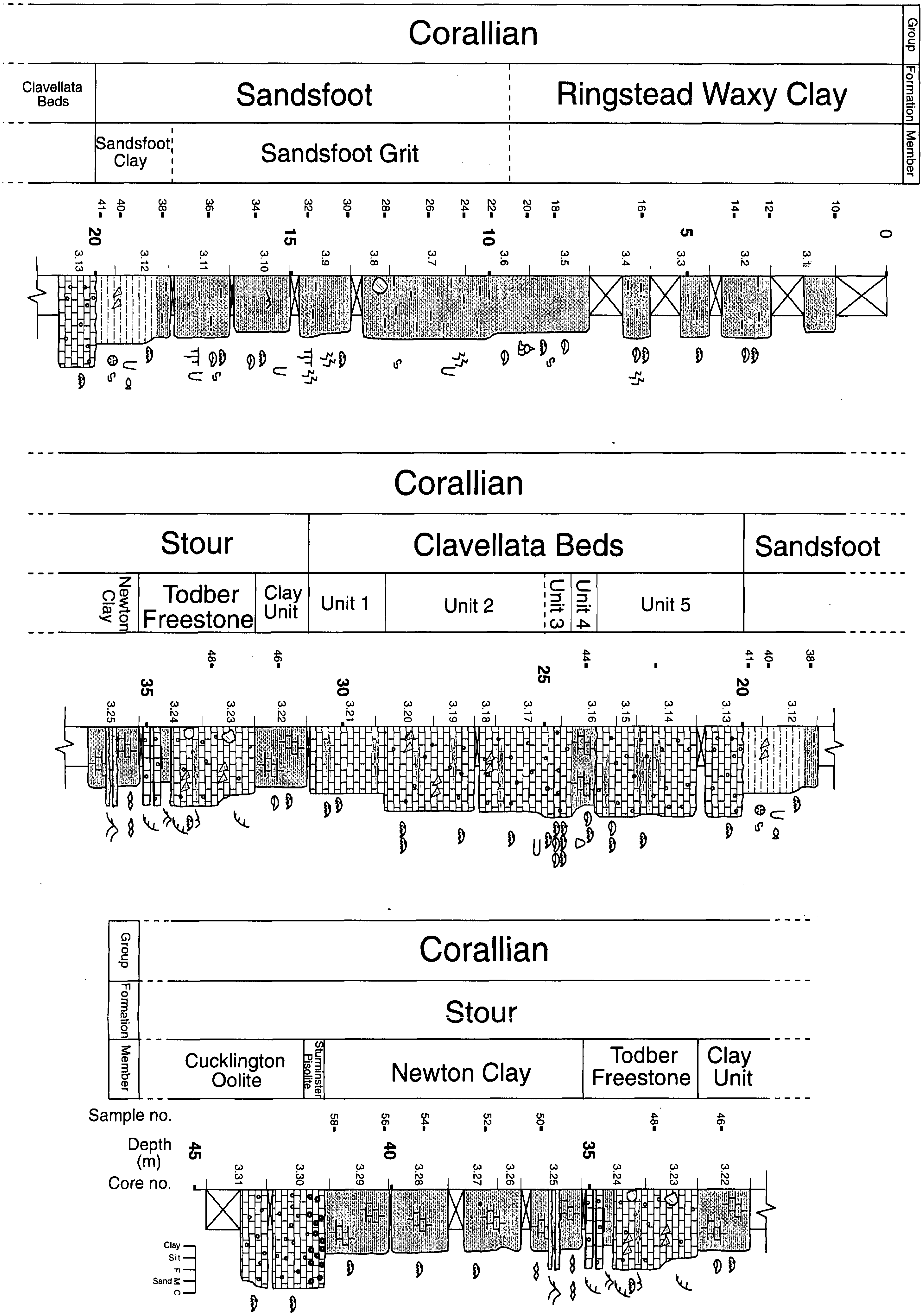


Figure 3.1. Sedimentary log of the Hallett's Farm Borehole showing core and sample positions.

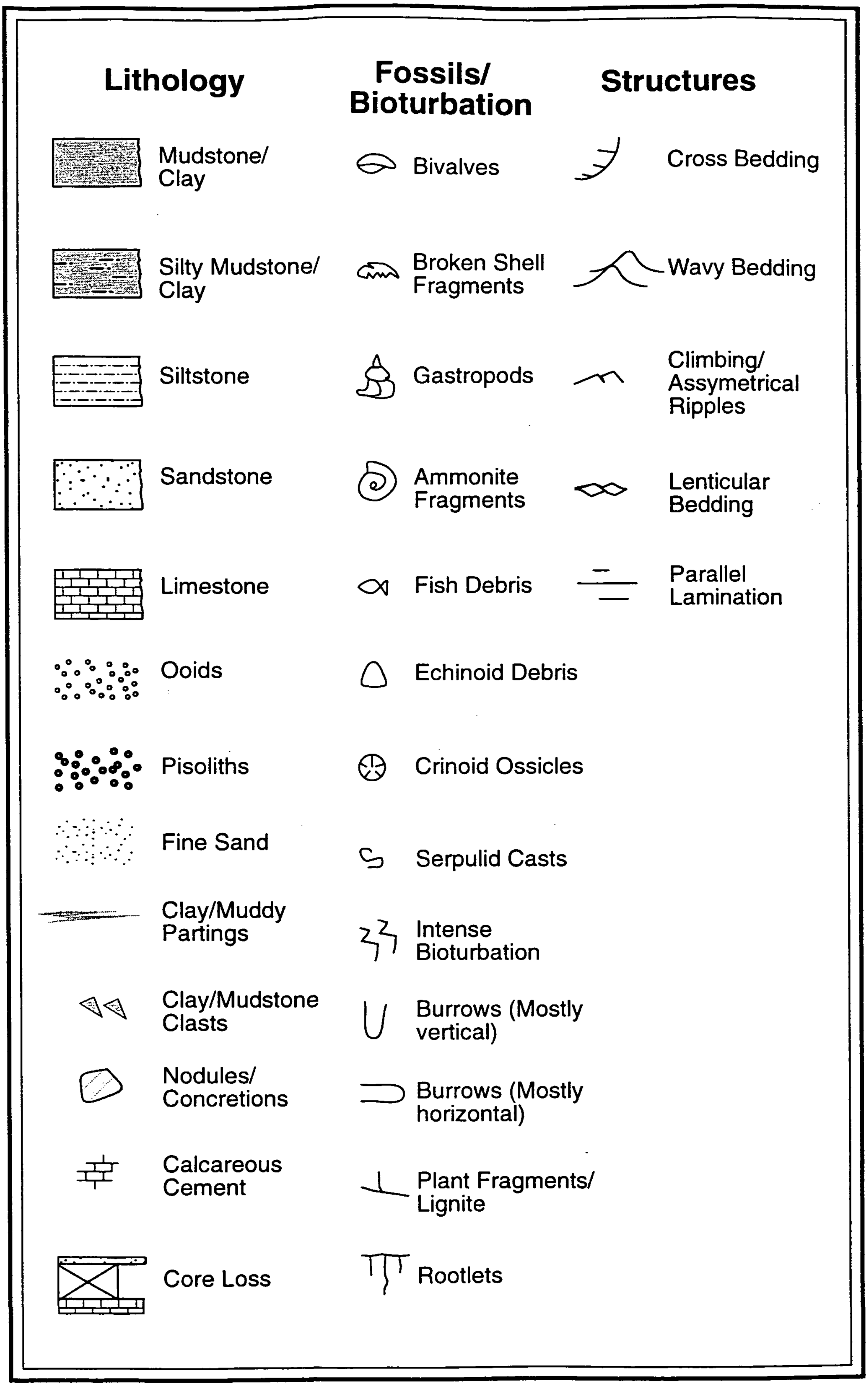


Figure 3.1a. Legend for Figures 3.1, 3.6, 3.12, 3.17 and 3.18.

3.2.1 Ringstead Waxy Clay Formation.

This formation spans from 1.30 m to 9.89 m and includes cores 3.1 to 3.6 (*pars.*) (Figs 3.2 and 3.3).

The lithology consists of a buff/light brown to grey clay becoming light grey towards the base. It is a massive bedded clay becoming silty in places.

Scattered small thin shell fragments are common, large *Ostrea* fragments, occasionally greater than 10mm in thickness and up to 50mm in length, occur frequently. Many gastropod fragments are found from 9.19m to 9.59m. Ammonite fragments are present at 6.30m (iridescent, crushed) and 7.60m (part phosphatised) consistent with *Ringsteadia.* Small flecks of carbonaceous material are also frequent. Gypsum (Selenite) crystals are present, particularly towards the top of the borehole. A bioturbated silty horizon occurs from 6.44 m to 6.59 m, within core 3.4.

3.2.2 Sandsfoot Grit Member.

This member ranges from 9.89 m to 18.51 m and includes cores 3.6 (*pars.*) to 3.12 (*pars.*) (Figs 3.1, 3.2 and 3.3).

The boundary with the overlying Ringstead Waxy Clay Formation is somewhat arbitrary, at least sedimentologically, being placed at the first input of silty clay down hole. There is also a small concentrated shell layer (3-5mm thick) at the junction, consisting of small, delicate, whole bivalve shells. The succession above the Clavellata Beds Formation is a fairly uniform clay and silty clay. The junction between the Ringstead Waxy Clay Formation and the Sandsfoot Formation and the junction between the Sandsfoot Grit and Clay difficult to ascertain (see Figs 3.2 and 3.3).

The Sandsfoot Grit Member consists of grey to light grey clay, becoming siltier at certain horizons. Possible climbing ripples occur in a 60mm thick bed at 15.48 m. There is a colour

Figure 3.2. Hallett's Farm Borehole core photographs. Cores 3.1 to 3.8 (*pars*). The core numbers are situated at the base of each core and represent the following depths. Core **3.1** – 2.91m, **3.2** – 4.43m, **3.3** – 5.95m, **3.4** – 7.47m, **3.5** – 8.99m, **3.6** – 10.51m, **3.7** – 12.03m. (**NB.** In this Figure and all subsequent Figures depicting core photographs, the core box length = 1m).

Figure 3.3. Hallett's Farm Borehole core photographs. Cores 3.8 (*pars*) to 3.16 (*pars*). The core numbers are situated at the base of each core and represent the following depths. Core **3.8** – 13.55m, **3.9** – 15.07m, **3.10** – 16.59m, **3.11** –18.11m, **3.12** – 19.63m, **3.13** – 21.15m, **3.14** – 22.67m, **3.15** – 23.18m.

change from darker siltier clay to lighter less silty clay at 12.88m. Nodules are present at 12.13m, 13.11m and 17.20m.

Scattered shell fragments occur frequently and consist of a mixture of small shell fragments and the occasional thick-shelled *Ostrea*-type fragments. Often whole valves are intact, especially small highly convex bivalves, which are also present as articulated valves. A large (40mm in length) razor-shaped shell with articulated valves was recorded at 16.34m. Concentrated layers of serpulid casts are also common. An unidentified fish vertebrate was found at 18.34 m. Often bioturbated layers and small rootlets are common, especially concentrated at 14.45m. Small, often calcified vertical burrows occur. Scattered flecks of carbonaceous material are common throughout this member.

3.2.3 Sandsfoot Clay Member.

The Sandsfoot Clay Member in this borehole ranges from 18.51m to 19.96m and is included in cores 3.12 (*pars.*) and 3.13 (*pars.*) (Figs 3.1 and 3.3)

The boundary between this member and the overlying Sandsfoot Grit Member is taken at the first occurrence of silt down hole, but this is, however, difficult to ascertain. There is an unconformable boundary with the underlying Clavellata Beds Formation.

The Sandsfoot Clay Member consists of dark grey silt with common interspersed clay clasts. Scattered thin-shelled bivalves are common, with the occasional *Ostrea*-type valve. A possible crinoid ossicle was recorded at 19.73m. A 20mm thick horizon of serpulid casts is present at 19.44m. This member is bioturbated at certain horizons and includes small vertical burrows.

3.2.4 Clavellata Beds Formation.

The Clavellata Beds Formation has an irregular boundary with the overlying Sandsfoot Clay Member and extends from 19.96m to 30.80m and is included in cores 3.13 (*pars.*) to 3.21. (Figs 3.1, 3.3 and 3.4). The Clavellata Beds Formation in this borehole can be divided

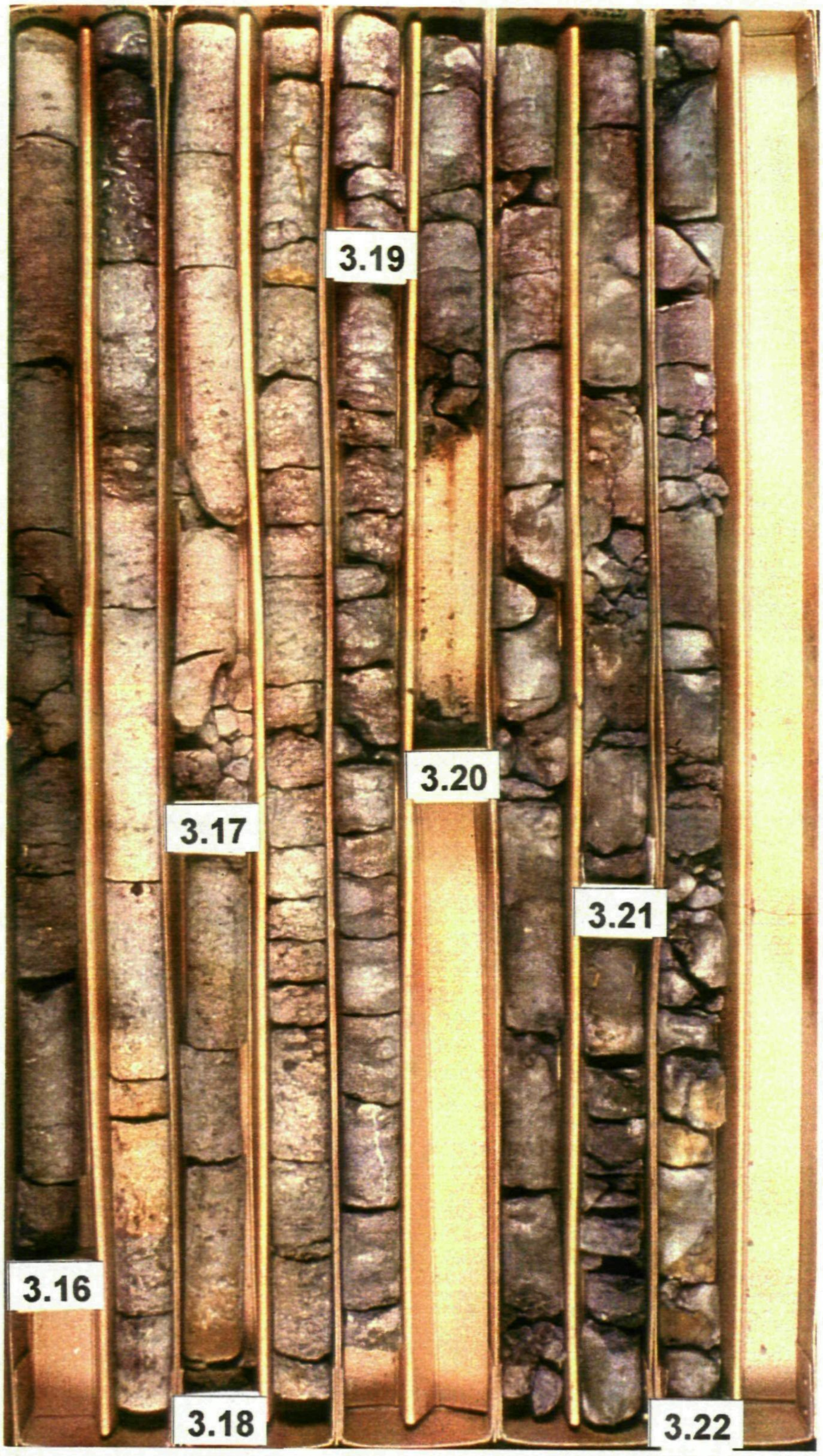


Figure 3.4. Hallett's Farm Borehole core photographs. Cores 3.16 (*pars*) to 3.22. The core numbers are situated at the base of each core and represent the following depths. Core **3.16** – 24.58m, **3.17** – 26.27m, **3.18** – 26.75m, **3.19** – 27.95m, **3.20** – 29.26m, **3.21** – 30.94m, **3.22** – 32.25m.

informally into 5 units.

3.2.4.1 Unit 5.

The uppermost unit reaches from 19.96m down to 23.68m and cores 3.13 (*pars.*) to 3.16 (*pars.*) (Figs 3.1, 3.3 and 3.4).

This unit consist of a uniform buff/cream oolitic limestone, becoming light grey towards the base. Frequent dark orange/brown weathering stains occur. This unit is well cemented with a sparry cement. It is grain supported alternating with areas which are matrix supported. At certain horizons influxes of clay result in a more muddy appearance of the limestone reducing the degree of cementation. Clay partings are common in places. The ooids are well sorted and medium-grained-sized. In general this unit has sparse bioclasts and only occasionally are shell fragments recorded. However, scattered shell fragments become more frequent towards the base of this unit, and occur in concentrated layers at 23.38m to 23.45m. This unit has been described by Bristow *et al.* (1995) as the Eccliffe Member. There is an erosional boundary with Unit 4 below.

3.2.4.2 Unit 4.

This unit occurs within core 3.16 and extends from 23.68m to 24.28m. (Figs 3.1 and 3.4).

This unit is only 0.6m thick and consists of light grey muddy oolite, much less well cemented than the units above and below. Infrequent small shell fragments occur, with valves of *Myophorella clavellata* present between 23.93m and 23.98m. The echinoid *Nucleolites scutatus* is present at 24.10m. There is a transitional boundary with unit 3 below.

3.2.4.3 Unit 3.

This unit extends from 24.28m to 24.91m and cores 3.16 (*pars.*) to 3.17. (Figs 3.1 and 3.4).

This unit consists of a thin horizon, 0.63m thick and consisting of a densely packed light grey bioclastic oolite, muddy in places. It is extremely shelly with large clasts of *M. clavellata*, some valves reaching 50mm in length. A particularly dense shell horizon is concentrated between 24.40m and 24.58m. Occasional sub-horizontal burrows approximately 10mm in diameter. There is a transitional boundary with unit 2 below.

3.2.4.4 Unit 2.

This unit extends from 24.91m to 28.89m and cores 3.17 (*pars.*) to 3.20 (*pars.*) (Figs 3.1 and 3.4).

This unit is a continuation of the unit above but not as coarse grained. It consists of light grey bioclastic oolitic limestone with a sparry cement. It becomes muddy in places with occasional clay drapes and clasts, becoming more frequent towards the base of the unit and in places (e.g. 27.55m to 27.65m) where they are elongated sub-horizontally forming a crude fabric. Calcite replaced shell fragments with calcite and stylolites occur in the basal 1m. Disseminated pyrite is present from 28.75m to 28. 82m. Shell fragments infrequent for the majority of the unit becoming more common in the basal 1.10m. There is a planar boundary with the underlying Unit 1.

3.2.4.5 Unit 1.

This unit extends from 28.89m to 30.94m and cores 3.20 (*pars.*) to 3.21 (*pars.*) (Figs 3.1 and 3.4).

This unit consist of a light/dark grey muddy micritic limestone, becoming a bioclastic silt-sized micritic limestone with muddy partings towards the base. Shell fragments are uncommon but become more frequent towards the base of this unit.

The division of the Clavellata Beds into 5 units is similar to the formal division of the Trigonia Clavellata Formation the Coast (see Fig. 1.4 and Section 1.4.5.2 for details).

3.2.5 Clay Unit.

This unit extends from 30.94m to 32.25m and core 3.22 (Figs 3.1 and 3.4).

This unit consist of a light grey/ medium grey silty-clay sized bioclastic biomicrite, alternating with more muddy less well cemented partings. Scattered shell fragments are common with occasional small valves present.

This unit lies between the Clavellata Bed Formation and the Todber Freestone Member of the underlying Stour Formation. It may represent the lower portion of Unit 1 from the Clavellata Beds Formation above, but is sufficiently different in composition to merit its exclusion from this Formation or the Todber Freestone Member below.

3.2.6. Todber Freestone Member.

This member extends from 32.25m to 34.35m and cores 3.23 and 3.24 (Figs 3.1 and 3.5).

From 32.25m to 32.95m this unit consists of a medium grey silty calcareous mudstone, with fine grained micritic nodules or hard bands. Infrequent scattered ooids and carbonaceous material are present. Scattered clay clasts are also common. Cross lamination occurs in the upper part of this unit with parallel lamination below. Small shell fragments are very infrequent.

The ooid content gradually increases downward until from 32.83m to 33.53m the lithology becomes a medium grey oolitic siltstone interspersed with oobiomicritic hardbands/nodules. Inter-fingered oolitic rich silts with pure clay clasts are common. Ooids range up to 1mm in diameter and are generally poorly sorted. Nodules, forming around pyrite replaced ooids and shell fragments, also occur. The shell fragments tend to concentrate within the nodules.

From 33.53m to 35.01m the lithology changes to a buff coloured cross-bedded oolite, with small clay clasts/drapes often aligned along the cross laminations. Interbedded with this are dark/medium grey calcareous clay beds, between 5mm and 20mm thick. Clay also forms

Figure 3.5. Hallett's Farm Borehole core photographs. Cores 3.23 to 3.31. The core numbers are situated at the base of each core and represent the following depths. Core **3.23** – 33.62m, **3.24** – 35.16m, **3.25** – 36.68m, **3.26** – 37.23m, **3.27** – 38.53m, **3.28** – 40.07m, **3.29** – 41.59m, **3.30** – 43.11m, **3.31** – 44.65m.

drapes on asymmetrical ripples. There is possible evidence of a basal lag at 33.85m. Between 34.35m and 34.63m oolitic clay forms wavy bedding/flaser bedding and dominates the lithology. Towards the base of this unit the cross-bedded oolitic beds become thinner. Shell fragments occur occasionally, tending to concentrate towards the base of the oolite beds. The base with the underlying Newton Clay Member is transitional and the author defines the junction at the last occurrence of cross-bedded oolite down hole.

3.2.7 Newton Clay Member.

This member starts at 35.16m and extends down to 41.64m represented by cores 3.25 to 3.30 (*pars.*) (Figs 3.1 and 3.5).

The Newton Clay generally consists of a medium grey silty to slightly silty calcareous clay. Some interbedded silt lenses are common towards the base. Scattered carbonaceous material occurs throughout, with an occasional ooid rich lens.

Towards the top of the member, from the junction with the Todber Freestone Member (35.16m) to around 36.44m, various types of lenticular bedding are exhibited, from connected to single, from thick to thin. Two distinctive beds occur at 35.71m and 35.81m where wavy bedding is exhibited; these beds are each around 50mm thick.

Shell fragments are very infrequent and occur as crushed small valves. A concentration of shell fragments occurs in a thin bed at 40.94m. At certain horizons the clay is quite well cemented. There is a distinctive transgressive boundary with the underlying Sturminster Pisolite Member.

3.2.8 Sturminster Pisolite Member.

This member extends from 41.64m to 42.14m and is included in core 3.30 (Figs 3.1 and 3.5).

The Sturminster Pisolite Member consists of a buff/grey oobioclastic limestone with very large pisoliths. Most of the pisoliths are compressed and decrease in size towards the base. They reach a maximum size of 15mm along their longest axis, towards the top of the Member. Scattered small shell fragments occur throughout. A large *Ostrea* fragment occurs in the first 50mm. There is a transitional boundary with the Cucklington Oolite below, and is taken as the last occurrence of pisolite.

3.2.9 Cucklington Oolite Member.

This unit extends from 42.14m to the base of the borehole (44.65m) and covers cores 3.30 (*pars.*) and 3.31 (Figs 3.1 and 3.5).

The Cucklington Oolite Member occurs in this borehole as a continuation of the overlying Sturminster Pisolite Member. It consists of poorly sorted grey/buff coloured coarse grained oolitic limestone, becoming finer towards the base. Sparite cement is present with occasional infills of micrite, which is often altered to pyrite. Scattered small shell fragments are present throughout this Member.

3.3 Bowden Farm Borehole (Borehole number 1).

Bowden Farm Borehole [ST 7741 2364], located approximately 1.1km NE of the village Kington Magna (Fig. 2.2), overlaps with the borehole at Hallett's Farm and recorded the succession below the Sturminster Pisolite Member spanning the Cucklington Oolite Member and the Woodrow Clay Member and terminates within the Hazelbury Bryan Formation. Bowden Farm Borehole commenced at 1.28m below ground and penetrated to a depth of 48.53m. It consists of cores 1.1 to 1.37 (Figs 3.6 to 3.11).

3.3.1 Sturminster Pisolite member.

This unit extends from the top of the borehole (1.28m) to 1.5m and is incorporated in core 1.1. (Fig. 3.6).

The Sturminster Pisolite Member comprises a creamy yellow to buff coloured oobioclastic pisolitic limestone with very little matrix, clast supported, weathering to an orange colour.

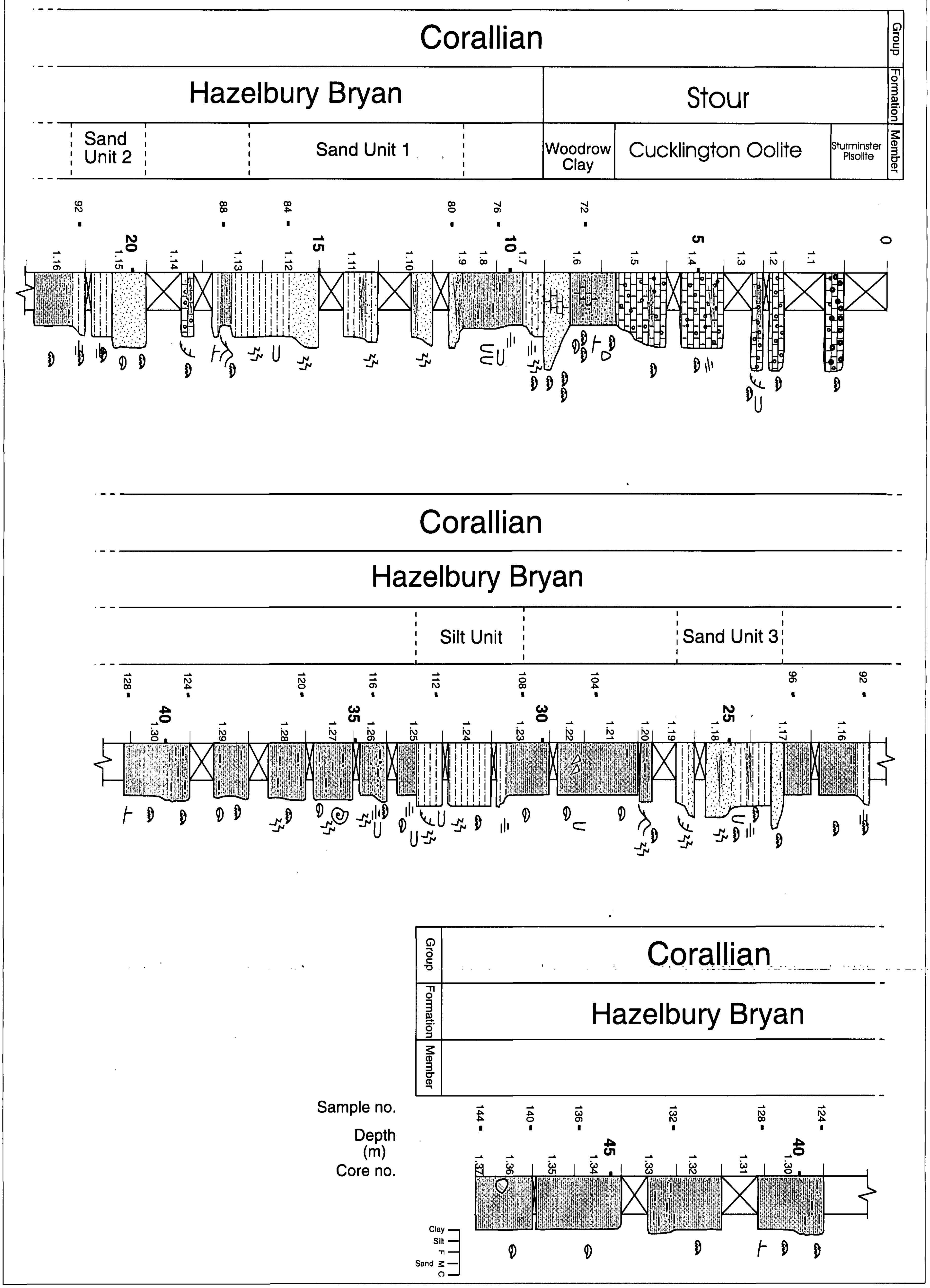


Figure 3.6. Sedimentary log of the Bowden Farm Borehole showing core and sample positions.

The unit is possibly sparry calcite cemented in places. Pisoliths are compressed and their maximum longest diameter measures 6mm; ooids are also compressed. Small thin bivalve fragments are scattered throughout. There is a transitional boundary with the Cucklington Oolite Member below.

3.3.2 Cucklington Oolite Member.

This unit extends from 1.5m to 6.93m and cores 1.1 (*pars.*) to 1.5 (*pars.*) (Figs 3.6 and 3.7).

The Cucklington Oolite Member consists of a yellow to buff coloured oobiosparite which is grain supported and generally well cemented. The oolite is often interspersed with less well cemented dark grey, carbonate, oolitic muds, which sometimes exhibit planar cross lamination (3.23m to 3.46m, 4.92m and 5.22m). Sparite cement is present in places. The ooids are compressed and some show a preferred orientation, the average diameter is around 1mm. The larger ooids can reach 4.5mm in diameter and are usually compressed. Scattered small shell fragments are present throughout.

From below 4.32m the number of clay partings increases and there are frequent mud breaks. Here there are abundant shell fragments set in a muddy matrix. Irregular patches indicate a colour change to mid grey, bordered with a calcitic boundary. This may indicate blocks of secondary cementation; there is no accompanying textural change.

From 5.88m to the base of this member (6.93m) there is a decrease in grain size and the lithology changes to a grey, fine grained sandy to silty oolitic limestone with frequent shell fragments.

3.3.3 Woodrow Clay Member.

This unit extends from 6.93m to 8.88m and cores 1.5 (*pars.*) to 1.6 (*pars.*) (Figs 3.6 and 3.7).

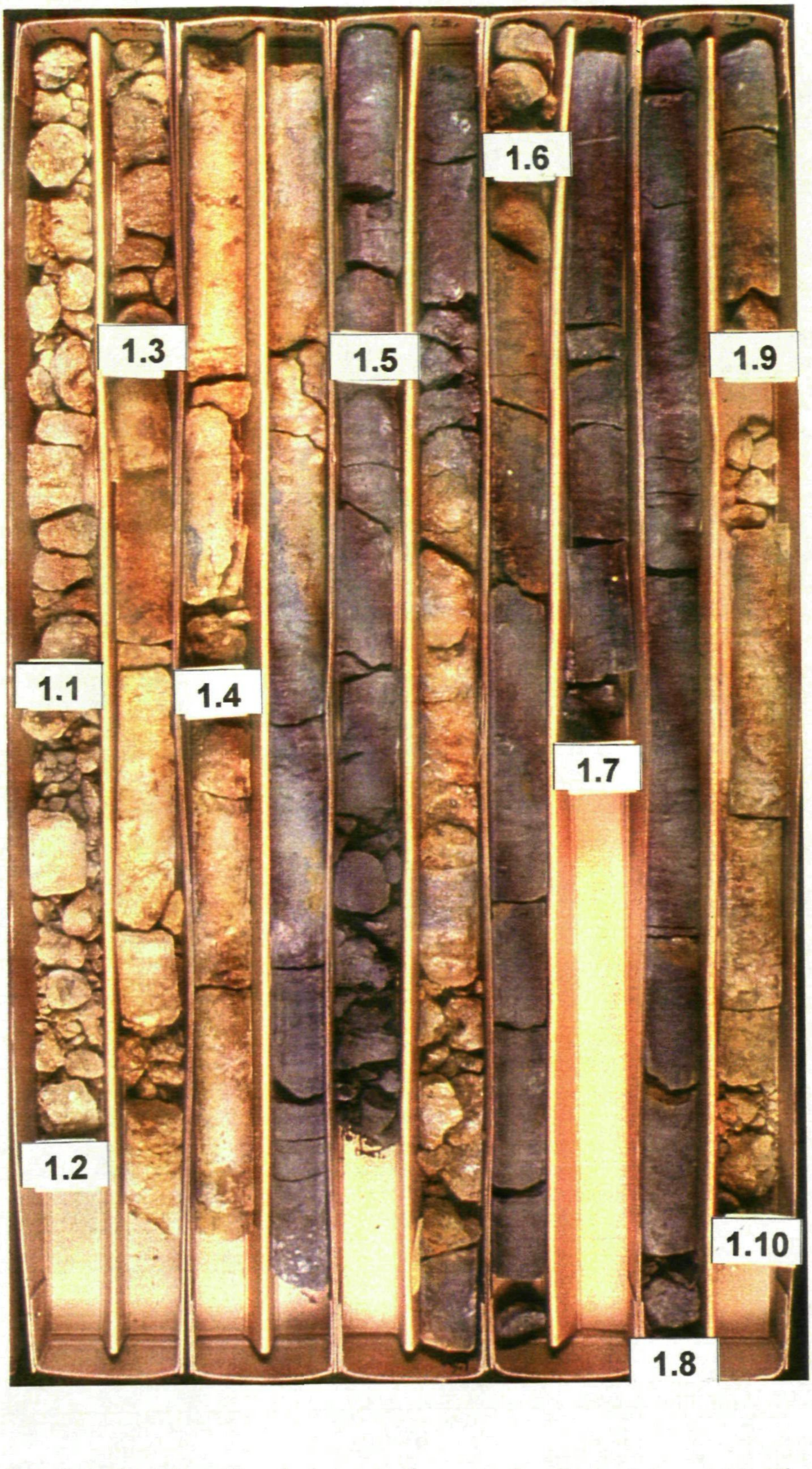


Figure 3.7. Bowden Farm Borehole core photographs. Cores 1.1 to 1.10. The core numbers are situated at the base of each core and represent the following depths. Core **1.1** – 2.78m, **1.2** – 3.23m, **1.3** – 4.32m, **1.4** – 5.88m, **1.5** – 7.51m, **1.6** – 9.03m, **1.7** – 10.51m, **1.8** – 11.44m, **1.9** – 12.08m, **1.10** – 13.60m.

The Woodrow Clay Member consists initially (at the top of the Member) of a light grey, fine sandy to silty calcareously cemented mudstone with scattered shell fragments. Some well cemented shell concentrates are present at 7.16m to 7.20m and 8.21m to 8.25m with large *Myophorella.* A cast of *Nucleolites scutatus* occurs at 7.05m. A large fragment of charcoaled wood is present at 7.53m. From 8.33m to the base of this member (8.88m) the lithology changes to a rusty coloured, calcareous cemented, fine, muddy sandstone. Red colouration suggests evidence of Fe within the carbonate cement. The initial formation stages of carbonate concretions also occur. Broken bivalve shells occur throughout this unit and are matrix supported. The basal 50mm is extremely coarse, and may represent a basal lag deposit. There is an abrupt boundary with the Hazelbury Bryan Formation below.

3.3.4 Hazelbury Bryan Formation.

This formation extends from 8.88m to the base of the borehole (48.53) and spans cores 1.6 (*pars.*) to 1. 37 (Figs 3.6 to 3.11).

The Hazelbury Bryan Formation in this borehole can be divided informally into 2 major sand units and a silt unit with intervening, predominantly clay units. Below the Woodrow Clay Member is a clay unit which extends from 8.88m to 11.61m and includes cores 1.6 (*pars.*) to 1.9. This unit consists of orange stained, grey, fine, sandy mudstone with a gradual decrease in grain size at around 9.33m to a more massive grey mudstone with occasional Fe staining. Possible parallel laminations occur in the top 1.5m. Infrequent shell fragments are present. Bioturbation is common with horizontal burrows occurring 5mm x 40mm in size. Intensely burrowed and bioturbated *Chondrites* horizons are present especially 10.64m to 10.79m. An increase in the grain size forms a transition to the first sandy unit at 11.61m.

This sandy unit begins with a buff/yellow coloured well cemented and strongly bioturbated fine sandstone. The top 0.36m is extremely hard which coincides with intense bioturbation. Sub-vertical burrows, clay filled, and reaching 20mm long x 6mm in diameter also occur. The sandy unit becomes less well cemented towards the base, but with locally cemented bioturbated horizons. Clay drapes are common.

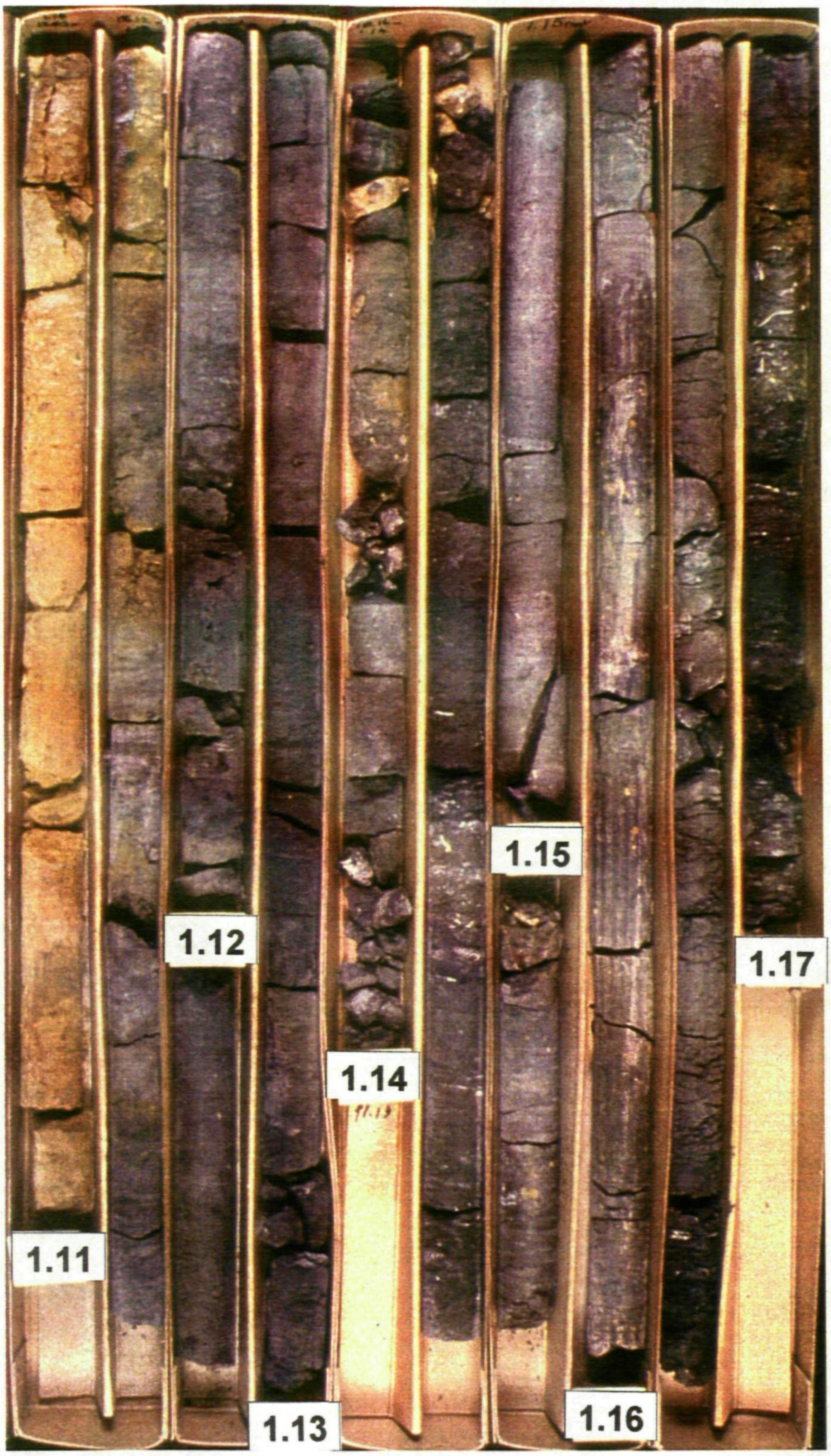


Figure 3.8. Bowden Farm Borehole core photographs. Cores 1.11 to 1.17. The core numbers are situated at the base of each core and represent the following depths. Core **1.11** – 15.12m, **1.12** – 16.64m, **1.13** – 18.16m, **1.14** – 19.68m, **1.15** – 21.30m, **1.16** – 22.82m, **1.17** – 24.34m.

There is a decrease in grain size at around 15.62m and the lithology changes to a light grey coloured fine sandstone/silt. Scattered carbonaceous material and bioturbated horizons are common. A distinctive horizontal burrow (6mm in diameter) occurs at 16.60m and at 17.14m to 17.44m larger horizontal burrows (10mm in diameter) are replaced by pyrite. A thin 0.1m thick clay horizon occurs at 17.49m where crude lamination and symmetrical ripples are present, with some large broken shell fragments.

At 18.16m to 18.66m beds of light grey fine sandy micritic limestone occur, exhibiting low angle cross-bedding and crude laminations picked out by silt and clay drapes. Occasional dark/black coloured ooids occur and scattered broken shell fragments are common. From 19.68m to 20.51m the lithology is a medium grey coloured, poorly sorted, fine sand with scattered shell fragments. This unit is highly bioturbated. Below this unit to the base of this first "sand unit" is a light grey weakly laminated massive siltstone with fine broken shells common. At around 21.52m there is a transition to massive light grey clay. This massive clay unit extends from 21.61m to 23.62m. It contains scattered carbonaceous material and very fine shell debris.

The second sand unit occurs below with a distinct boundary and extends from 23.62m to 26.46m, cores 1.17 (*pars.*) to 1.19 (Fig. 3.8 and 3.9). The unit is typified by an extremely shelly light grey to brown fine sand/siltstone. Layers of medium grained orange/yellow coloured friable sandstone are interbedded. A shelly horizon occurs from 23.87m to 25.14m and comprises a highly bioturbated very shelly, light grey, fine silty sandstone. Small nodules are present with common scattered carbonaceous material and pebbles of sandstone. Thick *Myophorella*-type bivalve shells are common and range up to 50mm x 5mm in size. Clay infilled burrows are common.

From 25.14m to 25.91m the lithology changes gradually to a massively bedded, yellow/orange coloured, very fine, poorly sorted sand. Siltier layers present are also present. The base grades into a light grey siltstone at 25.91m where the heavily bioturbated un-

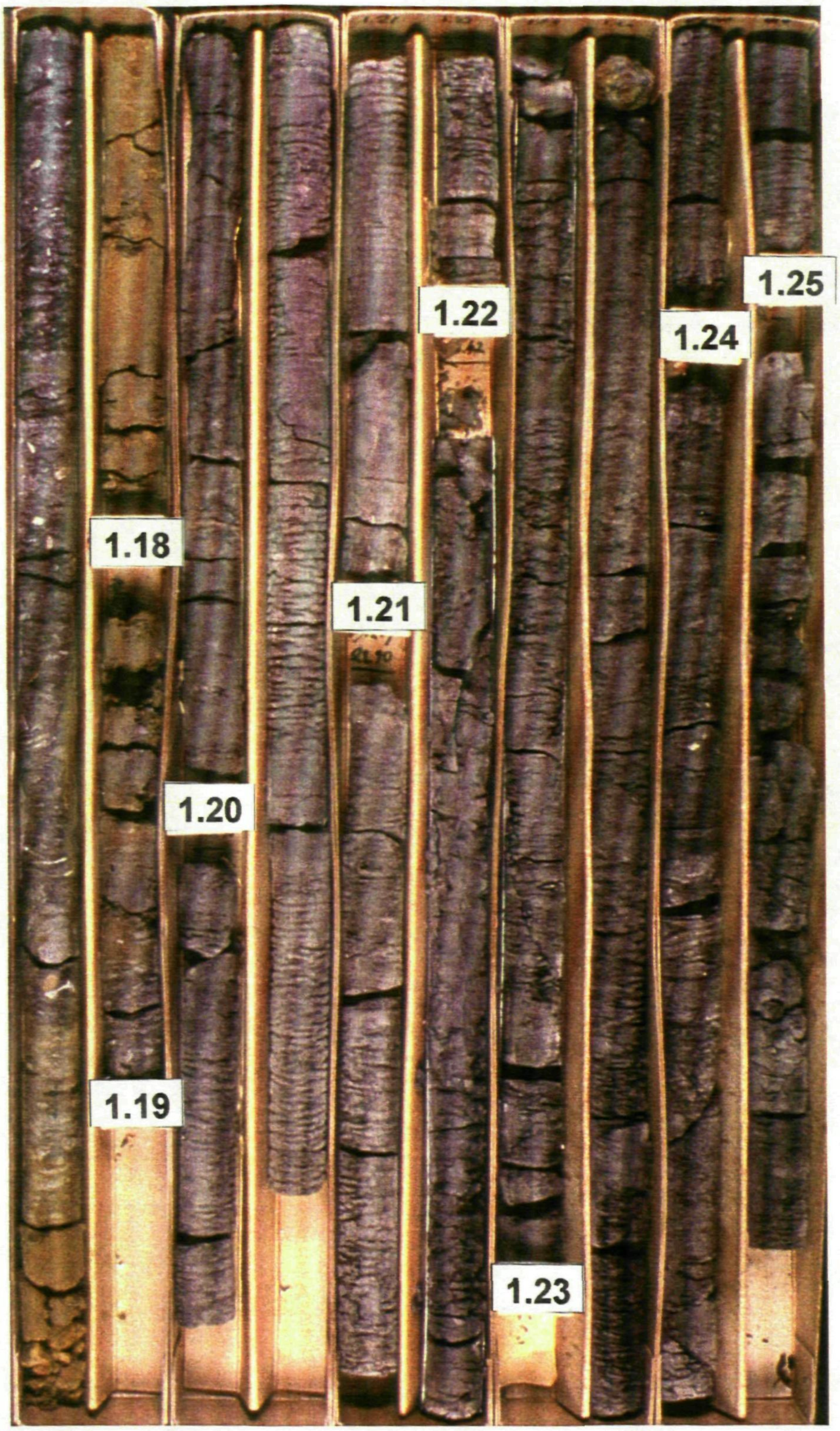


Figure 3.9. Bowden Farm Borehole core photographs. Cores 1.18 to 1.26 (*pars*). The core numbers are situated at the base of each core and represent the following depths. Core **1.18** – 25.86m, **1.19** – 27.06m, **1.20** – 27.38m, **1.21** – 28.90m, **1.22** – 30.42m, **1.23** – 31.37m, **1.24** – 32.67m, **1.25** – 34.19m.

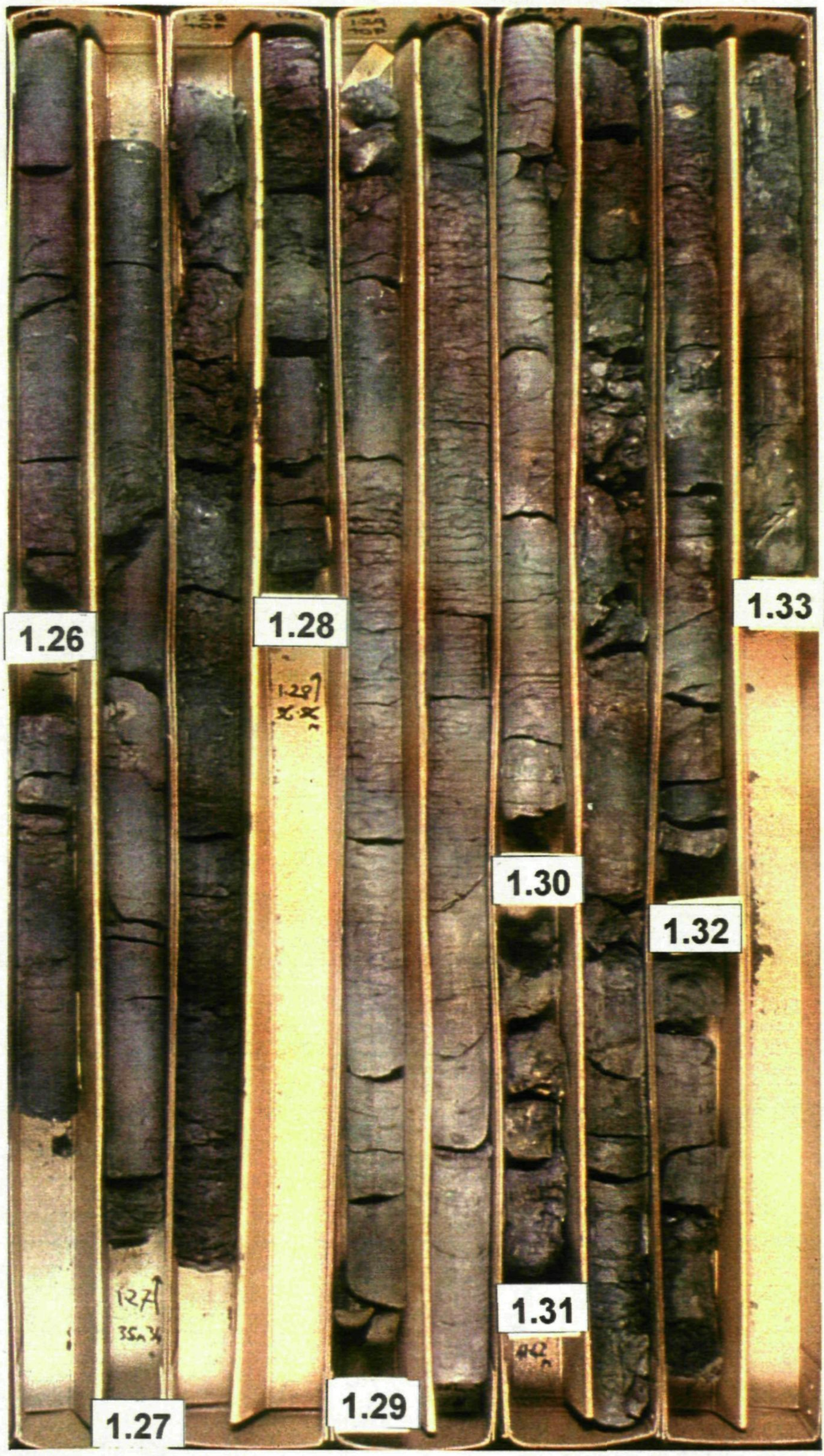


Figure 3.10. Bowden Farm Borehole core photographs. Cores 1.26 (*pars*) to 1.33. The core numbers are situated at the base of each core and represent the following depths. Core **1.26** – 34.99m, **1.27** – 36.34m, **1.28** – 37.86m, **1.29** – 39.38m, **1.30** – 40.90m, **1.31** – 42.42m, **1.32** – 43.23m, **1.33** – 44.75m.

fossiliferous siltstone continues to 26.51m (core 1.19, Fig. 3.9).

From 27.06m to 31.07m a shelly, bioturbated, silty mudstone alternates with massive un-fossiliferous clay. The massive clay grades into a siltstone unit at 31.07m. The siltstone comprises light grey bioturbated silt with infrequent shell fragments, with evidence of parallel lamination at the top. From 32.67m to 33.32m (core 1.25) the siltstone contains lenticular-flaser heterolithic units and some well cemented horizons showing cross-laminations. Distinctive horizontal burrows (5mm x 50mm) are common as are small irregular burrows.

Below this siltstone unit silty clay resumes. From 33.32m crudely parallel laminated silty clay extends down to 40.08m and contains scattered shell fragments, subhorizontal burrows and occasional very fine sand laminae. Shells occur as small articulated valves to large *Myophorella* valves. A fragment of the ammonite *Cardioceras* sp. cf. *costicardia* is also present.

From 40.08m to the base of the borehole (48.53m) the lithology comprises alternating light grey clayey silt, clay and silt horizons. Scattered carbonaceous fragments are common and occasional plant fragments occur. Shell fragments are common, burrows and bioturbation are absent. Ammonite fragments, including *Cardioceras* sp. juv., are also present. A hard cementstone nodule occurs at 48.05m and evidence for other nodules forming at 48.28m (Fig. 3.11).

3.4 Hartmoor Hill Borehole and Auger Hole (Borehole 2 and 2A).

Hartmoor Hill Borehole [ST 7659 2438], located approximately 1 km ESE of the village of Buckhorn Weston (Fig. 2.2) started within the Hazelbury Bryan Formation and continues down into the Weymouth Member from the Oxford Clay Formation. Hartmoor Hill Borehole commenced at a depth of 1.17m below ground and penetrated to 40.95m depth. In this borehole the upper 7m yielded a very poor recovery due to the unconsolidated nature of the sand units at this level. This was rectified by re-sampling using a hollow-stem auger. The

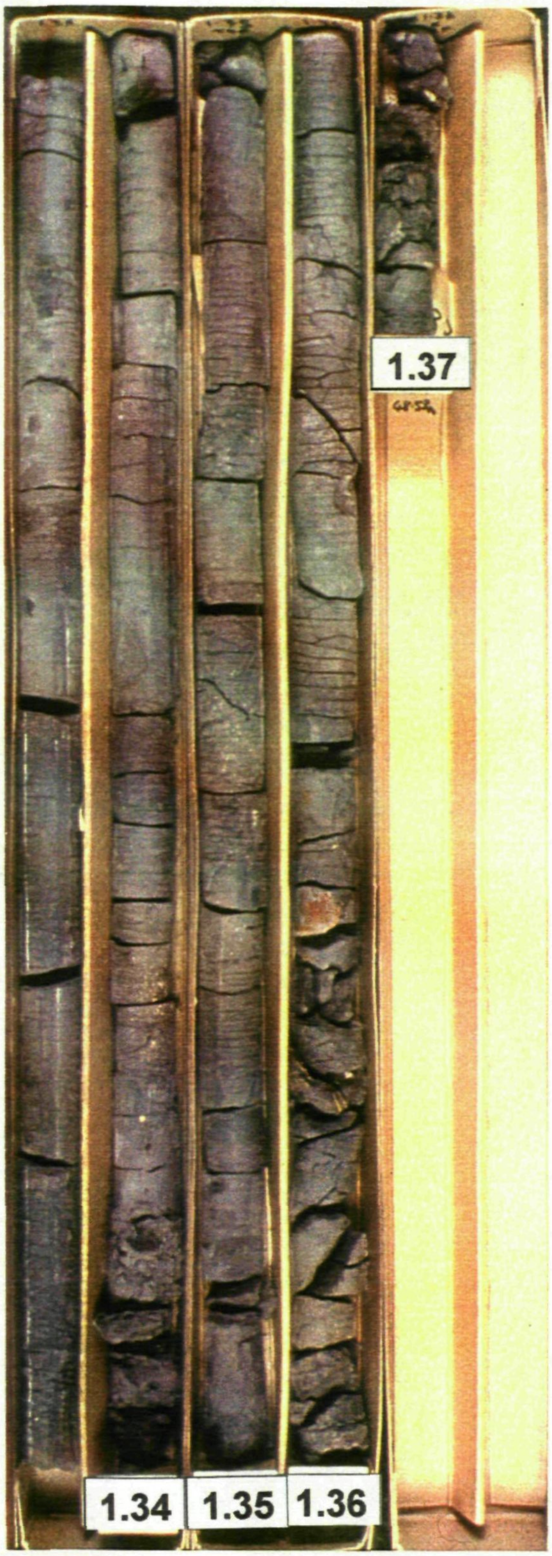


Figure 3.11. Bowden Farm Borehole core photographs. Cores 1.34 to 1.37. The core numbers are situated at the base of each core and represent the following depths. Core **1.34** – 46.00m, **1.35** – 47.03m, **1.36** – 48.28m, **1.37** – 48.53m.

hollow stem augered section consists of cores 2A1 to 2A8 and the borehole consists of cores 2.1 to 2.30.

3.4.1. Hartmoor Hill auger hole.

The hollow stem auger hole was drilled to recover the top 7m of the Hartmoor Hill Borehole which was washed out in the drilling process. The auger hole extends from ground level to 6.22m and covers cores 2A1 to 2A8 (Figs 3.12 and 3.13).

3.4.1.1. Hazelbury Bryan Formation.

The uppermost sand unit encountered in the Hartmoor Hill Borehole is also present in this auger section. It consists of a mottled orange/yellow and grey fine-grained sandstone with very little cement and scattered carbonaceous material and possible plant fragments. The sandstone is very friable and becomes poorly sorted at 2.42m where shell fragments and clasts of mudstones are abundant.

An abrupt erosional boundary with a dark grey clay bed occurs at 3.32m. This clay bed consists of fine clay with scattered large *Ostrea*-type bivalves, as well as small shell fragments and carbonaceous material.

A gradational boundary at 4.91m marks a transition from the clay down into a poorly sorted medium grained, orange/yellow sandstone. The sandstone becomes finer grained and better cemented towards its base, and contains numerous very fine shell fragments and carbonaceous material.

3.4.2. Hartmoor Hill Borehole

The borehole starts within the Hazelbury Bryan Formation at 1.17m and extends to 27.40m and includes cores 2.1 to 2.21 (Figs 3.12 to 3.14 to 3.16).

3.4.2.1. Hazelbury Bryan Formation.

The Hazelbury Bryan Formation in this borehole can be divided into one major sand body

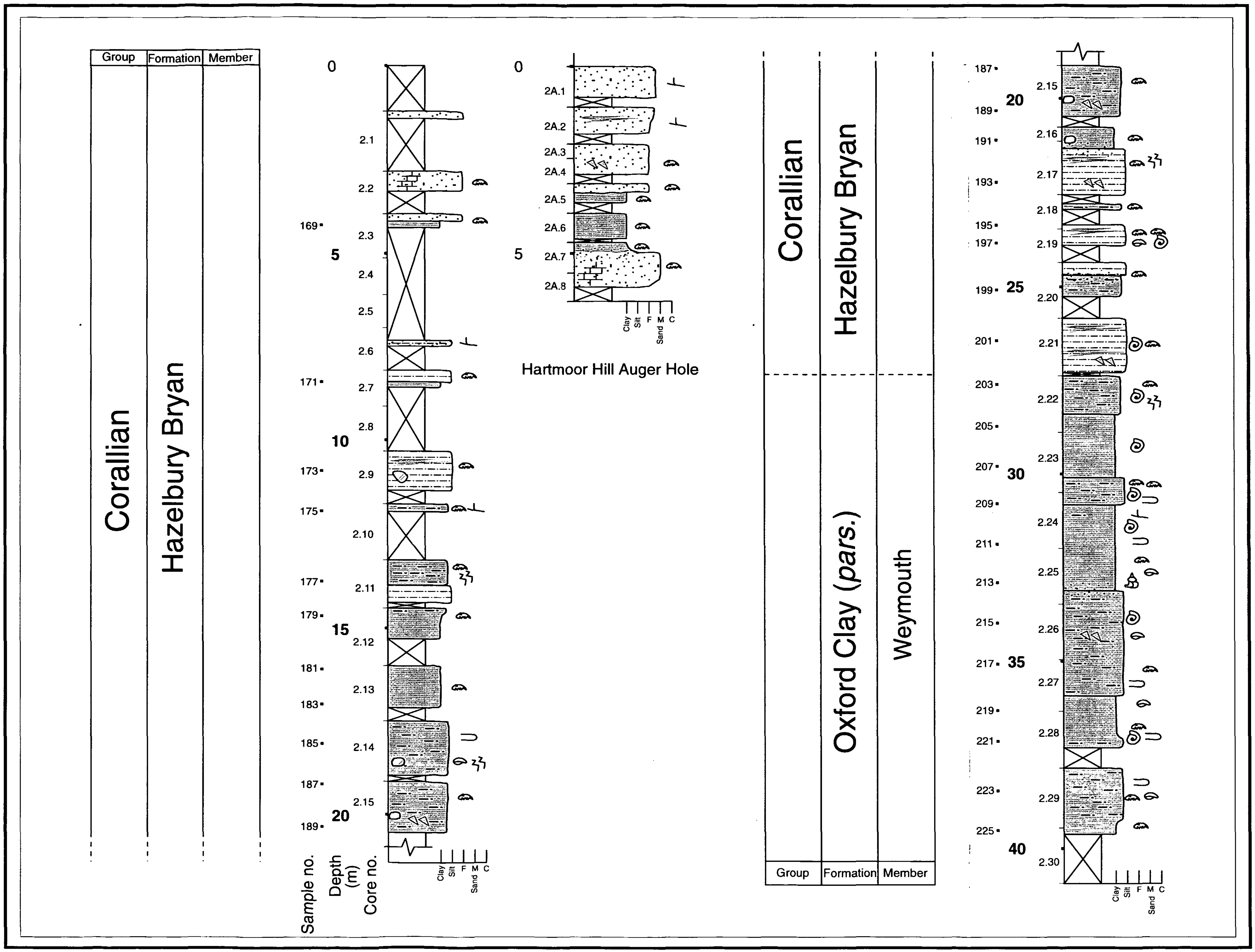


Figure 3.12. Sedimentary log of the Hartmoor Hill Borehole and Auger Hole showing core and sample positions.

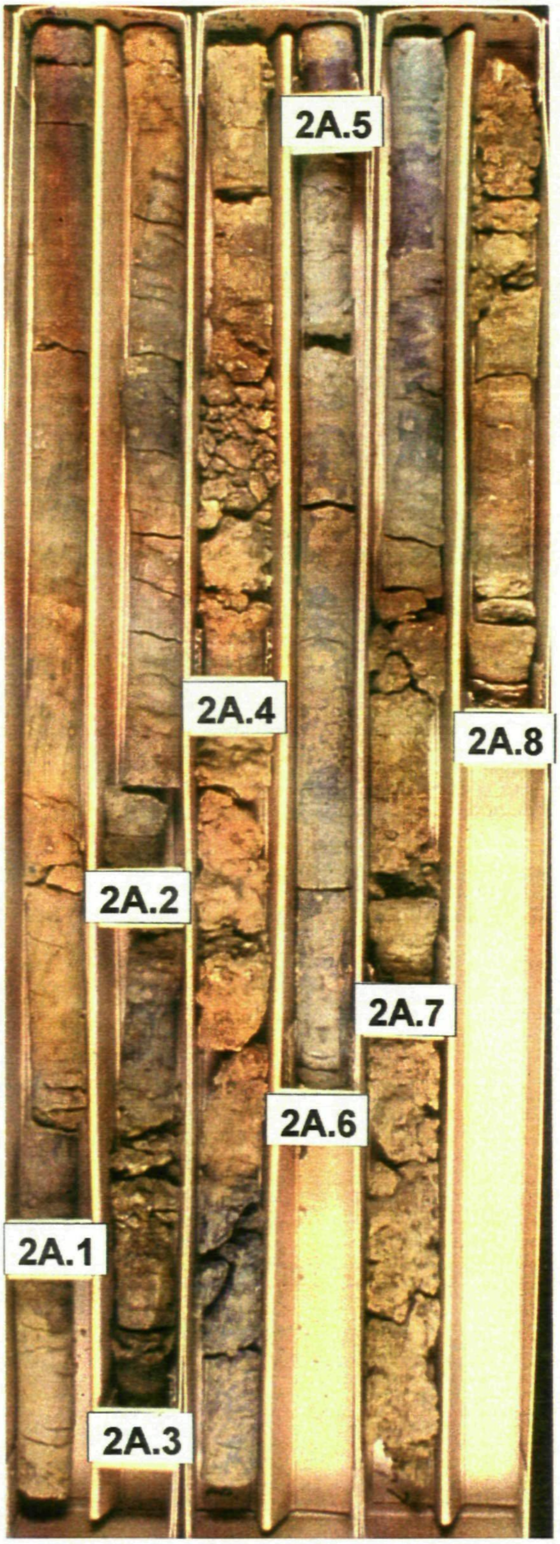


Figure 3.13. Hartmoor Hill Auger Hole core photographs. Cores 2A.1 to 2A.8. The core numbers are situated at the base of each core and represent the following depths. Core **2A.1** – 1.10m, **2A.2** – 2.10m, **2A.3** – 2.42m, **2A.4** – 3.17m, **2A.5** – 3.92m, **2A.6** – 4.67m, **2A.7** – 5.47m, **2A.8** – 6.22m.

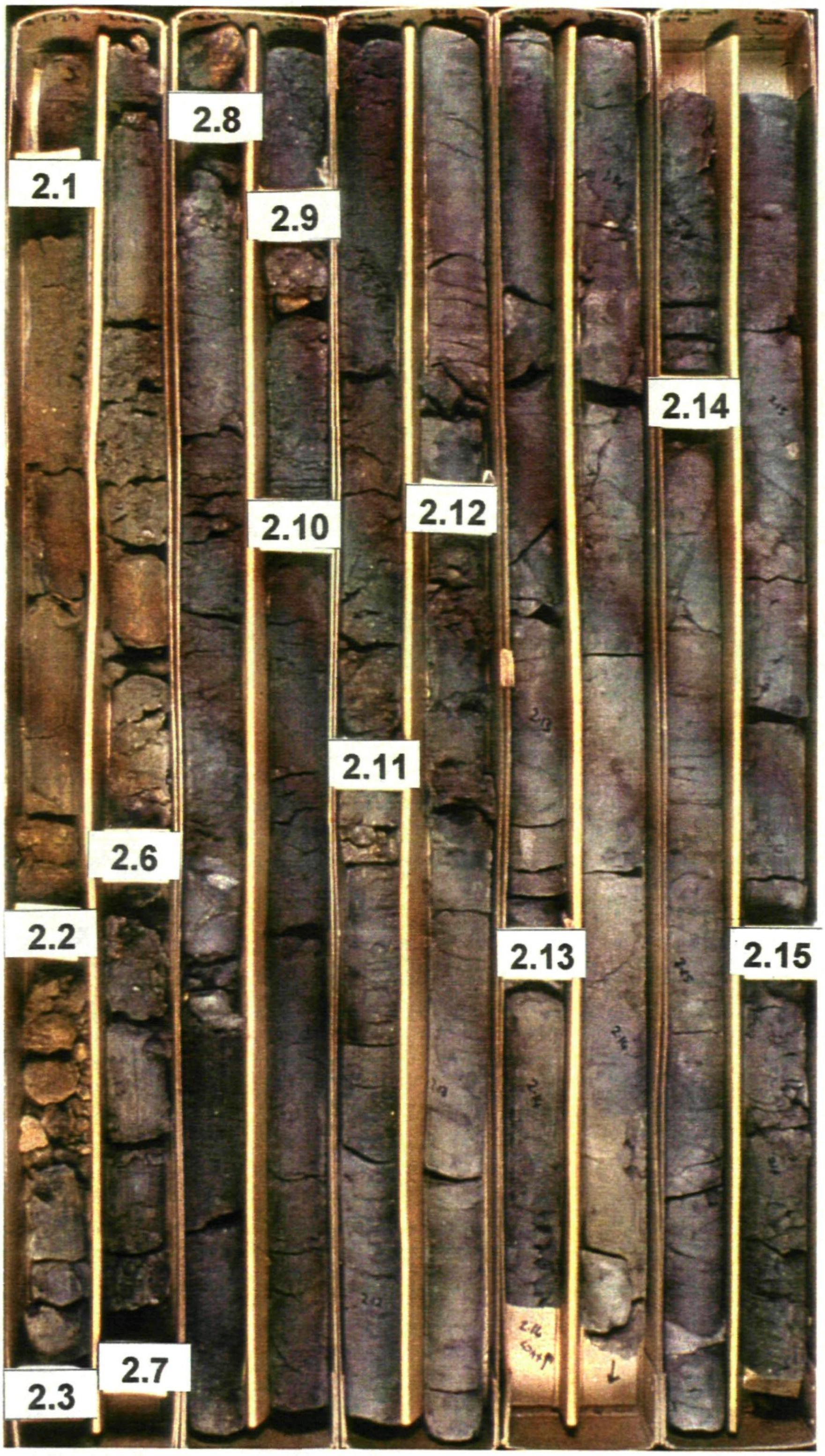


Figure 3.14. Hartmoor Hill Borehole core photographs. Cores 2.1 to 2.16 (*pars*). NB. Core loss = 100% for cores **2.4** and **2.5**. The core numbers are situated at the base of each core and represent the following depths. Core **2.1** – 2.80m, **2.2** – 3.96m, **2.3** – 5.14m, **2.6** – 8.17m, **2.7** – 9.15m, **2.8** – 10.32m, **2.9** – 11.74m, **2.10** – 13.19m, **2.11** – 14.55m, **2.12** – 16.03m, **2.13** – 17.53m, **2.14** – 19.11m, **2.15** – 20.66m.

and two silt units. These are separated by clays and silty clays. The core loss in the initial sand unit was quite severe and only a portion was cored.

From the top of the borehole to 8.37m the lithology consist of a buff/yellow/brown coloured, poorly sorted, fine to medium grained, friable sandstone. Large clasts of siltstone and small shell fragments are common. The sandstone is less friable in places where calcareous cement is present. Carbonaceous fragments are common. Interbedded at 4.10m is a light grey clay around 0.1 m thick (although due to core loss it is probably much thicker, see description for the hollow stem auger). Towards the base the sand becomes muddier and from 8.17m to 8. 37m the lithology is a light grey silty clay with shell fragments.

Below this sand unit and extending to 13.83m is a light grey silty clay with scattered shell fragments and carbonaceous material. Shell fragments are denser at the more silty horizons. A large septarian nodule with irregular lenticular cracks is present at 10.84m to 10.92m. An intense bioturbated horizon occurs from 13.62m to 13.64m.

From 13.83m to 14.65m the lithology changes to a medium grey siltstone. Large scattered shell fragments are common. Carbonaceous material is also present.

Below the siltstone the lithology remains constant and extends to 21.32m. This lithology consists of light grey, silty clay becoming clay in places. Shell fragments are common and carbonaceous material is frequent. Fragments of ammonite (*Cardioceras* sp. juv.) occur at 20.23m. Orange/light brown cementstone nodules common. Small burrows occur but are infrequent.

From 21.32m the lithology changes to a light grey siltstone with very common, large and small, shell fragments. Intense bioturbation in certain layers. Thick, large, shell fragments are common around 23.56m (possibly fragments of *Deltoideum*). A thin bed of silty clay occurs from 24.64m to 25.18m. Frequent ammonite fragments including *Cardioceras* sp., *Cardioceras* sp. juv. and ?*Peltoceras*. After 27.40m the lithology changes to a clay and

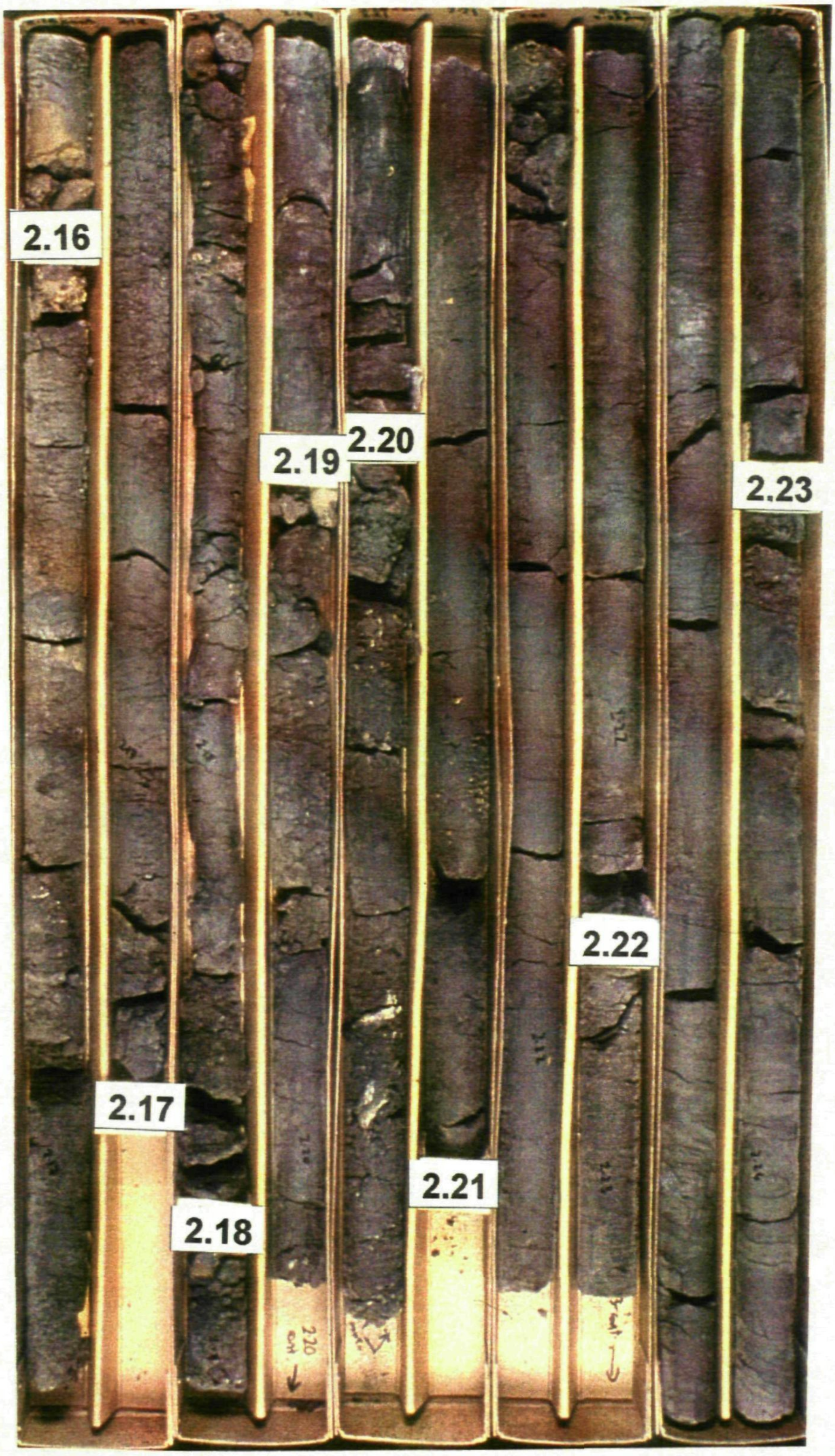


Figure 3.15. Hartmoor Hill Borehole core photographs. Cores 2.16 (*pars*) to 2.24 (*pars*). The core numbers are situated at the base of each core and represent the following depths. Core **2.16** – 21.02m, **2.17** – 22.54m, **2.18** – 23.44m, **2.19** – 24.34m, **2.20** – 25.87m, **2.21** – 27.40m, **2.22** – 28.93m, **2.23** – 30.47m.

slightly silty clay. The boundary with the underlying Weymouth Member is placed at the last occurrence of silt down hole.

The BGS define the base of the Hazelbury Bryan Formation as the base of the lowest sand in the sequence, which varies depending on geographical location.

3.4.2.2. Weymouth Member.

This member extends from 27.40m to the base of the borehole (40.95m) and includes cores 2.22 to 2.30 (Figs 3.12, 3.15 and 3.16).

The Weymouth Member consists of light grey, slightly silty clay to light grey, fine clay. Scattered fine shell fragments and carbonaceous material are common. Crushed shell material often occurs in plasts up to 0.1m thick. Common large horizontal and vertical burrows are also present in beds. Large thin shelled bivalves up to 35mm in length are common. Gastropods are also common at certain horizons. Frequent ammonite fragments are recorded including *Cardioceras* sp., *Cardioceras* sp. juv. cf. *buckowskii*, ?*Peltoceras* sp. and *Cardioceras* sp. cf. *praecordatum.*

3.5 East Stour Borehole.

The East Stour Borehole [ST 8013 2297] is situated within the village of East Stour (Fig. 2.2) and began within the Clavellata Beds Formation and spans the entire Stour Formation (Todber Freestone, Newton Clay, Sturminster Pisolite, Cucklington Oolite and Woodrow Clay Members) and terminates in the Hazelbury Bryan Formation. It was drilled by the BGS in 1988. A graphic log is presented based on the BGS published descriptive log (Bristow, 1989a) and is illustrated in Figure 3.17. For simplicity only the last two digits of the sample numbers for the East Stour Borehole are used. The full BGS number for sample 54, for instance, would be MPA 30454. The descriptive log is included in Appendix 1.

3.6. Borehole Correlation.

The correlation of the 4 boreholes is attempted using lithostratigraphic criteria alone (Figure

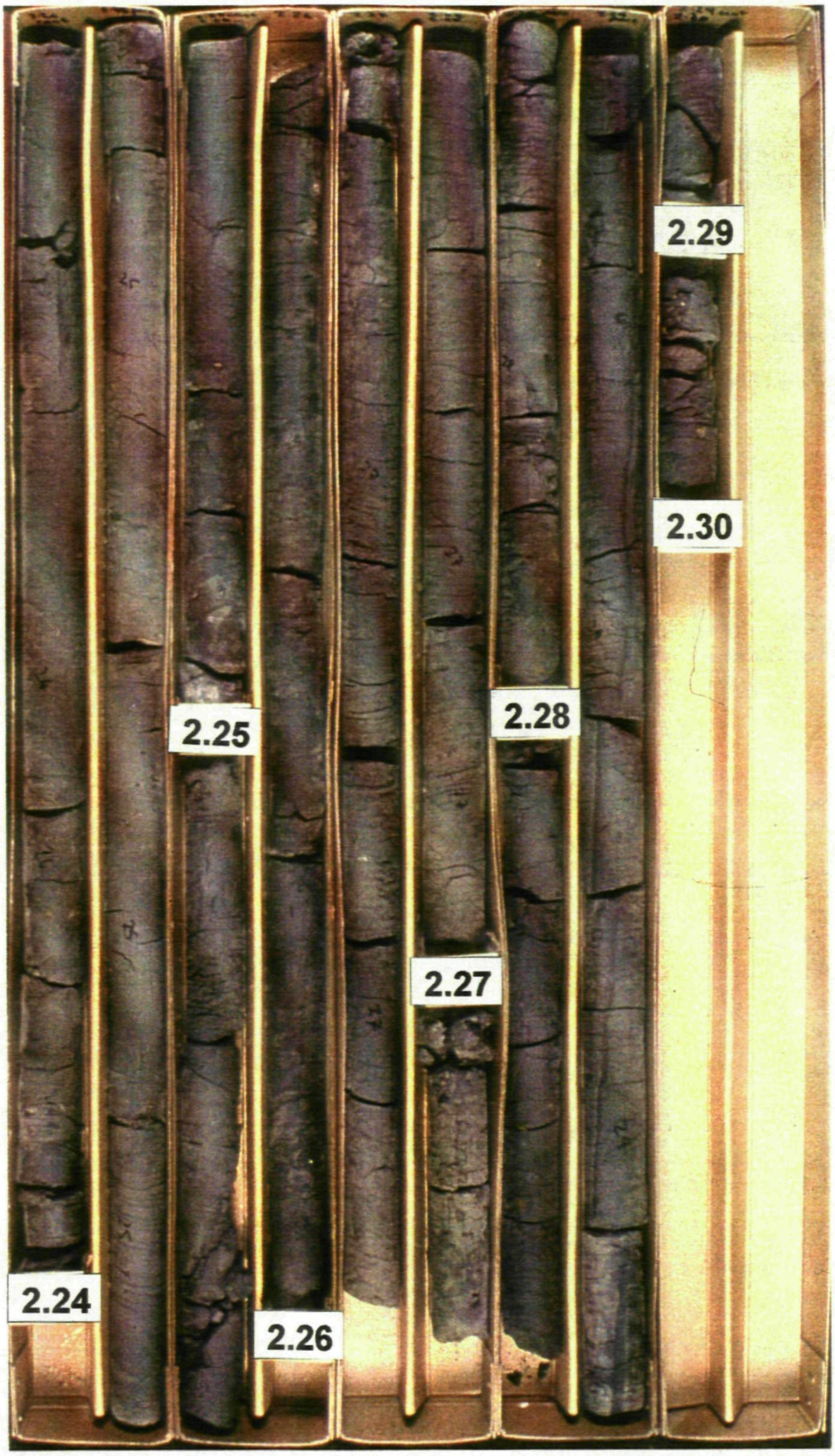


Figure 3.16. Hartmoor Hill Borehole core photographs. Cores 2.24 (*pars*) to 2.30. The core numbers are situated at the base of each core and represent the following depths. Core **2.24** – 32.00m, **2.25** – 33.54m, **2.26** – 34.91m, **2.27** – 36.45m, **2.28** – 37.88m, **2.29** – 39.42m, **2.30** - 40.95m.

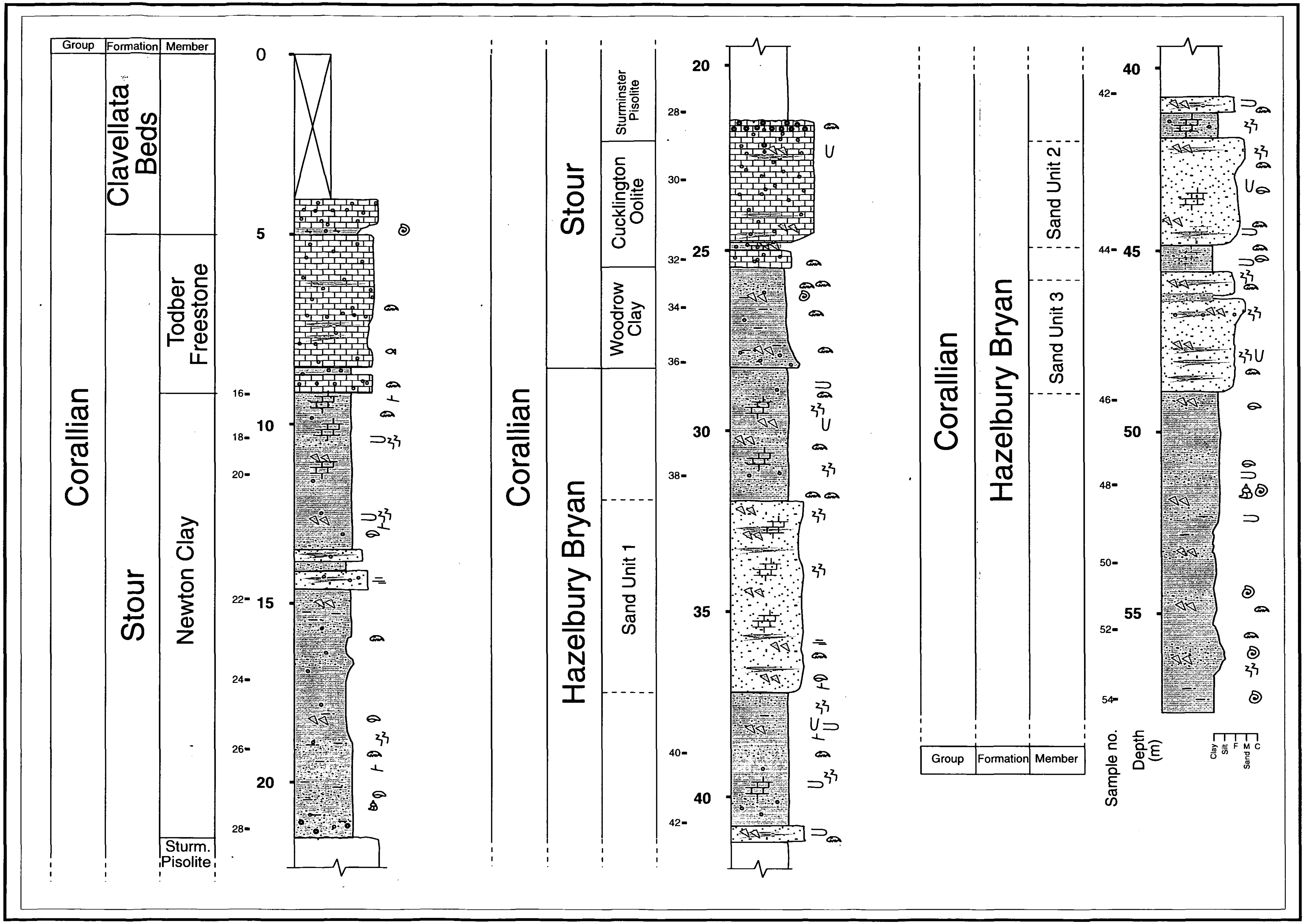


Figure 3.17. Sedimentary log of the East Stour Borehole showing sample positions.

3.18). Correlating Hallett's Farm, East Stour and Bowden Farm Boreholes is relatively simple because of the occurrence of the distinctive Sturminster Pisolite Member. The sand units within the Hazelbury Bryan Formation are also reasonably easy to correlate although the thickness varies across the area. The Hartmoor Hill Borehole proved more difficult to correlate as the important sand horizons within the Hazelbury Bryan Formation were washed out during drilling. The hollow stem auger hole helps alleviate this problem. As there is no distinctive final sand unit within either the Hartmoor Hill or Bowden Farm Boreholes the boundary with the underlying Oxford Clay Formation is presumed to occur at the last occurrence down hole of a siltstone unit. This is present within the Hartmoor Hill Borehole but not within Bowden Farm Borehole. It is probable that the sequence covered by the Bowden Farm Borehole has a greater rate of sedimentation and that the silt horizon was not penetrated. However, it is also possible that there is no siltstone equivalent within the Bowden Farm Borehole which marks the junction with the Oxford Clay Formation. In this case it is almost impossible, at least lithologically, to assign a boundary with any certainty. This boundary is therefore only tentative.

Most of the other lithological boundaries show distinctive lithological changes and are easy to assign, however, the sequence above the Clavellata Beds Formation is almost uniform so again, the boundaries between the Sandsfoot Formation Members and between the overlying Ringstead Waxy Clay Formation are also tentative, as discussed above.

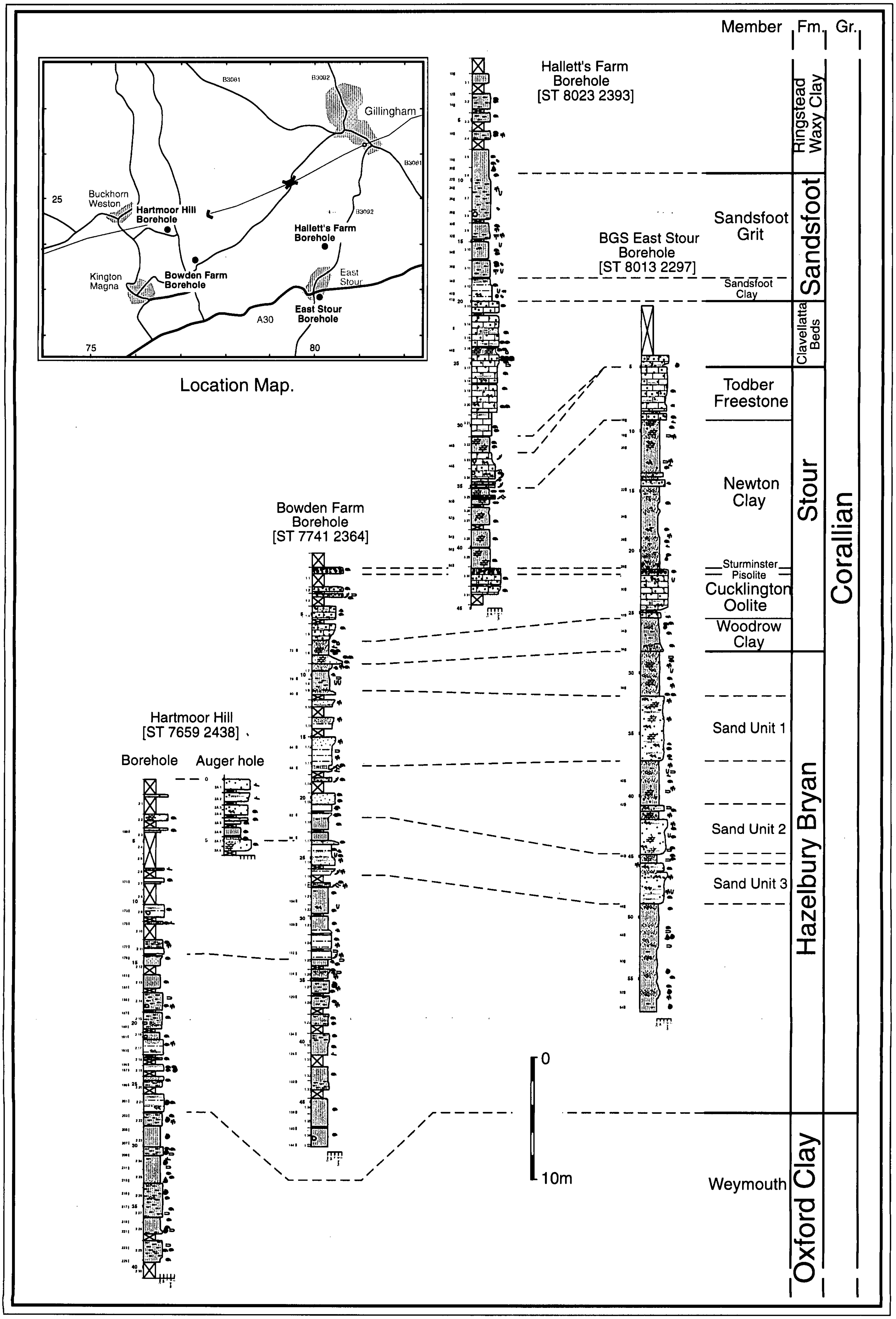


Figure 3.18. Lithostratigraphic Correlation of the East Stour, Hallett's Farm, Bowden Farm and Hartmoor Hill Boreholes. See inset map for borehole location.

Chapter 4.Taxonomy.

4.1. Introduction.

The generic and suprageneric classification used in this section is essentially that of Loeblich and Tappan (1988). Where deviation is made from this classification a definition will follow the taxonomic unit, and a short description will indicate the differences and if possible references to other classifications or usage. Any deviation from Loeblich and Tappan's (1988) classification is generally due to their diagnosis of any specific taxon not being pertinent to the commonly used Jurassic concept of the species, or where confusion would be introduced.

The systematic description of the fauna is not given a full monographic treatment. Following each Genus, where applicable, a remarks section will describe the author's concept of that particular Genus and will include any variation of the taxon.

Synonymies will be generally abbreviated and limited to the original designation with subsequent references only included to show major generic shifts; additional references may be included if necessary or where a superior description or illustration is present and which closely resemble the present diagnosis of the taxon, a recent designation will also be included where possible. A fuller synonymy may be given where there is some confusion in the literature to the nature of the taxon.

Specific descriptions will be limited to a brief diagnosis in the case of a well-known species which is well established in the literature. A full description will only be included where the author's concept of the species is significantly different, or in the case of poorly described or new taxa. Any distinctive variation within the species will also be discussed.

A remarks section follows each species and is intended to emphasise any taxonomic or identification problems, and any other notes or comments which the author feels are pertinent or important to the discussion of the taxon.

Dimensions for the species are given in microns unless otherwise stated: h = height, l = length, w = width and d = diameter; all measurements are for the maximum distance.

The total number of specimens encountered in all studied material is given for each species and is included under the heading "Material".

The majority of species encountered in this study are stratigraphically long-ranging and occur throughout the studied sections. A small number of species are stratigraphically useful and are discussed in Chapter 8, Biostratigraphy. It is therefore unnecessary to include a "Distribution" section under each taxon.

Specimens are illustrated by SEM photomicrographs and are presented in Plates 1-24.

4.2 Systematic Descriptions.

Order FORAMINIFERIDA Eichwald, 1830
Suborder TEXTULARIINA Delage and Hérouard, 1896
Superfamily ASTRORHIZACEA Brady, 1881
Family SACCAMMINIDAE Brady, 1884
Subfamily SACCAMINIINAE Brady, 1884
Genus *Lagenammina* Rhumbler, 1911
Type Species: *Lagenammina laguncula* Rhumbler, 1911

Lagenammina difflugiformis (Brady)
Pl. 1, Figs 1-3.

1879 *Reophax difflugiformis* Brady, p. 51, pl. 4, fig. 32b.
1959 *Proteonina difflugiformis* (Brady); Lloyd, p. 305, pl. 54, figs 1-4.
1965 *Lagenammina difflugiformis* (Brady); Gordon, p. 832, text-fig. 3 (8-11).

Diagnosis: Test small to medium, unilocular, flask-shaped. Sub-spherical body, greatest width around mid-point of chamber, ovate to circular cross section with slightly flattened base, tapering to a slender neck, aperture circular, terminal, at the end of the neck. Wall agglutinated with medium-sized quartz grains.

Variation: The specimens vary in shape from near spherical to flask-shaped to oblate spheroid. In some forms the apertural neck is long and slender while in other specimens short and stout.

Remarks: Many specimens are compressed laterally. Previous authors have referred compressed (or possibly compacted) forms to different species. The present author agrees with Lloyd (1959) in including these specimens as variants of *L. difflugiformis*.

Material: 795 specimens.

Superfamily AMMODISCACEA Reuss, 1862
Family AMMODISCIDAE Reuss, 1862
Subfamily TOLYPAMMININAE Cushman, 1928
Genus *Ammovertella* Cushman, 1928
Type Species: *Ammodiscus (Psammophis) inversus* Schellwien, 1898

Ammovertella liassica Barnard
Pl. 1, Fig. 5.

1950b *Ammovertella liassica* Barnard, p. 354, fig. 1c.

Diagnosis: Test small, attached, hemispherical. Initially planispirally enrolled, followed by an irregularly unwinding tube. Aperture simple, at open end of tube.

Remarks: Most specimens represented by an irregular meandering tube. Where the initial coil is present some specimens exhibit a reversal in the coiling direction. Barnard (1958) notes that this is also a feature of the type species. Few specimens are, however, found with the initial coil intact. These specimens are almost identical to specimens of *Tolypammina* Rumbler, 1895. As Barnard (1958) mentions, without the initial portion of the test intact, it is impossible to separate the genera. The specimens studied are, therefore, all included in the genus *Ammovertella* given the above difficulties.

Material: 1 specimen.

Genus *Tolypammina* Rhumbler, 1895
Type Species: *Hyperammina vagans* Brady, 1879.

Tolypammina sp. cf. *T. virgula* Kosyreva
Pl. 1, Fig. 6.

cf. 1972 *Tolypammina virgula* Kosyreva in Dain, p. 31, pl. 1, figs 2-5.

Diagnosis: A small species of *Tolypammina* with an irregularly winding second chamber, variable outline. Aperture very difficult to ascertain.

Remarks: The two specimens are similar to those figured by Kosyreva in Dain (1972). Although an attached genus, the coiling mode is dependant upon the substrate. On loose substrate an irregularly wound specimen would normally be found. The specimens are also similar to *Glomospira irregularis* Grzybowski, although the author has found no mention of this species in the Jurassic literature. As the specimens are poorly preserved they are only tentatively assigned to this taxon.

Material: 2 specimens.

Superfamily HORMOSINACEA Haeckel, 1894
Family HORMOSINIDAE Haeckel, 1894
Subfamily REOPHACINAE Cushman, 1910
Genus *Reophax* de Montfort, 1808
Type species: *Reophax scorpiurus* de Montfort, 1808

Reophax helvetica (Häusler)
Pl. 1, Fig. 4.

1881 *Dentalina helvetica* Häusler, p. 34, pl. 2, fig. 45.
1959 *Reophax helvetica* (Häusler); Lloyd, p. 308, pl. 54, fig. 8.
1965 *Reophax agglutinans* (Terquem); Gordon, p. 832, text-fig. 3, (23, 24).
1972 *Reophax helvetica* (Häusler); Norling, p. 41, fig. 14 A-B.

Diagnosis: Test small, elongate, slender, greatest width at base of final chamber, ovate in section, slightly compressed; 2-4 sub-rectangular chambers increasing in width gradually, initially twice as wide as high, becoming higher with each chamber, last chamber up to twice as high as wide, tendency to become slightly pyriform; sutures distinct, impressed, constricted; wall agglutinated with medium grained quartz; aperture round, terminal, produced on a short neck.

Remarks: The specimens generally are not intact, with the initial 1 to 2 chambers destroyed. A common species in the Jurassic, it was originally described by Häusler from the Upper Jurassic of Switzerland. The specimens are referred to this species rather than *R. agglutinans* (Terquem, 1870) which was originally described from the Bajocian of France. *R. horridus* (Schwager, 1865) may be a potential senior synonym.

Material: 227 specimens.

Reophax multilocularis Häusler
Pl. 1, Fig. 8.

1883 *Reophax multilocularis* Häusler, p. 26.
1967 *Reophax multilocularis* Häusler; Gordon, p. 449, pl. 1, fig. 12.

Description: Test small, elongate, slender, compressed, ovate in section, lobate, increasing in width gradually, length 5-6 times the width, greatest width at the base of the final chamber; approximately 6 chambers increasing gradually in size, initially wider than high, becoming equidimensional, barrel-like, final chambers higher than wide, somewhat pyriform; sutures distinct, impressed, straight; wall finely agglutinated quartz with occasional large grains, poorly sorted; aperture rounded, indistinct, central and terminal, slightly produced on a short neck.

Remarks: Specimens compressed, but otherwise similar to that figured by Gordon (1967). Specimens generally with initial chambers broken. Norling (1972) suggests that specimens referred to this species may be better placed within *R. helvetica* (Häusler, 1881). In this study it is distinguished by its very narrow test, small size and generally greater number of chambers than *R. helvetica.*

Material: 11 specimens.

Reophax sterkii Häusler
Pl. 1, Figs 9-11.

1890 *Reophax sterkii* Häusler, p. 26, pl. 3, fig. 23.
1967 *Reophax sterkii* Häusler; Gordon, p. 449, pl. 1, figs 16-17.

Diagnosis: Test large, uniserial, elongate, simple, lobate periphery, greatest width at base of final chamber, ovate in section; initial chambers small, equidimensional, increasing rapidly, final chamber large, pyriform, invariably half the length of the test; sutures distinct, horizontal, straight, impressed; wall agglutinated with coarse grained quartz, including shell material; aperture slightly produced, circular, terminal.

Remarks: Due to the delicate nature of the test, specimens tend to have only the last few chambers present; commonly the last two. Chamber arrangement varies from rectilinear to strongly curvilinear. A very distinctive species due to the nature of the last chamber.

Material: 256 specimens.

Reophax variabilis Herrmann
Pl. 1, Fig. 7.

1917 *Reophax variabilis* Herrmann, p. 286, pl. 2, fig. 19a-c.
1959 *Reophax* cf. *variabilis* Herrmann *non* Häusler 1885; Lloyd, p. 307, pl. 54, fig. 13.

Diagnosis: A species of *Reophax* consisting of 3-4 globular chambers aranged in a curvilinear or irregular series. Chambers circular in section, final chamber inflated. Aperture terminal, circular, produced on a prominent thin neck.

Variation: The specimens tend to have the chambers arranged in a curvilinear or irregular series. Some forms are rectilinear. The final chambers may be compressed in the axis of growth. The apertural neck may be absent on some specimens.

Material: 16 specimens.

Reophax spp. indet.

Remarks: Specimens of Reophax represented by broken tests, single or few chambers only and those which are badly preserved, are included in this category. Many forms may possibly belong to *Reophax helvetica* (Häusler, 1881) but due to compression, poor preservation or any of the points mentioned above, the author prefers to group these specimens into this category.

Material: 35 specimens.

Superfamily LITUOLACEA de Blainville, 1827
Family HAPLOPHRAGMOIDIDAE Maync, 1952
Genus *Haplophragmoides* Cushman, 1910
Type species: *Nonionina canariensis* d'Orbigny, 1839

Haplophragmoides sp. cf. *H. excavatus* Cushman and Waters
Pl. 2, Fig. 1.

cf. 1927 *Haplophragmoides excavatus* Cushman and Waters, p. 82, pl. 10, fig. 3.
1990 *Haplophragmoides* cf. *excavatus* Cushman and Waters; Nagy, Löfaldi, Bäckström and Johansen, p. 991, pl. 2, figs 6-7.

Diagnosis: A small inflated species of *Haplophragmoides* with 5-6 slightly inflated sub-triangular chambers. Parallel sided with an indistinct umbilicus. Slightly lobate periphery. Sutures slightly impressed. Aperture obscured by adventitious particles.

Remarks: The small number of specimens precludes a definite identification of this taxa. The specimens are similar to those illustrated by Nagy *et. al.* (1990) from the Jurassic of central Spitsbergen as *H.* cf. *excavatus.*

Material: 3 specimens.

Haplophragmoides haeusleri Lloyd
Pl. 2, Fig. 2.

1959 *Haplophragmoides haeusleri* Lloyd, p. 314, pl. 54, fig. 22, text-fig. 5i, j.

Diagnosis: A species of *Haplophragmoides* with 6 chambers in the final whorl, parallel sided in apertural view. Chambers increasing gradually in size, slightly inflated towards the final chamber. Sutures impressed and radial. Aperture a basal interio-marginal thin slit.

Remarks: Specimens are generally very coarsely agglutinated and, as a consequence, the sutures and aperture are difficult to observe.

Material: 66 specimens.

Haplophragmoides kingakensis Tappan
Pl. 2, Figs 3-4.

1955 *Haplophragmoides kingakensis* Tappan, p. 43, pl. 10, figs 1-6.

Diagnosis: A variable species of *Haplophragmoides* with 5-8 globular chambers, the final chamber is often inflated. Periphery lobate, with impressed radial sutures, umbilicus small and deep. Aperture a small arch at the base of the final chamber.

Variation: The number of chambers varies from 5-8 and some specimens exhibit a greater, or lesser, degree of inflation of chambers. Most forms are compressed. The amount and direction of compression is variable from specimen to specimen, producing a wide range of forms.

Remarks: The species was first described by Tappan (1955) from the Jurassic of the Arctic Slope of Alaska. The illustrations of this species show a significant variation in size and morphology (Tappan, 1955, pl. 10, figs. 1-6). The specimens recorded in this study show the same degree of variation.

Material: 130 specimens.

Haplophragmoides latidorsatum (Bornemann) *sensu* Lloyd
Pl. 2, Fig. 5.

1855 *Nonionina latidorsata* Bornemann, p. 339, pl. 16, fig. 4
1959 *Haplophragmoides latidorsatum* (Bornemann); Lloyd, p. 313, pl. 54, fig. 23a, b.

Diagnosis: An inflated *Haplophragmoides* with a lobate periphery consisting of 6 sub-triangular inflated chambers in the last whorl. Umbilicus small and deep; sutures impressed and radial. Aperture an interio-marginal basal slit, situated on the final chamber, surrounded by a slight lip.

Remarks: Specimens are almost invariably laterally compressed. First described by Bornemann from the Tertiary deposits from Hermsdorf near Berlin, Germany. The concept of this species follows Lloyd (1959) who included *Haplophragmoides subglobosus* (Sars) recorded by Bartenstein and Brand (1937) as synonymous.

Material: 78 specimens.

Haplophragmoides tryssa Loeblich and Tappan
Pl. 2, Fig. 6.

1950 *Haplophragmoides tryssa* Loeblich and Tappan, p. 41, pl. 11, figs 2a-b.

Diagnosis: A compressed species of *Haplophragmoides* with a lobate periphery; 5 chambers in the final whorl, rapidly increasing in size as added. Sutures slightly depressed and radial. Aperture a low basal slit.

Variation: The final chamber in most specimens is enlarged and extended.

Remarks: Loeblich and Tappan (1950) first describe this species from the Redwater Shale Member (Oxfordian) of South Dakota and note that it is very similar to *H. kirki* Wickenden in its chamber arrangement, but with 5 chambers instead of 4.

Material: 16 specimens.

Haplophragmoides sp. 1
Pl. 2, Figs 7-9.

Description: Test small, planispiral, inflated with a rounded periphery. Five chambers in the last whorl increasing rapidly in size, final chamber large, flaring and inflated. Sutures impressed, radial. Small shallow umbilicus. Aperture a narrow arcuate slit at the base of the final chamber.

Remarks: Most specimens examined are compressed. The final chamber is approximately half the size of the test and reaches back towards the umbilicus. The exact nature of the sutural and apertural characteristics are difficult to ascertain due to the coarseness of the adventitious material.

Material: 676 specimens.

Haplophragmoides sp. 2
Pl. 2, Figs 10-11.

Description: Test very small, compressed, planispirally coiled, consisting of 6-7 subtriangular chambers in the final whorl, increasing gradually in size. Periphery rounded and entire. Small deep umbilicus. Sutures radial, slightly impressed. Aperture indistinct. Margin sub-acute, becoming acute at the final chamber.

Remarks: Specimens vary in the amount of compression. Some specimens have slightly inflated final chambers. These specimens may better placed within the genus *Kutsevella*, Dain.

Material: 863 specimens.

Haplophragmoides sp. 3
Pl. 2, Fig. 12.

Description: Test small, compressed, planispirally coiled with a lobate periphery and 7-8 chambers in the final whorl. Chambers rapidly increasing in size as added, the final two chambers extended in height. Sutures distinct and impressed, radial, connecting with a small deep umbilicus. Aperture characteristics not visible.

Remarks: The sutures in this specimen are distinctly incised. Only one specimen with a broken final chamber precludes the proper identification of this species. It also prohibits observation of the aperture, which may affect the generic position of the species.

Material: 1 broken specimen.

Haplophragmoides/Trochammina spp. indet.

Remarks: This category is reserved the number of specimens of *Haplophragmoides* or *Trochammina* which are not distinguishable from each other or are difficult to assign to a specific taxon. This category includes specimens which are badly preserved, damaged, pyritized or severely compressed. In each case every effort has been made to assign each specimen to a specific taxon. However, if detail is lost which precludes this, then the specimen is included within this category.

Material: 616 specimens.

Family LITUOLIDAE de Blainville, 1827
Subfamily AMMOMARGINULININAE Podobina, 1978
Genus *Ammobaculites* Cushman, 1910
Type Species: *Spirolina agglutinans* d'Orbigny, 1846

Ammobaculites agglutinans (d' Orbigny)
Pl. 3, Figs 1-2.

1846 *Spirolina agglutinans* d'Orbigny, p. 137, pl. 7, figs 10-12.
1965 *Ammobaculites agglutinans* (d'Orbigny); Gordon, p. 833, text-fig. 3 (16-18).

Description: Test small, periphery lobate, section ovate (compressed) to rounded; 4-5 subtriangular chambers increasing slowly in size arranged in an involute large planispire with a small depressed umbilicus; uniserial portion arranged in a rectilinear series of 2-6 chambers approximately twice as wide as high, constant in size, added regularly, centrally placed above and not exceeding the width of the planispire; wall finely agglutinated with occasional large grains; sutures distinct, impressed, constricted and straight on the uniserial portion, sutures radial, straight and impressed on the planispiral portion; aperture not visible.

Remarks: Similar to *Ammobaculites fontinensis* (Terquem) but less coarsely agglutinated, the uniserial portion is centrally placed above the planispire and with an involute planispire rather than an evolute one. Lloyd (1959) recognised three variants within this species based on the evolute/involute nature of the coil, the amount of depression of sutures and umbilicus and the size of the coil. This variation is observed within the present material, but the specimens of Lloyd tend to be more evolute in general. Most of the specimens studied are involute and are in between variants B and C (Lloyd, 1959, p. 309, text-fig. 4c, d). A distinct variant is recognisable, recorded in this study as *Ammobaculites* sp. cf. *A. agglutinans* form B; see below for a description. The specimens also are very similar to *Ammobaculites pungaensis* Levina, 1990. It may be more appropriate to refer the specimens to this taxon which has been described from the Jurassic of Russia.

Material: 1974 specimens.

Ammobaculites sp. cf. *A. agglutinans* (d'Orbigny) form B.
Pl. 3, Figs 3-4.

1846 *Spirolina agglutinans* d'Orbigny, p. 137, pl. 7, figs 10-12.
cf. 1951 *Ammobaculites* cf. *agglutinans* (d'Orbigny); Bartenstein and Brand, p. 269, pl. 2, figs 33-35.
cf. 1951 *Ammobaculites* cf. *agglutinans* (d'Orbigny) Form a; Bartenstein and Brand, p. 269, pl. 2, fig. 38.

Diagnosis: A compressed variant of the species *Ammobacuites agglutinans*. An initial planispire composed of 5-7 chambers, generally wider in diameter than the width of the following uniserial portion, which comprises 4-6 compressed, barrel-like chambers.

Remarks: Bartenstein and Brand (1951) referred distinctly compressed specimens to "*A.* cf. *agglutinans*" and "*A.* cf. *agglutinans* Form a" although the figures (pl. 2, figs 33-35) seem to indicate merely flattened forms of *A. agglutinans sensu stricto*. The specimens encountered in this study are generally compressed and are smaller than specimens referred to *A. agglutinans*. The author believes that these characteristics are not distinct enough to merit classification as a new species and includes these specimens as a variant of *A. agglutinans*.

Material: 42 specimens.

Ammobaculites barrowensis Tappan
Pl. 3, Figs 5-7.

1955 *Ammobaculites barrowensis* Tappan, p. 45, pl. 11, figs 7-12.

Diagnosis: A medium-sized species of *Ammobaculites* with a distinct lobate periphery. Biumbilicate with a small deep umbilicus; 3-6 sub-triangular, inflated chambers, rapidly increasing in size as added. Uniserial portion consists of 2-4 inflated chambers which are often constricted distally, producing a lobate periphery in lateral view. Sutures distinct, deeply impressed, radial and straight in the planispire. Final chamber often inflated or pyriform. Aperture circular, terminal and produced.

Variation: Some specimens are almost evolute with the initial chambers clearly visible. The uniserial portion varies from one pyriform chamber to 4 inflated chambers. Chambers often decrease in width distally.

Remarks: Many specimens have the planispiral portion broken off. In such cases they are very similar to certain species of *Haplophragmoides*. A deep umbilicus in some specimens exposes the initial chambers. First described by Tappan (1955) from the Jurassic of the Arctic Slope of Alaska.

Material: 191 specimens.

Ammobaculites canui (Cushman)
Pl. 3, Fig. 8-11.

1930 *Haplophragmoides canui* Cushman, p. 133, pl. 4, fig. 1a, b.
1959 *Ammobaculites laevigata* Lozo *sensu* Lloyd, p. 313, pl. 54, fig. 14, text-fig. 4a.

Description: Test medium to large, biconvex with a slightly lobate outline, flattened sides and sub-angular periphery; sub-triangular chambers arranged in an involute planispiral coil, with a tendancy to uncoil over the last few chambers; 8-11 chambers increasing gradually in size, twice as high as wide, last chamber may be added outside the plane of coiling, biumbilicate with a small, depressed (excavated) umbilicus, umbilical ends of chambers sometimes extending into umbilicus; sutures impressed, radial, straight to slightly curved, curving backwards distally; wall finely agglutinated; aperture oval to circular, large, centrally placed on apertural face.

Remarks: The large oval aperture is areal in the final chamber, but becomes circular, central and terminal in those forms with an uncoiled portion. The position of the aperture suggests that this species belongs within the genus *Ammobaculites*, rather than *Haplophragmoides* or *Cribrostomoides* as previously referred. Specimens with a distinct uniserial uncoiled portion are few, although many forms exhibit uncoiling over the last few chambers, indicating the inclusion of this species in the genus *Ammobaculites*. Many specimens include small opaque oxide minerals at the junction of each chamber bordering the sutures.

Material: 1598 specimens.

Ammobaculites coprolithiformis (Schwager)
Pl. 3, Figs 12-14; Pl. 4, Figs 1-11.

1867 *Haplophragmium coprolithiformis* Schwager, p. 654, pl. 34, fig. 3.
1959 *Ammobaculites subaequalis* Myatliuk; Lloyd, p. 311, pl. 54, figs 16, 17.
1965 *Ammobaculites coprolithiformis* Schwager; Gordon, p. 833, text-figs 2, 3(25-28).
1981 *Ammobaculites coprolithiformis* Schwager; Barnard, Cordey and Shipp, p. 389, pl. 1, figs 3-4, text-fig. 4. Form A, pl. 1, fig. 9.

Description: There is a marked distinction between the different generations (megalospheric and microspheric, A or B). So each form is described seperately.

Megalospheric (A form): Test large, initially compressed, later circular in cross section, elongate or squat, planispiral then uncoiled, slender with well developed uniserial portion similar in width to the diameter of the planispire; chambers arranged in an initial, sometimes reduced involute planispire followed by an elongate rectilinear or slightly curvilinear uncoiled uniserial portion; around 3-6 sub-triangular globular chambers increasing gradually in size; small umbilicus, rarely small raised sub-spherical umbilical shield, last chamber of planispire reaching back towards initial chambers, becoming twice as wide as high, low and triangular; commonly 2 chambers but can be up to 4 chambers in the uncoiled portion, usually rectilinear, occasionally curvilinear, last chamber slightly inflated and commonly pyriform, higher than wide, previous chambers wider than high; wall finely or coarsely agglutinated; sutures distinct, depressed, radial and straight in the planispire, in the uncoiled portion sloping towards the initial chambers of the planispire, s-shaped (sigmoidal), or straight; aperture circular, large, terminal, centrally placed, may be produced on the end of a distinctive short neck.

Variation: Highly variable. Number of chambers varies from 1 to 4 in the uncoiled portion, commonly exhibiting a pyriform final chamber, with produced apertural neck; the common variant has two chambers. Coil is generally a small planispire of 3-5 chambers. Probable juvenile forms occur quite frequently, consisting of 3 to 4 small globular chambers with a larger inflated final chamber; aperture flush, circular, centrally placed on last chamber.

Microspheric (B form): Test large, squat sometimes elongate, cross section initially compressed later circular and inflated; chambers arranged initially in a large slightly compressed planispire consisting of up to half the test, 5 to 7 sub-triangular chambers, increasing gradually in size, last chamber wider than high, small depressed umbilicus, sometimes exhibiting a raised umbilical shield or boss; uncoiled portion of 1 to 3 large inflated chambers, up to twice as wide as high, last chamber inflated, can be up to half the size of the test, usually pyriform or globular; wall finely or coarsely agglutinated; sutures distinct, impressed, radial, straight to slightly curved, in the planispire, straight, depressed, constricted in the uniserial portion; aperture large, circular sometimes tri-radiate, terminal, centrally placed, produced on a short neck.

Variation: The width of the uniserial portion varies from as much as 3/4 the width of the diameter of the planispire to around 1/2 the width. The number of chambers in the uniserial portion varies from 1 to 3. If the uniserial portion has only one chamber, then it tends to be pyriform or extended.

Remarks: Variation occurs in the size and type of adventitious material. Some specimens agglutinate regular fine-grained quartz, while others contain very large grains, utilising shell fragments, quartz grains, spicules, other small foraminifera and ooids; no preference is exhibited in agglutinated material between microspheric and megalospheric forms. Specimens with coarse tests and those with a fine-grained test co-exist within the same sample and therefore no distinction can be made stratigraphically between the two forms. Barnard *et al.* (1981) distinguish a separate form, due to the extremely coarse nature of the test, which is also stratigraphically restricted. The fine grained specimens are also similar to *Haplophragmium elenae* Dain.The microspheric:megalospheric ratio can range from 1:15 to 1:20. The variation exhibited by this species probably includes the species *A. eocretaceous* Bartenstein and Brand; *A. infrajurensis* Terquem; *A. subaequalis* Myatliuk and *A. braunsteini* Cushman and Applin.

Material: 16, 979 specimens. Very common to flood abundance. In some samples *A. coprolithiformis* is the only agglutinated taxon present and can make up 90% of the total assemblage.

Ammobaculites deceptorius (Häusler)
Pl. 5, Figs 1-2.

1890 *Reophax* sp. indet. Häusler, p. 30, pl. 3, fig. 13, *sensu* Lloyd, 1959
1890 *Bigenerina deceptoria* Häusler (*pars*), pl. 74, pl. 12, figs 11-13, (*non* figs 8-10).
1959 *Ammobaculites deceptorius* (Häusler); Lloyd, p. 310, pl. 54, fig. 24a, b.

Diagnosis: A small to medium sized species of *Ammobaculites* with a restricted initial coil of 2-3 globular chambers. The uniserial portion consists of 3-5 sub-globular chambers increasing gradually in size, sometimes remaining parallel sided; final chamber slightly inflated, or pyriform; aperture circular, centrally placed, terminal and produced on a short neck.

Variation: The width of the uniserial portion is variable from specimens with parallel sided portions not wider than the initial coil, to specimens with chambers in the uniserial portion rapidly increasing in size.

Remarks: Many specimens have only 2 globular chambers in the initial "coil".

Material: 530 specimens.

Ammobaculites fisheri Crespin.
Pl. 5, Fig. 4.

1953 *Ammobaculites fisheri* Crespin, p. 29, pl. 5, figs 4, 5.
1965 *Ammobaculites fisheri* Crespin; Gordon, p. 833, text-fig. 3 (13-15).

Description: Test small, elongate, slender, section ovate; initial planispiral coil of approximately 4 chambers, diameter about 1/5 of the length of the test, chambers sub-triangular, increasing slowly in size as added, sub-polygonal in outline; uncoiled portion rectilinear with approximately 5 chambers decreasing in size as added, first chamber almost twice as wide as high, later chambers becoming equal in width and height; sutures constricted, producing a polygonal lobate periphery; wall finely agglutinated with the occasional larger grain; aperture indistinct.

Remarks: Aperture characteristics are not visible the specimen has the final chamber missing. Similar to *Ammobaculites agglutinans* (d'Orbigny) and may represent a variant.

Material: Very rare, 1 specimen.

Ammobaculites fontinensis (Terquem)
Pl. 5, Fig. 3.

1870 *Haplophragmium fontinense* Terquem, p. 235, pl. 24, figs 29, 30.
1989 *Ammobaculites fontinensis* (Terquem); Morris and Coleman, p. 218, pl. 6.3.6, fig. 3

Description: Test small to medium, compressed with large evolute initial coil, periphery rounded, lobate; planispiral portion with 2-3 whorls, around 6 sub-triangular chambers per whorl, increasing gradually in size, prior to uncoiling becoming barrel-shaped, twice as wide as high, slightly compressed to inflated; 3-4 chambers added rectilinearly, similar in size; sutures depressed, distinct, straight within the uniserial portion, spiral suture distinct, impressed; wall agglutinated with poorly sorted quartz grains including relatively large particles; aperture indistinct, circular, centrally placed, terminal.

Remarks: Similar to *A. agglutinans* (d'Orbigny) but tends to be compressed with an evolute planispire. Many specimens with uniserial portion broken, so apertural characters are difficult to establish and difficult to separate from species of *Haplophragmoides*.

Material: 84 specimens.

Ammobaculites godmani (Barnard)
Pl. 5, Figs 5-8.

1953 *Ammobaculites minuta* Barnard, p. 185, fig. A, 3a, b, c.
1955 *Ammobaculites godmani* Barnard, in Thalmann, p. 53.
1981 *Ammobaculites godmani* (Barnard); Barnard, Cordey and Shipp, p. 390, pl. 1, fig. 5.

Diagnosis: A small species of *Ammobaculites* with 4-5 sub-triangular chambers in the initial planispire. The uniserial portion consists of 4-6 chambers, wider than high, increasing gradually in height as added, final chamber may be slightly inflated. Sutures slightly impressed, more so in the uniserial portion which results in an often lobate periphery. Aperture circular and terminal.

Variation: Forms vary from having a small and compressed planispire followed by a uniserial portion gradually increasing in width, to other variants with a larger planispire followed by equal sized chambers in the uniserial portion. This may represent the difference between the microspheric and megalospheric forms.

Remarks: One of the smallest species of *Ammobaculites* encountered in this study. This species is very similar to *A. agglutinans* (d'Orbigny) in external morphology but is very much smaller. Barnard (1953) first described this species as *A. minuta* although this name was already occupied *by A. minuta* Waters, 1927. Subsequently Thalmann (1955) proposed *A. godmani* for Barnard's forms, "This new name is proposed with the authorization of T. Barnard (letter dated London, February 23, 1954)".

Material: 1728 specimens

Ammobaculites irregulariformis Bartenstein and Brand
Pl. 5, Fig. 10.

1951 *Ammobaculites irregulariformis* Bartenstein and Brand, p. 20, pl. 2, figs 41-44, 46; pl. 19, figs 9-10, 36; pl. 17, figs 10-12; pl. 18, figs 1, 8-10, 17-27, 31-35; pl. 19a, figs 12, 18-19.
1981 *Ammobaculites irregulariformis* Bartenstein and Brand; Barnard, Cordey and Shipp, p. 391, pl. 1, fig. 6.

Diagnosis: A small species of *Ammobaculites*, consisting of an initial compressed coil of 6-7 sub-triangular chambers, followed by an irregular series of between 3-8 chambers. Sutures distinct, impressed. Aperture terminal, circular to irregular slit-like.

Variation: A species with a variable uniserial portion. Specimens vary from those with overlapping chambers arranged in a rectilinear series, to forms with curvilinear or distinctly angled series of chambers. In general the coil is compressed and the subsequent chambers are ovoid in cross-section, although completely compressed specimens are occasionally recorded.

Remarks: First described from the Lower Cretaceous of Germany by Bartenstein and Brand (1951) who illustrate specimens with a wide range of variation. It is probable that more than one species is represented by the range of specimens, but the author prefers to assign irregular specimens of *Ammobaculites* that fall within range of variation illustrated by Bartenstein and Brand (1951), to this one species.

Material: 32 specimens.

Ammobaculites vetusta (Terquem and Berthelin)
Pl. 5, Fig. 10.

1875 *Haplophragmium vetusta* Terquem and Berthelin, p. 53, pl. 4, fig. 16a-d.
1955 *Ammobaculites vetusta* (Terquem and Berthelin); Tappan, p. 45, pl. 13, figs 1-3.

Diagnosis: A minute species of *Ammobaculites* with a comparatively large planispire consisting of 4-5 sub-triangular chambers. Uniserial portion not as wide as the diameter of the planispire and consists of 4-6 low chambers. Uniserial portion is rectilinear or curvilinear. Sutures flush to slightly impressed. Aperture small, terminal and circular.

Variation: The uniserial portion is centrally placed above the planispire and is generally not as wide as the diameter. The transition to the rectilinear uniserial portion is either abrupt or through a series of chambers arranged in a curvilinear fashion. The uniserial portion is often irregular in shape and commonly consists of 4-6 chambers.

Remarks: A distinctive species because of its extremely small size. First described by Terquem and Berthelin (1875) from the Lias. The specimens are very similar to those illustrated by Tappan (1955) from the Arctic Slope of Alaska.

Material: 10 specimens.

Ammobaculites sp. cf. *Ammobaculites* sp. 2. Bartenstein and Brand
Pl. 5, Fig. 11.

1951 *Ammobaculites* sp. 2. Bartenstein and Brand, p. 271, pl. 2, fig. 45.

Diagnosis: A compressed species of *Ammobaculites*, with a small compressed initial coil consisting of 4-5 chambers. Uniserial portion compressed longitudinally consisting of 4-5 disk-like chambers. Sutures impressed. Aperture an irregular opening, terminal, sometimes produced.

Remarks: The two specimens are very similar to those figured by Bartenstein and Brand (1951), but could merely represent compressed specimens of *A. agglutinans* (d'Orbigny).

Material: 2 specimens.

Subfamily FLABELLAMMININAE Podobina, 1978
Genus Triplasia Reuss, 1854
Type Species: *Triplasia murchisoni* Reuss, 1854

Triplasia ex. gp. sp. 1
Pl. 6, Figs 1-9.

Description: Test medium to large, varying from elongate to squat, wedge-shaped, increasing in width slowly with height, some forms more parallel-sided, others flaring abruptly, greatest width at last chamber, periphery lobate, tri-radiate to triangular in section; chambers arranged in an initial planispiral coil of 4-5 indistinct chambers usually very small, later an uncoiled rectilinear series of 4-6 chambers, becoming greater in height as added, final chamber slightly inflated reaching back over previous chambers; sutures distinct, impressed, arcuate, convex-up to strongly arched, sometimes chevron shaped; wall coarsely agglutinated with some extra large quartz grains and sponge spicules; aperture rounded, circular to ovate, sometimes slit-like, produced on the end of a short neck, centrally placed, terminal.

Variation: This "species" is extremely variable. The most noted variation is the presence of *Flabellammina*-like flat forms. Specimens also show a wide range of variation in terms of size and morphology, from small, squat, flaring tests to those which are elongate, narrow and parallel sided. Some of the specimens have an elongate ovate aperture while others have a circular aperture raised on a slight neck. The sides of the test can vary from almost triangular in section to completely tri-radiate with sub-angular sharp margins.

Remarks: Loeblich & Tappan (1988) note that species of *Triplasia* tend to show variation between quadrate, tri-radiate and flat forms, although they mention that flat forms only appear rarely. Due to the co-existence of both tri-radiate and flat forms within the samples, all forms are referred to the one species. This species is very variable in nature and should perhaps be referred to as a plexus or species group. The variation is consistant between all forms and it is very difficult to divide the group into distinct species based on a single characteristic or combination of characteristics. All specimens are recorded from a very restricted stratigraphical range, where they occur in abundance. This may also suggest that all specimens belong to a single evolving group. There are many species of *Triplasia* recorded in the literature and, as noted in numerous synonymies, specimens have been referred to a number of different species. Some of the more commonly mentioned species are *T. acuta* (Bartenstein and Brand, 1951), *T. althoffi* (Bartenstein and Brand, 1937), *T. bartensteini* Loeblich and Tappan, 1952, *T. emslandensis* (Bartenstein and Brand, 1951), *T. kimeridensis* (Bielecka and Pozaryski, 1954) and *T. variabilis* (Mahlecki, 1954). Barnard *et al.* (1981) record two species of *Triplasia* (*T. acuta* and *T. kimeridensis*) as restricted to the Athleta Zone from the Oxford Clay of Woodham and Weymouth, England. Although these species have the same stratigraphic range they distinguish between the two on the basis of size, growth rate, coil morphology and gross morphology.

Given the restricted occurrence, the continual smooth gradation between the end members and the possible inclusion of dimorphic forms, the author prefers to retain all specimens in the present study as a single species group. A morphometric study of the specimens may reveal the presence of one or more species.

Material: 238 specimens.

Family PLACOPSILINIDAE Rhumbler, 1913
Subfamily PLACOPSILININAE Rhumbler, 1913

Genus *Placopsilina* d'Orbigny, 1850
Type species:*Placopsilina cenomana* d'Orbigny, 1850

Remarks: Hodgkinson (1992) states that Cushman's (1920) designation of *P. cenomana* d'Orbigny (1850b) as type species is incorrect, as he was seemingly unaware that *P. scorpionis* (1850a) was the genotype by monotypy. The true identity of the type species has not been recognised and as a consequence the definition of *Placopsilina* in terms of wall structure needs further investigation. Hodgkinson (1992) recomended a thorough revision of the genus, and assigned his material to "*Placopsilina*" as a neotype has not been chosen for *P. scorpionis*. The author follows this recommendation by citing this genus in inverted comas.

"*Placopsilina*" sp. cf. *P. cenomana* d'Orbigny
Pl. 7, Fig. 2.

cf. 1850 *Placopsilina cenomana* d'Orbigny, p. 259.
cf. 1882 *Placopsilina cenomana* d'Orbigny; Häusler, p. 27, pl. 3, fig. 1.

Diagnosis: An attached species with an initial small coil, planispirally arranged, followed by 2-4 barrel-like chambers. The initial coil is quadrate in outline and is composed of 4-5 sub-triangular chambers. Aperture circular, the open end of the final chamber.

Remarks: The specimens are very similar to *P. cenomana* as figured by Loeblich and Tappan (1988) after Perner (1892) in their revised classification (pl. 65, figs 11-12). Barnard (1958) mentions that Jurassic forms do not exhibit well formed initial coils, but rather hemispherical chambers. The specimens encountered in this study have a distinct initial coil. Häusler (1882) remarks that *P. cenomana* is one of the most common arenaceous species of the whole Swiss Jurassic formation, and especially from the Lower Malm. The genus "*Placopsilina*" is referred to in inverted comas following Hodgkinson (1992) who states that Cushman (1920) was in error in designating *cenomana* d'Orbigny (1850b) as type. Hodgkinson (1992) erected the species "*P*". *northfleetensis* for the specimens from Britain previously referred to *cenomana* which he proved to have a different wall structure. The recorded specimens are similar to "*P*". *northfleetensis* figured by Hodgkinson (1992, figs 16-20 only). Due to the limited number of specimens recorded in this study they are only tentatively assigned to this taxon.

Material: 3 specimens.

Genus *Subbdelloidina* Frentzen
Type species: *Subbdelloidina häusleri* Frentzen, 1944

Subbdelloidina sp.
Pl. 7, Fig. 1.

Diagnosis: A medium sized attached test consisting of a number of compressed barrel-like chambers arranged in a rectilinear series. Aperture open end of the last chamber.

Remarks: Many specimens are very irregular with numerous chambers arranged in curvilinear series or completely irregular. Some specimens very similar to those figured by Loeblich and Tappan (1988) as *S. häusleri* Frentzen (from Häusler, 1890).

Material: 15 specimens.

Superfamily SPIROPLECTAMMINACEA Cushman, 1927
Family SPIROPLECTAMMINIDAE Cushman, 1927
Subfamily SPIROPLECTAMMININAE Cushman, 1927
Genus *Spiroplectammina* Cushman, 1927
Type Species: *Textularia agglutinans* d'Orbigny var. *biformis* Parker and Jones, 1865

Spiroplectammina biformis (Parker & Jones)
Pl. 7, Fig. 3.

1865 *Textularia agglutinans* d'Orbigny var. *biformis* Parker & Jones, p. 370, pl. 15, fig. 23a, b.
1959 *Spiroplectammina biformis* (Parker and Jones); Lloyd, p. 315, pl. 54, fig. 28.

Description: Test small, slightly compressed (?flattened), small initial portion with emphasised junction before the commencement of the gradually widening adult portion, 5-6 chambers in the coil, 6 pairs of chambers, increasing in size very gradually at first in the adult portion, last 3 pairs of chambers becoming inflated, chambers flattened, up to 4 times wider than high; sutures distinct, impressed; finely agglutinated wall made up of quartz grains; aperture a low arch at the base of the final chamber, in the median line.

Remarks: Test is flattened in the plane of the planispire and slightly twisted around the long axis. Initial coil indistinct, probably comprising 5 chambers. Lloyd (1959) notes that this species is very similar to *Textularia jurassica* and could be the microspheric form. The specimens are also similar to *S. tobolskensis* Beljaevskaja and Komissarenko.

Material: 10 specimens.

Spiroplectammina sp. aff. *S. suprajurassica* Kosyreva
Pl. 7, Fig. 4.

1972 *Spiroplectammina suprajurassica* Kosyreva, in Dain, pl. 20, figs 7-16.

Description: Test small, compressed, slender with a lobate periphery and ovate section, almost parallel sided, length 4 times the width, greatest width at penultimate chamber; 3-4 subtriangular chambers arranged in a small planispiral coil; initial chambers of the uncoiled portion wider than the coil, later chambers added regularly, similar in size, sub-globular, arranged in the plane of coiling, last two chambers slightly inflated added perpendicular to plane of coiling, and tending towards uniserial developement; sutures straight, distinct and impressed, zig-zag central suture impressed; wall finely agglutinated; aperture indistinct.

Remarks: Species similar to *Spiroplectammina suprajurassica* as figured Dain (1972), although the initial planispire is much reduced.

Material: Very rare, 1 specimen.

Spiroplectammina sp. 1

Remarks: Only one broken specimen recorded. Distinguished from other species by its small size and the nature of the chamber arrangement in the biserial portion. Chambers orientated towards the aperture, sutures slanting upwards. The ends of the chambers have small flanges extending beyond the margin of the test.

Material: 1 broken specimen.

Superfamily TROCHAMMINACEA Schwager, 1877
Family TROCHAMMINIDAE Schwager, 1877
Subfamily TROCHAMMININAE Schwager, 1877
Genus *Trochammina* Parker and Jones, 1859
Type Species: *Nautilus inflatus* Montagu, 1808

Trochammina canningensis Tappan
Pl. 7, Fig. 5-7.

1955 *Trochammina canningensis* Tappan, p. 49, pl. 14, figs 15-19.
1989 *Trochammina canningensis* Tappan; Morris and Coleman, p. 234, pl. 6.3.12, figs 1-2.
1990 *Trochammina canningensis* Tappan; Nagy, Löfaldi, Bäckström and Johansen, p. 995, pl. 4, figs 13-16.

Diagnosis: A small subglobular species of *Trochammina*. Trochospiral with 3-5 sub-globular chambers visible on the ventral side. Approximately 6 chambers per whorl, all visible on the dorsal side. Sutures distinct and impressed. Aperture a long elongate slit at the base of the final chamber; may extend ventrally.

Variation: Generally 3 or 4 chambers visible on the ventral side where they usually extend to the umbilicus, but may be up to 6. Between 5-7 chambers visible on the dorsal side, 6 being the most common. Chambers sub-globular to globular increasing in size rapidly. Most specimens exhibit a degree of compression.

Remarks: First described by Tappan (1955) from the Arctic Slope of Alaska. She notes that her specimens are slightly larger than the holotype of *T. globigeriniformis* (Parker and Jones) and have more chambers per whorl. In the specimens studied *T. canningensis* can be distinguished from *T. globigeriniformis* by its larger size and more irregular coiling mode. *T. globigeriniformis* tends to have only 4 chambers on the ventral side.

Material: 39 specimens.

Trochammmina globigeriniformis (Parker and Jones)
Pl. 7, Fig. 8-11.

1865 *Lituola nautiloidea* Lamarck var. *globigeriniformis* Parker and Jones, p. 407, pl. 15, figs 46-47.
1981 *Trochammmina globigeriniformis* (Parker and Jones); Barnard, Cordey and Shipp, p. 393, pl. 1, fig. 12, text-fig. 6C.

Diagnosis: Small Species of *Trochammina* with 3 1/2 - 4 whorls arranged in a low trochospire, 4 chambers per whorl; chambers of last whorl globular and inflated.

Variation: Many specimens are found which are compressed (see *Trochammina*. sp. 2. below). The last 4 globular and inflated but squashed ventral chambers are always visible, with a very small angular trochospire extending from the dorsal side. These specimens have not been identified with any certainty, but could possibly represent a high spired variant of *T. globigeriniformis*. Why this variant is so susceptible to compression is not known.

Remarks: This species is distinguised by its globular final chambers. *Trochamminopsis challengeri* has been suggested as a new name for this species by Charnock and Jones (1990) following the work of Brönnimann and Whittaker (1988) who noted that the lectotype designated by Loeblich and Tappan (1964) for *Lituola nautiloidea* Lamarck var. *globigeriniformis* Parker and Jones, 1865 is unrecognisable. Charnock and Jones (1990) suggest *Trochammmina globigeriniformis* var. *altiformis* Cushman and Renz, 1946 as a potential senior synonym and *T. challengeri* Hedley *et al.* (1964) as a potential senior homonym. Some specimens are similar to *T. lobata* Levina.

Material: 1354 specimens.

Trochammmina sp. cf. *T. inflata* (Montagu)
Pl. 8, Fig. 1-2.

1808 *Nautilus inflata* Montagu, p.81, pl. 18, fig. 3.
1951 (*pars*) *Trochammmina inflata* (Montagu); Bartenstein and Brand, p. 280, pl. 4, fig. 97, *non* fig. 98.

Diagnosis: Medium-sized, globose trochamminid, concavo-convex with a low spire, approximately 3 whorls, 4-5 sub-globular chambers in the final whorl, dorsal side broadly rounded and smooth.

Remarks: The poor preservation of the tests precludes exact identification of this species. Specimens are very similar to species illustrated from the Recent (e.g. Haynes, 1973).

Material: 21 specimens.

Trochammina kosyrevae Levina
Pl. 8, Figs 3-4.

1972 *Trochammina kosyrevae* Levina, in Dain, p. 83, pl. 22, figs 5-9; pl. 29, fig. 4
1990 *Trochammina kosyrevae* Levina; Nagy, Löfaldi, Bäckström and Johansen, p. 995, pl. 4, figs 17-20.

Diagnosis: A low compressed species of *Trochammina* consisting of 6-7 quadrate chambers in the final whorl. The dorsal side is slightly convex, ventral side convex with a wide umbilicus. Chambers increasing gradually in size. Sutures depressed and distinct, curving backwards towards the periphery on the dorsal side. Periphery lobate particularly towards the final chambers. Aperture not visible on the specimens studied.

Variation: Most specimens have a convex dorsal side but some specimens exhibit a planar dorsal side. In other specimens the ends of the ventral chambers extend almost to the centre of the ventral side, producing a small shallow umbilcus.

Remarks: This species was first illustrated by Levina in Dain (1972). The specimens recorded in this study are very similar but do not exhibit inflated chambers. This may be due to compaction or compression of the specimens, as exhibited by other trochamminids, rather than a true morphological difference.

Material: 5 specimens.

Trochammina sp. cf. *T. minutissima* Dain

cf. 1972 *Trochammina minutissima* Dain, p. 86, pl. 24, figs 1-5.
cf. 1995 *Trochammina minutissima* Dain; Nagy, Gradstein, Kaminski and Holbourn, p. 201, pl. 1, figs 16-18.

Diagnosis: A small compressed species of *Trochammina* with chambers arranged in a low trochospiral. Up to 8 chambers in the final whorl, rapidly increasing in size. Previous whorls consisting of small regular sized chambers. Chambers quadrate on the ventral side, extending towards the umbilicus. Sutures depressed ventrally and dorsally. Aperture not visible.

Remarks: Only two specimens recorded, both of which have pyritized chambers. The specimens are distinctly compressed, and compare favourably with some of the specimens illustrated by Dain (1972). Due to the small number of specimens and their compresed and pyritized nature, an exact identification is not possible.

Material: 2 specimens.

Trochammina omskensis Kosyreva
Pl. 8, Fig. 5.

1957 *Trochammina omskensis* Kosyreva, pl. 1, figs 5a-c. (*nom. nud.*)
1972 *Trochammina omskensis* Kosyreva; Dain, p. 85, pl. 23, figs 1-7, 12; pl. 29, fig. 9.

Diagnosis: A flat compressed species of *Trochammina* consisting of 1 1/2-2 whorls with 8 chambers per whorl, arranged in a low trochospiral. Chambers sub-triangular, increasing gradually as added. Sutures radial on the ventral side and slightly depressed, flush on the dorsal side. Small umbilicus.

Remarks: The specimens are generally more compressed than those figured by Dain (1972), although very similar to fig. 6.

Material: 5 specimens.

Trochammina sp. cf. *T. quinquilocularis* Dain
Pl. 8, Fig. 6.

cf. 1972 *Trochammina quinquilocularis* Dain, p. 87, pl. 24, figs 6, 8-10.

Diagnosis: A plano-convex species of *Trochammina*. The planar ventral side consists of inflated chambers, the final chamber twice the size of the penultimate. Sutures radial on the ventral side and impressed, as are the spiral sutures on the dorsal side. Periphery lobate. Aperture not visible.

Remarks: One slightly damaged specimen makes identification to specific level difficult.

Material: 2 specimens.

Trochammina sp. cf. *T.* aff. *rosaceaformis* Romanova
Pl. 8, Figs 7-8.

cf. 1972 *Trochammina* aff. *rosaceaformis* Romanova; Dain, pl. 28, figs 4-6.

Diagnosis: A compressed species of *Trochammina* with 6-7 chambers in the final whorl, rapidly increasing in size. Sutures flush, umbilicus shallow and wide. Aperture not visible.

Remarks: The limited number of specimens precludes an exact identification. The specimens are very similar to the illustrations of *T.* aff. *rosaceaformis* in Dain (1972). The original reference by Romanova could not be obtained.

Material: 3 specimens.

Trochammmina squamata Parker and Jones
Pl. 9, Figs 1-9.

1860 *Trochammina squamata* Parker & Jones, p. 304.
1965 *Trochammina squamata* Parker & Jones, Gordon, p. 838, text-fig. 3, (33-35).

Diagnosis: A distinctive trochamminid with a compressed test, periphery very irregular, lobate, very slightly concavo-convex; 3 whorls of approximately 6 chambers becoming sub-triangular, twice as wide as high; sutures distinct and impressed, radial and curving backwards, umbilicus small and indistinct, wall agglutinated with fine-grained material, with minute opaque particles. Nepion pyritised with a distinctive brown colouration. Aperture not visible.

Variation: This species is very susceptable to compaction and as such most of the specimens are compressed and flat in appearance. Some specimens are compressed within the plane of coiling producing specimens similar to inflated haplophragmoidids. In general, the recorded specimens differ from the type specimen in their compacted nature. True uncompacted forms are present although rare.

Remarks: A very flattened, irregular test, distinguishes this species from the other trochamminids. Very distinctive pyritised proloculus and nepionic chambers visible from the dorsal side. The periphery of specimens is broadly rounded, very irregular and lobate. The test is variable in the nature of compression, though this is generally in the axis of coiling. Illustrations of this species by previous authors show regularly coiled specimens. In the present study a distinctive feature of this species is the inclusion of many specimens which are very irregular in their coiling.

Material: 2267 specimens.

Trochammina sp. cf. *T. taboryensis* Levina
Pl. 9, Fig. 11.

cf. 1972 *Trochammina taboryensis* Levina, in Dain, p. 89, pl. 25, figs 1-3; pl. 29, fig. 8.

Diagnosis: A species of *Trochammina* consisting of 3 whorls with 5-6 chambers per whorl. Chambers arranged in a low trochospiral with the final whorl separated from the initial whorls, which are produced slightly. Five chambers visible on the ventral side, which extend into the small umbilicus. Aperture not visible.

Remarks: As only a few compressed specimens are recorded in the studied material, the exact specific identification is difficult. The specimens are very similar to *T. taboryensis* Levina, as figured by Dain (1972).

Material: 3 specimens.

Trochammina sp. 1
Pl. 9, Fig. 10.

Description: A large, very coarsely agglutinated species of *Trochammina* with 4-5 chambers in the final whorl. Small spherical initial proloculus followed by small spherical initial chambers rapidly increasing in size in the final whorl. Final chamber is almost double the size of the penultimate. Sutures distinct and radial with a small umbilicus on the ventral side. Aperture not visible.

Remarks: Only a few broken specimens recorded making an exact identification impossible. Specimens are also compressed.

Material: 3 specimens.

Trochammina sp.2.
Pl. 8, Figs 9-12.

Description: Test minute, high trochospiral, conical with inflated and flattened last three chambers where the test is at its greatest width, width almost twice the length; chambers arranged in a medium-high conical trochospire of around 4 whorls, initially trochospiral becoming triserial; initial chambers on dorsal side small, equal sized, becoming wider than high; approximately 4 chambers per whorl, last three chambers greatly enlarged, inflated, globular and flattened; all 4 whorls visible on the conical dorsal side; sutures distinct, impressed; last three globular chambers visible on the flattened, slightly concave ventral side; sutures depressed, straight, triradiate; wall very finely agglutinated; aperture not visible, umbilicus indistinct.

Remarks: A minute species with a small pointed conical spire and large, flattened, flaring final chambers. Similar to *Trochammina squamata* Parker and Jones, but with an elevated spire and fewer chambers, and much smaller. Proloculus and nepionic chambers pyritised to give a distinctive brown colouration. Specimens could be placed in the genus *Eomarssonella* due to progression from an initial trochospiral chamber arrangement to triserial in the later stages. The type species *Eomarssonella paraconica* as figured by Dain (1972) is similar but with a larger trochospire and smaller triserial portion, chambers not flattened. Also similar to ?*Eggerella meentzeni* Klinger but with final chambers enlarged and flattened, and *T. elevata* Kosyreva.

Material: 176 specimens.

Superfamily VERNEUILINACEA Cushman, 1911
Family VERNEUILINIDAE Cushman, 1911
Subfamily VERNEUILINOIDINAE Suleymanov, 1973
Genus *Verneuilinoides* Loeblich and Tappan, 1949
Type Species: *Verneuilina schizea* Cushman and Alexander, 1930

Verneuilinoides tryphera Loeblich & Tappan
Pl. 10, Figs 1-2.

1950 *Verneuilinoides tryphera* Loeblich & Tappan, p. 42, pl. 11, fig. 16a, b.
1989 *Verneuilinoides tryphera* Loeblich & Tappan; Morris and Coleman, p. 220, pl. 6.3.6, fig. 17.

Description: Test very small, triangular to subtriangular in section, with a lobate periphery, greatest width at last set of chambers, length 2-3 times the width; sub-globular chambers increasing in size gradually at first, then rapidly; last set of chambers inflated, around 4-5 sets of three chambers; sutures distinct, impressed; wall very finely agglutinated; aperture a large rounded arch, basal, situated towards the penultimate chamber.

Remarks: Specimens resembles the species figured by Loeblich & Tappan (1950), although with a tendancy to develop more chambers. Loeblich and Tappan (1950) illustrate this specimen with around 4 sets of chambers; no mention as to the number of chambers was given in the description. Subsequent references and illustrations of this species (eg. Morris and Coleman, 1989) indicate a more slender, less flaring test with a greater number of chambers. Whether this variation is exhibited by *V. tryphera sensu stricto* or could represent a separate species is uncertain. Specimens also resemble *Verneuilinoides* sp.1 as figured by Morris and Coleman in the Stratigraphic Atlas for the Middle Bathonian to mid-Callovian of the Magnus Field, North Sea. (*Verneuilinoides* sp. 1 Morris and Coleman, 1989, p. 234, pl. 6.3.12, figs 8-9).

Material: 264 specimens.

Verneuilinoides sp.1.
Pl. 10, Figs 3-4.

cf. 1989 *Verneuilinoides* sp.2 Morris and Coleman, p. 234, pl. 6.3.12, figs 10-12.

Description: Test small, triangular to sub-triangular in section, squat, flaring rapidly towards last few chambers, greatest width at last three globular, slightly inflated chambers; chambers generally subglobular, increasing rapidly in size, triserially arranged in 4-5 sets; sutures impressed, can be indistinct; wall medium to coarsely agglutinated; aperture not visible.

Remarks: Larger, more coarsely agglutinated, more triangular and wider at maximum width than *Verneuilinoides tryphera* Loeblich and Tappan. Specimens are similar to *Verneuilinoides* sp. 2 as figured by Morris and Coleman in the Stratigraphic Atlas for the Middle Bathonian to early Callovian of the lower Heather Formation. (*Verneuilinoides* sp 2. Morris and Coleman, 1989, p.234, pl. 6.3.12, figs 10-12).

Material: 44 specimens.

Subfamily VERNEUILININAE Cushman, 1911
Genus *Gaudryina* d'Orbigny, 1839
Type species: *Gaudryina rugosa* d'orbigny, 1840

Gaudryina sherlocki (Bettenstaedt)
Pl. 10, Fig. 7.

1952 *Gaudryinella sherlocki* Bettenstaedt, p. 268, pl. 1, figs 1-5.
1981 *Gaudryinella sherlocki* Bettenstaedt; Barnard, Cordey and Shipp, pl. 1, fig. 17, text-fig. 6A, B.
1989 *Gaudryinella sherlocki* Bettenstaedt; Shipp, p. 252, pl. 6.4.1, fig. 7.

Diagnosis: An elongate cuniform species of *Gaudryina*. Initial trochospiral portion of 3-5 chambers often difficult to distinguish, later 3 chambers per whorl then biserial. Aperture variable.

Remarks: Specimens vary in their final chamber arrangement from biserial to almost uniserial, although never fully uniserial. The aperture on the more uniserial forms is central and terminal, otherwise a crescentic basal slit.

Material: 6 specimens.

Superfamily TEXTULARIACEA Ehrenberg, 1838
Family EGGERELLIDAE Cushman, 1937
Subfamily EGGERELLINAE Cushman, 1937
Genus *Eggerella* Cushman, 1935
Type Species: *Verneuilina bradyi* Cushman, 1935

Eggerella? meentzeni (Klinger) *sensu* Lloyd
Pl. 10, Figs 5-6.

1955 *Valvulina meentzeni* Klinger, p. 201, pl. 12, fig. 13a-c.
1959 *Eggerella? meentzeni* (Klinger); Lloyd, p. 317, pl. 54, fig. 32; text-fig. 5f-h.

Description: Test small and wedge-shaped with a rounded lobate periphery, reaching its greatest width at the inflated final chambers; approximately 15 chambers arranged initially in a trochoid spiral, becoming triserial, increasing in size slowly at first, becoming sub-globular and inflated by the last 3, last set of chambers double in size than penultimate set; sutures distinct and impressed; aperture a medium arch (loop) in the middle of the final chamber, extending over the previous 2 chambers, apertural face slightly concave (?excavated); wall finely agglutinated, including opaque minerals (partially pyritised) within a fine grained quartz matrix.

Remarks: May be better placed in *Eggerelloides* Haynes due to the high loop-shaped aperture.

Material: 23 specimens.

Family TEXTULARIIDAE Ehrenberg, 1838
Subfamily TEXTULARIINAE Ehrenberg, 1838
Genus *Bigenerina* d'Orbigny, 1826
Type Species: *Bigenerina nodosaria* d'Orbigny, 1826

Bigenerina clavellata Loeblich and Tappan
Pl. 10, Figs 9-10.

1946 *Bigenerina clavellata* Loeblich and Tappan, p. 245, pl. 35, figs 7-8.
1951 *Bigenerina clavellata* Loeblich and Tappan; Bartenstein and Brand, p. 275, pl. 4, figs 75, 76.

Diagnosis: Test elongate and narrow. Biserial portion 1/3 the length of the test, flaring rapidly, 5 pairs of chambers following an initial compressed proloculus. Uniserial portion rectilinear, slightly twisted, compressed with 5 barrel-like chambers, increasing in height gradually, final chamber slightly extended. Sutures impressed on the biserial portion, constricted and impressed on the uniserial portion. Aperture terminal, ovate.

Variation: The uniserial portion of the test can, in some forms, be broken off. In this case the specimens resemble *Textularia jurassica* (Gümbel). The number of chambers in the uniserial portion varies from 1-4, and they are generally compressed.

Remarks: *Bigenerina clavellata* Loeblich and Tappan, 1946 is now the type species of *Aaptotoichus* Loeblich and Tappan, 1982 which is non-canaliculate, insoluble in HCL and composed of silica particles in an organic cement. The wall structure of the studied specimens has not been examined, so it is difficult to refer these forms to *Aaptotoichus* with any certainty. The specimens very closely resemble *B. clavellata* as figured by Bartenstein and Brand (1951). Loeblich and Tappan (1982) note that specimens refered to *B. clavellata* by Bartenstein and Brand (*ibid*) appear to be a distinct species and differ from their specimens in having a larger biserial stage. The specimens have been referred to *B. clavellata* until a new species is erected.

Material: 33 specimens.

Genus *Textularia* Defrance, 1824

This Genus is reserved for specimens which are calcareously cemented and canaliculate. At present there is debate as to where specimens with organic cement should be placed. The author therefore follows the classification of Loeblich and Tappan (1964) in retaining the broader diagnosis of the Genus *Textularia.*

Type Species: *Textularia sagittula* Defrance in de Blainville, 1824

Textularia dumortieri (Schwager)
Pl. 10, Fig. 8.

1866 *Textilaria dumortieri* Schwager, p. 309, text-fig. 14.
1965 *Textularia dumortieri* (Schwager), Gordon, p. 834, text-fig. 3, (30-32).

Diagnosis: A distinct conical species of *Textularia*, circular in section, consisting of 14-16 chambers arranged biserially, height the same as the width across the final chambers. Last few chambers flaring and becoming ellipsoidal in section. Sutures flush, periphery entire although irregular at the last few chambers. Apertural face concave, aperture a rectangular slit at the base of the final chamber.

Remarks: A very distinct species of *Textularia*, in all respects exactly the same as described by Gordon (1965). Proloculus and initial chambers missing. Gordon (1965) records this species only from the upper part of the Clavellata Beds of the Dorset coast. The specimens from the present study are found from the same position within the Clavellata Beds and could represent a biostratigraphically useful species.

Material: 3 broken specimens.

Textularia pugiunculus (Schwager)
Pl. 10, Figs 11-13; Pl. 11, Fig. 1.

1865 *Textilaria pugiunculus* Schwager, p. 140, pl. 7, fig. 16.
1965 *Textularia pugiunculus* (Schwager); Gordon, p. 834, text-fig. 3 (20-22).

Description: Test small and slender, sub-triangular, elongate with a lobate periphery, thickness half the width, length 3 times the width, greatest width at last pair of chambers, width increasing slowly; 12-14 chambers, initially wider than high, compressed, slowly increasing in size, later becoming inflated, last few chambers globular and semi-spherical; sutures impressed, distinct, lateral sutures straight to curved, sloping down towards periphery from central zig-zag suture; wall agglutinated with fine equi-granular quartz particles; aperture indistinct, a basal arch, medianly positioned within an excavated portion of the apertural face.

Variation: A very variable species. The final chambers of some specimens can be inflated and sub-spherical being distinctly larger than the previous chambers. The final chambers may be added in an almost uniserial arrangement, added alternately either side of the medial line. Some specimens are also twisted around the vertical axis, sometimes up to 90°.

Remarks: Similar to *Textularia jurassica* (Gümbel) to which this species may be related. Shipp (1989) suggests that this species is a variant of *T. jurassica.* Gordon (1965) records both species from the Corallian of the Dorset coast. Distinguished from *T. jurassica* by this author by its less regular triangular outline, and small compressed non-globular initial chambers. Most specimens have an almost regular initial portion but the final chambers are more inflated, with a tendancy to become almost uniserial, inflated and sub-spherical, in *T. jurassica* all chambers tend to be regulary arranged. The sutures tend to slope downwards towards the proloculus whereas in *T. jurassica* they are generally horizontal. An initial coil may be present but is indistinct.

Gordon (1965) recorded only 37 specimens of both textularids from the Dorset coast; with *T. pugiunculus* being recorded higher up in the succession than *T. jurassica.* In the present study a similar division is encountered. A far larger number of specimens are recorded by the present author which indicate a distinct stratigraphical division between the two species. However it also must be noted that the variation of both species is such that the end members may be included in either species.

Material: 399 specimens.

Textularia jurassica (Gümbel)
Pl. 11, Figs 2-3.

1862 *Textilaria jurassica* Gümbel, p. 228, pl. 4, fig. 17a, b.
1965 *Textularia jurassica* (Gümbel); Gordon, p. 835, text-fig. 3 (19).

Description: Test small, triangular, elongate and compressed, ovate to rhombic in section, periphery lobate, thickness 1/3 to 1/2 the width, length 2-3 times the width, width increasing regularly with each pair of chambers added, maximum width at final chambers; 10-14 chambers, initially twice as wide as high, slowly increasing in size until final chambers, slightly inflated, equally high as wide; sutures impressed, distinct and straight, indistinct central zig-zag suture; wall finely agglutinated with irregularly sized particles; aperture a basal arch medianly placed on the apertural face.

Remarks: Most specimens tend to have regularly arranged chambers, becoming slightly inflated distally although not as inflated as in *T. pugiunculus* (Schwager). Refer to the previous remarks for *T. pugiunculus.*

Material: 242 specimens.

Textularia sp. 1
Pl. 11, Fig. 4.

Diagnosis: A large squat species of *Textularia* consisting of large globular chambers arranged loosely biserialy. Sutures depressed, margins lobate. Aperture a thin basal slit.

Remarks: The large size of these specimens separates them from other species of *Textularia.*

Material: 2 broken specimens.

Textularia sp. 2
Pl. 11, Fig. 5.

Diagnosis: A small squat species of *Textularia* consisting of 4 sets of two chambers biserially aranged. An initial small proloculus is followed by 8 chambers rapidly increasing in size, final two chambers are around 1/3 the size of the test. Sutures distinct and depressed, sloping down towards the proloculus. Medial zigzag suture depressed and distinct, medial area also depressed producing a bi-lobed appearance to the test. Aperture a large basal slit.

Remarks: A distinctive species, which is not referable to any recorded species from the Jurassic, but due to the lack of material it is left in open nomenclature.

Material: 2 specimens.

Suborder INVOLUTININA Hohenegger and Piller, 1977
Family INVOLUTINIDAE Bütschli, 1880
Subfamily INVOLUTININAE Bütschli, 1880
Genus *Trocholina* Paalzow, 1922
Type Species: *Involutina conica* Schlumberger, 1898

Trocholina nodulosa Seibold and Seibold
Pl. 11, Figs 6-11.

1960 *Trocholina nodulosa* Seibold and Seibold, p. 376, text-fig. 7i, m, n, pl. 7, fig. 1.
1989 *Trocholina nodulosa* Seibold and Seibold; Shipp, p. 255, pl. 6.4.1, figs 17, 18.

Diagnosis: A small species of *Trocholina* consisting of an initial small proloculus followed by a second chamber coiled in a low trochospiral of 4-5 whorls. Final chamber wide, covering approximately half of the ventral side, and producing a deep umbilicus. Dorsal side convex, ventral side concave, covered by small nodules. Aperture the open end of the second chamber, simple, flattened, circular.

Remarks: A small species with a distinct ventral side. The final whorl is thickened and surrounds a concave inner area. This is covered in small nodules, around 10 in number, often difficult to distinguish due to adherent material. Low trochospiral with an apical angle of around 120°, which helps to distinguish it from *T. conica* (Schlumberger) which, although generally larger, may have adherent material on its ventral side which is sometimes similar in appearance to the nodules of *T. nodulosa.* Conical variants of *Spirillina tenuissima* Gümbel, are similar but lack the nodular ventral side.

Material: 332 specimens.

?Trocholina sp.
Pl. 11, Fig. 13.

Diagnosis: A large species of *Trocholina* with an indistinct coil. Dorsal surface smooth, sutures flush. Ventral side pitted and rough with a central area often covered in an aggregate of calcite.

Remarks: Similar in appearance to the figures of *Trocholina* sp. 1 as figured by Lutze (1960, pl. 33, fig. 7a-c). The specimens are very badly preserved and most are damaged. It is difficult to assign these specimens to a specific taxon.

Material: 27 specimens.

Suborder SPIRILLININA Hohenegger and Piller, 1975
Family SPIRILLINIDAE Reuss and Fritsch, 1861
Genus *Spirillina* Ehrenberg, 1843
Type Species: *Spirillina vivapara* Ehrenberg, 1843

Spirillina andreae Bielecka
Pl. 11, Fig. 12.

1960 *Spirillina andreae* Bielecka, p. 144, pl. 8, fig. 65.

Diagnosis: A very small plano-convex species of *Spirillina*, planispirally enrolled. Small proloculus followed by 4-5 whorls which increase in width as added. Later whorls becoming higher and thinner, producing a small internal depression. Final whorl wider and flat against the penultimate whorl.

Remarks: Bielecka (1960) describes this species from the Polish Jurassic and the specimen recorded in this investigation compares favourable to those illustrated by Bielecka, differing in having fewer whorls. The specimen may not be fully adult.

Material: 1 specimen.

Spirillina infima (Strickland) *emend.* Barnard
Pl. 12, Figs 1-2.

1846 *Orbis infima* Strickland, p. 13, text-fig. a.
1952 *Spirillina infima* (Strickland); Barnard, p. 906, text-figs 1-3.
1962 *Spirillina infima* (Strickland); Lloyd, p. 374, pl. 1, figs 2a-b, 3a-b.
1981 *Spirillina infima* (Strickland); Barnard, Cordey and Shipp, p. 427, pl. 4, figs 1-2.

Diagnosis: A small species of *Spirillina*, planispirally enrolled, sometimes slightly trochospiral. 5-8 whorls following a globular proloculus, gently increasing in size and width producing a shallow umbilicus. Final whorl generally larger than previous, involute, embracing previous whorls. Aperture the open end of the chamber.

Remarks: Many specimens are recorded, although the preservation is varaible. A distinctive feature of this species is its large inflated final whorl, which most specimens exhibit. The arangement of the whorls tends to be slightly involute. These diagnostic features help distinguish this species from *S. tenuissima* Gümbel. The presence of distinct pores in well preserved specimens distinguishes these specimens as *Spirillina* rather than *Cornuspira* or *Ammodiscus* to which they have been referred in the past.

FEQUENCY: 657 specimens.

Spirillina tenuissima Gümbel
Pl. 12, Figs 3-4.

1862 *Spirillina tenuissima* Gümbel, p. 214, pl. 4, fig. 12a, b.
1981 *Spirillina tenuissima* Gümbel, Barnard, Cordey and Shipp, p. 428, pl. 4, figs 4, 8.

Diagnosis: A small species of *Spirillina* planispirally enrolled with 7-11 whorls gradually increasing in width, following a small spherical proloculus. Whorls evolute and remaining similar in size and width. Aperture the open end of the tube.

Remarks: A lack of umbilicus and generally larger size help distinguish this species from *S. infima*. The whorls are also generally evolute and are more circular in section than *S. infima*. Many specimens are trochospiral and there is a continual variation of specimens from true planispirally enrolled to those specimens which are similar in appearance to species of *Trocholina*. Some specimens have the concave side of the test covered in minute tubercles although, in all other respects these specimens are identical to the others.

Material: 3402 specimens.

Suborder MILIOLINA Delage and Hérouard, 1896
Superfamily CORNUSPIRACEA Schultze, 1854
Family CORNUSPIRINAE Schultze, 1854
Subfamily CORNUSPIRA Schultze, 1854
Genus *Cornuspira* Schultze, 1854
Type Species: *Orbis foliaceus* Philippi, 1844

?*Cornuspira* sp. 1
Pl. 11, Fig. 14.

Diagnosis: A concavo-convex species of *Cornuspira* with a circular lateral view. An initial globular proloculus is followed by a second chamber spirally wound then trochospiral into 3-4 coils. The second chamber becomes flattened and irregular towards the periphery. The last whorl developes a central groove and becomes pinched towards the periphery, almost carinate. Aperture at the open end of the tube, compressed, quadrate.

Variation: An irregular species of *Cornuspira* with a somewhat irregularly coiled planispiral second chamber. Although not a true trochospire, the final whorls are added below the previous, producing a distinctive concave side. The spiral sutures distinctive and depressed on the convex side, obscured on the concave.

Remarks: *Spirillina polygyrata* Gümbel, 1862, as illustrated by Bielecka (1960), is similar but shows a greater number of whorls. Due to the lack of material the exact identification of this taxa is impossible.

Material: 1 specimen.

Cornuspira sp. 2
Pl. 12, Fig. 5.

?1962 *Cornuspira* sp., A form, Lloyd, p. 375, pl. 1, fig. 12.

Description: Test extremely compressed with a planispirally enrolled second chamber. Six to eight whorls increasing in width as added. Proloculus small and indistinct. Initial whorls somewhat irregular. Aperture the open end of the 2nd chamber, slit-like and compressed. Test opaque with a milky white colour.

Remarks: Test flat with a very thin cross-section. This may represent the compressed variant of a species with chambers of a circular cross-section(e.g. *Cornuspira eichbergensis* Kübler and Zwingli, 1870). The test of all specimens is crenulated with an irregular end view. Final chamber is ribbed radially, which may represent growth lines. Lloyd (1962) distinguishes two "types", A and B, of *Cornuspira* sp. The specimens are similar to type A in most respects.

Material: 101 specimens.

Family NUBECULARIIDAE Jones, 1875
Subfamily NUBECULINELLINAE Avnimelech and Reiss, 1954
Genus *Nubeculinella* Cushman, 1930
Type species: *Nubeculinella bigoti* Cushman, 1930

Remarks: Voight (1973) showed that *Vinelloidea* Canu is a senior synonym of *Nubeculinella*. The author however, retains the use of *Nubeculinella* as it is a more widely known genus and used extensively in the Jurassic.

Nubeculinella bigoti Cushman, 1930
Pl. 12, Figs 6-7.

1930 *Nubeculinella bigoti* Cushman, p. 134, pl. 4, figs 3-4.
1962 *Nubeculinella bigoti* Cushman; Adams, p. 162, pl. 22, figs 1-7, text-fig. 1D, G, F.

Diagnosis: A species of *Nubeculinella* with an attached test consisting of an initial coil followed by a number of usually pyriform chambers, tapering to a tube like end, where they join to the base of the subsequent chamber. Aperture a simple semicircular opening at the end of the tube, against the attached substrate.

Variation: The chamber morphology is highly variable The majority of specimens exhibit pyriform chambers tapering towards the tube like neck, while some specimens have a series of drum-like chambers with no necks. Other forms exhibit chambers which are no more than slight swellings on a meandering tube. In others it is difficult to distinguish any chamber development.

Remarks: The initial coil generally consists of a small hemispherical proloculus followed by an inflated second whorl, sometimes constricted. Specimens are usually found attached to shell material or other flat substrates, occasionally to large foraminifera (e.g. *Ammobaculites coprolithiformis* (Schwager) or *Lenticulina münsteri* (Roemer)). Some specimens are found unattached and are circular in cross section. Unattached forms are only found as a number of incomplete chambers, which presumably are the more distal chambers of this species. Occasionally complete specimens have been found comprising of an attached proloculus followed by a large number of free chambers. In some instances specimens are observed to attach themselves to elongate particles, such as echinoid spines or sponge spicules. In these cases the form will almost entirely enclose the spine, and will resemble a free living species. Those forms which are attached to spines have been refered to *Nubeculinella tibia* (Jones and Parker) var. *bacularis* (Issler). Adams (1962) in his discussion of calcareous adherent forms, regards forms attached to spines as variants of *N. tibia* which is generally found free. However, the present author believes that specimens of *Nubeculinella bigoti* are capable of attaching themselves to spinose fragments as well as the usual flat substrate, and this does not warrant a separate species.

Material: Many specimens are recorded in the boreholes studied. In most cases this species occurs in flood abundance and is restricted within a short stratigraphic range.

Nubeculinella tibia (Jones and Parker) var. *bulbifera* (Paalzow)
Pl. 12, Figs 8-12.

1951 *Pseudonubeculina nodulosa* Bartenstein and Brand, p. 278, pl. 4, figs 82-84.
1962 *Nubeculinella tibia* (Jones and Parker) var. *bulbifera* (Paalzow); Adams, p. 165, pl. 23, fig. 29.

Diagnosis: A variable species of *Nubeculinella* with an attached test, consisting of a series of irregularly arranged chambers. The chambers are generally aludel in shape and are pustulose on the initial part of the test.

Variation: On examining a large number of specimens a high degree of variability was observed in chamber shape and arrangement. Generally aludel in shape, chambers can vary from being thin and elongate to more globular with pyriform chambers. The majority of specimens have a pustulose surface at the base of the chamber, in some cases this extends over the entire chamber. Chambers are arranged in a number of different styles, from specimens with a rectilinear to curvilinear series of chambers to those which are irregularly arranged; these are the most common. Some specimens have their chambers arranged in an irregular cluster, enclosing the surface they are attached to, which can vary from spines to granular fragments, to smaller foraminifera or other specimens. Many specimens are unattached in later stages but always begin in an attached form. Small to medium agglutinated particles are often incorporated within the test.

Remarks: The extremely variable nature of the test would suggest that more than one species is present. Some forms are very similar to *Nodobacularia nodulosa* Chapman, 1891, and to *Pseudonubeculina nodülosa* Bartenstein and Brand, 1951. Loeblich and Tappan (1989) tentatively include *P. nodulosa* within *Nodobacularia*. This genus is, however, reserved for completely unattached forms. In all other respects many forms studied resemble those figured by Bartenstein and Brand, 1951. Encrusting irregular specimens resemble *Nubecularia lucifuga* Defrance, 1825 but have simple apertures. The Cretaceous species *Nubecularia nodulosa* Chapman 1891, is also similar in appearance.

Material: Many specimens.

Family OPHTHALMIDIIDAE Wiesner, 1920
Genus *Ophthalmidium* Kübler and Zwingli, 1870
Type Species: *Oculina liasica* Kübler and Zwingli, 1870

Ophthalmidium compressum Barnard, Cordey and Shipp
Pl. 13, Fig. 1.

1981 *Ophthalmidium compressum* Barnard, Cordey and Shipp, p. 398, pl. 1, figs 25, 27, text-fig. 9A (1-9).

Diagnosis: A compressed species of *Ophthalmidium*, variable in outline, with an acute and sometimes keeled periphery. Aperture extended on a long neck, surrounded by a small lip, circular, terminal.

Remarks: First described by Barnard *et al.* (1981) where the complete range of variation is described.

Material: 24 specimens.

Ophthalmidium strumosum (Gümbel)
Pl. 13, Fig 2-4.

1862 *Guttulina strumosa* Gümbel, p. 227, pl. 4, figs 13-14.
1955 *Ophthalmidium strumosum* (Gümbel); Seibold and Seibold, p. 102, text-fig. 3h, i.
1956 *Ophthalmidium strumosum* (Gümbel); Seibold and Seibold, p. 109, text-fig. 3t.
1960 *Ophthalmidium strumosum* (Gümbel); Lutze, p. 485, pl. 28, figs 11, 12.
1965 *Ophthalmidium strumosum* (Gümbel); Gordon, p. 838, text-fig. 4 (8-10).
1989 *Ophthalmidium strumosum* (Gümbel); Shipp, p. 255, pl. 6.4.1, figs 13, 14.

Diagnosis: An elongate, compressed species of *Ophthalmidium* with approximately 8 chambers arranged two per whorl, following a small spherical proloculus. Final two chambers inflated, thicker than previous chambers, swollen aboraly. Aperture simple, circular or slightly ovate, terminal, extended on a short neck, often with a small "v-shaped" incision on the rim of the neck.

Variation: Specimens vary in their external morphology, from elongate sigmoidal forms to short squat forms. The final chamber is often extended below the junction with the penultimate one, aboraly, which is sometimes due to a reversal of coiling direction. Chambers become thicker as added, producing a depressed central area, in which in some forms, all previous chambers can be observed, including the proloculus. The proloculus varies from small spherical to ovoid.

Remarks: Specimens are best viewed by transmitted light immersed in an optical medium as this facilitates the better observation of proloculus and chamber arrangement. A thorough review was carried out by Wood and Barnard (1946) in which the nomenclature was discussed and the genus redefined.

Material: 572 specimens.

Superfamily MILIOLACEA Ehrenberg, 1839
Family SPIROLOCULINIDAE Wiesner, 1920
Genus *Spiroloculina* d'Orbigny, 1826
Type species: *Spiroloculina depressa* d'Orbigny, 1826

?Spiroloculina variabilis Barnard, Cordey and Shipp
Pl. 13, Fig. 5.

?1981 *Spiroloculina variabilis* Barnard, Cordey and Shipp, p. 402, text-figs 11B, a-g

Diagnosis: A compressed, smooth species of *Spiroloculina* with an ovate outline. Due to the nature of preservation chamber arrangement and aperture characteristics are difficult to observe.

Remarks: Only two poorly preserved, pyritised specimens are recorded, which are tentatively assigned to this taxon. Both specimens fall within the variation of this species as described by Barnard *et al.* (1981). They note that this species is highly variable and the chamber arrangement varies between *Quinqueloculina* and *Spiroloculina.*

Material: 2 specimens.

Family HAUERINIDAE Schwager, 1876
Subfamily HAUERININAE Schwager, 1876
Genus *Massilina* Schumberger, 1893
Type Species: *Quinqueloculina secans* d'Orbigny, 1826

Massilina sp. cf. *M. dorsetensis* Cifelli
Pl. 13, Fig. 6.

cf. 1959 *Massilina dorsetensis* Cifelli, p. 286, pl. 1, figs 15-17.

Diagnosis: A species of *Massilina* with a small oval to sub-oval outline. Six to eight chambers, 2 per whorl, increasing in size as added. Chamber arrangement initially quinqueloculine later added in opposition. Sutures flush. The aperture indistinct, terminal.

Remarks: The specimen is infilled by pyrite making the proloculus and initial chambers difficult to examine. Aperture is likewise difficult to acertain. This species was first described by Cifelli (1959) from the Bathonian Upper Fuller's Earth Clay and Forest Marble of England.

Material: 1 specimen, pyritized.

Genus: *Quinqueloculina* d'Orbigny, 1826
Type Species: *Serpula seminulum* Linné, 1758

Quinqueloculina horelli Barnard, Cordey and Shipp
Pl. 13, Figs 7-10.

1981 *Quinqueloculina horelli* Barnard, Cordey and Shipp, p. 405, pl. 1, fig. 24, text-figs 11A, a-c.

Diagnosis: Test small, elongate, ovate to sub-rectangular. Cross-section triangular to ovate. Five chambers visible externally, arranged in a quinquiloculine coil. Last two chambers large and embracing, final chamber with inflated proximal end. Aperture terminal, extended on the end of a short neck, bordered by a thin lip, circular, simple with a small tooth.

Variation: The majority of specimens are ovate to sub-rectangular but a few are short and squat. In the majority of specimens the periphery is sub-rounded, but in some forms can be acute. Generally sub-triangular in cross-section but can be ovate.

Remarks: Barnard *et al.* (1981) describe this species from the Oxford Clay of Weymouth where it is restricted to the Mariae Zone. They mention that assigning this species to the genus *Quinqueloculina* is not certain due to the variation in coiling mode, from true quinqueloculine through transitional forms to sigmoidally coiled forms.

Material: 588 specimens, generally well preserved.

Quinqueloculina sp. 1
Pl. 13, Fig. 11.

Description: A distinct species of *Quinqueloculina* with an elongate test, oval in cross section. Long and narrow chambers are added in a quinqueloculine coiling arrangement. Sutures distinct and impressed. Aperture simple, circular and extended on the end of a long neck.

Remarks: A distinctive species due to the elongate nature of the test. The author believes that the small number of specimens present however does not justify the erection of a new species.

Material: 4 specimens.

Suborder LAGENINA Delage and Hérouard, 1896
Superfamily ROBULOIDACEA Reiss, 1963
Family ROBULOIDIDAE Reuss, 1963
Genus *Falsopalmula* Bartenstein, 1948
Type Species: *Flabellina tenuistriata* Franke, 1936

Falsopalmula sp. cf. *F. deslongchampsi* (Terquem)
Pl. 14, Fig. 1.

cf. 1864 *Flabellina deslongchampsi* Terquem, p. 216, pl. 10, fig. 13.
cf. 1960 *Falsopalmula deslongschampsi* (Terquem); Lutze, p. 464, pl. 32, fig. 15.

Diagnosis: A small species of *Falsopalmula*, compressed and parallel sided. Sutures impressed and distinct. Four chambers arranged in an initial citharinid-like coil are followed later by chevron-shaped chambers. Final chambers broken, therfore the aperture characteristics could not be observed.

Remarks: Only one broken specimen was recorded. Lutze (1960) figures a specimen (pl. 32, fig. 15a, b) which is very similar to the specimen in this study.

Material: 1 broken specimen.

Falsopalmula sp. cf. *F. primordialis* (Terquem)
Pl. 14, Figs 2-3.

1870 *Flabellina primordialis* Terquem, p. 221, pl. 23, figs 19-24.

Diagnosis: Test compresed, flat and parallel sided, palmate with a lobate periphery. A spherical proloculus followed by two to four chambers arranged in a planispiral coil. Succeeding chambers chevron shaped, increasing in size as added, final 4 chambers similar in size. Final chamber slightly produced at the aperture. Sutures slightly depressed, becoming raised towards the priphery. Surface of the test smooth, with occasional small arcuate costae or ribs. Aperture extended at the end of the produced final chamber, terminal, radiate.

Variation: Outline of most specimens is lobate although a few exhibit an entire periphery. The chevron-shaped chambers in some specimens are irregular and pinched around the central area, which, may also be depressed at the periphery on both sides. In some forms thin striae and small nodules appear at the borders of chambers and can develop into full arcuate ribs that are restricted to each chamber or are continuous over a few chambers, particularly the initial ones.

Remarks: A very distinct thin-walled species. Only one specimen has the proloculus and initial chambers intact. The orignal illustrations show specimens with ribs and those without; this is in keeping with the specimens encountered in this study. The illustrations of the type specimens of *Flabellina procera* Wedekind (1940, pl. 9, figs 24-30, pl. 11, figs 6-7) are very similar to the recorded forms of this study, in particular the presence of small thin costae and nodules towards the margins of each chamber. This species was, however, recorded from the Upper Cretaceous of Germany. The author tentatively assignes these specimens to the present species as it was originally described from the Jurassic by Terquem (1870). *F.* sp. cf. *F. deslongchampsi* (Terquem) differs in having a totally smooth test with flush sutures.

Material: 8 specimens.

Superfamily NODOSARIACEA Ehrenberg, 1838
Family NODOSARIIDAE Ehrenberg, 1838
Subfamily NODOSARIINAE Ehrenberg, 1838
Genus *Dentalina* Risso, 1826
Type Species *Nodosaria* (*Dentaline*) *cuvieri* d'Orbigny, 1826

The author follows the Classification of Loeblich and Tappan (1964) in retaining the broader diagnosis of the Genus *Dentalina*. Loeblich and Tappan (1986) restricted the Genus *Dentalina* to those species with longitudinally costate surface, and erected *Laevidentalina* for smooth surfaced forms.

Dentalina bicornis Terquem
Pl. 14, Figs 4-5.

1870 *Dentalina bicornis* Terquem, p. 268, pl.29, figs 13-17.
1965 *Dentalina bicornis* Terquem; Gordon, p. 843, text-fig. 7, (1-3).

Diagnosis: An elongate, irregular species of *Dentalina*. Initial proloculus followed by 6 chambers rapidly increasing in size initially, then constant, becoming inflated later, final chamber slightly pyriform. Sutures initially flush, becoming impressed later, sloping obliquely from the apertural margin to the non-apertural margin. Periphery smooth initally, later lobate, especially the non-apertural margin. Aperture radiate terminal and peripheral, produced on a short neck.

Variation: After the proloculus the initial chambers are arranged in a rectilinear series, or a series of straight initial chambers followed later by a series of large chambers with a different growth axis.

Remarks: The specimens are similar to those figured by Gordon (1965).

Material: 3 specimens.

Dentalina sp.aff. *D. communis* d'Orbigny *sensu* Cifelli
Pl. 14, Fig. 7.

1959 *Dentalina* aff. *Dentalina communis* d'Orbigny; Cifelli, p. 307, pl. 4, figs 14-15.

Diagnosis: A small species of *Dentalina* with a curvilinear test, consisting of 5 inflated chambers, rapidly increasing in size. Initial chambers small and irregular, final chambers large, inflated and globular. Sutures impressed and almost straight. Aperture terminal, slightly produced and radiate.

Remarks: This specimen closely resembles the illustration of *D.* aff. *D. communis* by Cifelli, 1959. Without more specimens for confirmation it is difficult to be certain that this specimen represents a completely different species rather than merely a variant of another.

Material: 1 specimen.

Dentalina sp. cf. *D. debilis* (Berthelin)
Pl. 14, Fig. 6.

cf. 1880 *Marginulina debilis* Berthelin, p.35, pl. 3, fig. 28.
cf. 1951 *Dentalina debilis* (Berthelin); Bartenstein and Brand, p. 310, pl. 10, figs 239-240.

Diagnosis: An elongate, thin delicate species of *Dentalina.* Initial portion absent. Chambers elongate. Sutures distinct, impressed, sharply sloping from the apertural to non-apertural margin. Apertural margin distint, entire, non-apertural margin lobate. Aperture the produced end of the final chamber, simple, circular on the end of a short neck.

Remarks: Only one specimen recorded with with the initial chambers broken. First described by Berthelin (1880) from the French equivalent of the Gault Clay and illustrated subsequently by Bartenstein and Brand (1951). The specimen very closely resemble those figured by Bartenstein and Brand (1951) which also have the initial chambers absent. This species is generally recorded from the Cretaceous and the author has been unable to locate any reference to this species within the Jurassic Because of the broken nature of the test this specimen it is only tentatively assigned to this taxon.

Material: 1 broken specimen.

Dentalina gumbeli Schwager
Pl. 14, Figs 8-9.

1865 *Dentalina gümbeli* Schwager, p. 101, pl. 2, fig. 20.
1965 *Dentalina guembeli* Schwager; Gordon, p. 843, text-fig. 6, 13-18.

Diagnosis: An elongate, narrow *Dentalina* with approximately 9 chambers following an ellipsoidal proloculus. Sutures depressed and slightly constricted, barrel like chambers increasing in size gradually. Final chamber inflated and slightly pyriform. Aperture marginal, terminal and radiate.

Variation: Specimens assigned to this genus are very variable. The test varies from very arcuate to almost straight. The sutures are generally constricted but may be almost flush in some forms. The number of chambers varies from 6-10. The size of specimens is also variable with many of the larger forms probably representing the microspheric individuals, although no other difference is externally noted.

Remarks: Smooth dentalinids have been allocated to a number of different species by previous authors; most notably to *D. communis* d'Orbigny, a Recent species and *D. pseudocommunis* Franke which was first described from the Lias. As *D. gumbeli* is an Upper Jurassic species the author prefers to assign smooth dentalinids to this species. *D. communis* and *D. pseudocommunis* may represent the same long ranging taxon although more probably it is a feature of homeomorphy. The highly variable nature of smooth elongated specimens of *Dentalina* in the study present problems of assigning them to different taxa. In the past previous authors have erected many species of *Dentalina* on characteristiscs which the author believes can be considered as variation of a single species. To split the specimens into a number of different taxa would be confusing and arbitrary as there is a continual variation between each characteristic, and no one feature serves to distinguish variants.

Material: 135 specimens, in general well preserved.

Dentalina marsupifera Schwager
Pl. 14, Fig.10.

1865 *Dentalina marsupifera* Schwager, p. 110, pl. 3, fig. 27, pl. 4, figs 7, 9.

Diagnosis: A small species of *Dentalina* with 3 globular chambers and a lobate periphery. Initial large, globular proloculus followed by 2 inflated chambers, final chamber slightly pyriform. Sutures distinct and impressed. Aperture radiate, terminal produced on a short neck.

Remarks: This species was first described by Schwager (1865). The specimens closely resemble those illustrated by Schwager, especially in his figure 9. Some specimens are similar to certain illustartions of *D. bullata* Schwager (1865), but on the whole the variation exhibited by the specimens indicate a greater affinity to the illustrations of *D. marsupifera.*

Material: 7 specimens.

Dentalina torta Terquem
Pl. 14, Fig. 11.

1858 *Dentalina torta* Terquem, p.599, pl. 2, fig. 6a-b.
1981 *Dentalina torta* Terquem; Barnard, Cordey and Shipp, p. 406, pl. 2, fig. 1.

Diagnosis: A species of *Dentalina* with 6 chambers. Test often twisted. Sutures constricted, initially sloping but later horizontal. Aperture radiate, marginal, terminal.

Variation: Specimens vary as to the amount of constriction of the sutures. The majority of specimens exhibit a lobate periphery, although in some forms the periphery is entire.

Remarks: Similar to *D. gumbeli* but with fewer chambers which are larger.

Material: 15 specimens.

Dentalina varians Terquem *emend.* Barnard
Pl. 14, Fig. 12.

1866 *Dentalina varians* Terquem, p. 412, pl. 15, fig. 19b, c (*non* fig. 19d).
1950b *Dentalina varians* Terquem; Barnard, p. 22, text-fig. 13.

Diagnosis: An elongate species of *Dentalina* consisting of 3-4 elongated pyriform chambers following a large proloculus. Sutures constricted with small neck-like junctions between chambers. Aperture terminal, marginal and radiate.

Remarks: A distinctive species due to the elongated chambers tapering to a small neck at either end. Most specimens are missing the proloculus. Some specimens exhibit centrally placed chamber necks, although most are assymmetrical. This variation is in keeping with Barnard's (1950b) description of this species. Barnard (1950b) emended this species and selected as lectotypes figures 19b and c only from plate 15 of Terquem (1866). The other figures illustrate hispid and ribbed forms; Barnard (1950b) regarded only smooth forms as *D. varians*.

Material: 25 specimens.

Dentalina vetusta d'Orbigny
Pl. 15, Fig. 1.

1850 *Dentalina vetusta* d'Orbigny, p. 242, no. 258.
1981 *Dentalina vetusta* d'Orbigny; Barnard, Cordey and Shipp, p. 406, pl. 2, fig. 3.

Diagnosis: A small species of *Dentalina* with 6-8 chambers, sutures flush and not constricted, both margins entire. Aperture large, terminal extended on a slight neck, with approximately 10 radiating grooves, terminating at the junction with the chamber.

Remarks: Very distinctive smooth walled *Dentalina*. The sutures are very difficult to observe unless immersed in an optical medium and viewed with transmitted light.

Material: 37 specimens, commonly broken.

Dentalina sp. 1
Pl. 15, Fig. 2.

cf. 1952 *Dentalina* sp. Barnard, p. 346, fig. A, 8.

Description: A very delicate species of *Dentalina* consisting of two elongate chambers, drawn out distally into a thin elongated tube. Final chamber drawn out to a thin elongated neck with a simple circular aperture, surrounded by a small lip.

Remarks: Specimens mostly broken with only the final two chambers intact. Very similar to the figure by Barnard (1952), who notes the possiblity that his specimens represent the final chambers of a species of *Nodosaria*. The specimens are also similar to *D. varians* (Terquem) as illustrated by Barnard (1950) from the Lower Lias of the Dorset Coast, although more delicate in appearance.

Material: 6 specimens. All broken with only the last few chambers intact.

Genus *Nodosaria* Lamarck, 1812
Type Species: *Nautilus radicula* Linné, 1758

The author follows the Classification of Loeblich and Tappan (1964) in retaining the broader diagnosis of the Genus *Nodosaria*. Loeblich and Tappan (1988) restricted the Genus *Nodosaria* to those species with a smooth surface and assigned those species with prominent longitudinal ribs to *Pyrimidulina* Fornasini, 1894.

Nodosaria sp. cf *N. balteata* Loeblich & Tappan
Pl. 15, Fig. 3.

cf. 1950 *Nodosaria balteata* Loeblich & Tappan, pl. 13, figs 6-8.

Diagnosis: A small ribbed species of *Nodosaria*. Eight chambers increasing rapidly initially then added uniformly thereafter. Sutures straight and flush. Ornament consists of around 12 low blade-like ribs extending from the base of the proloculus vertically across the test. Aperture not visible.

Remarks: Only one broken specimen was recorded. Exact identification of this species is therefore difficult. The final chamber is missing so the aperture characteristics are not visible. Very similar to the specimens figured by Loeblich and Tappan (1950) especially figure 7 of plate 13.

Material: 1 broken specimen.

Nodosaria corallina Gümbel
Pl. 15, Fig. 4.

1862 *Nodosaria corallina* Gümbel, p. 218, pl. 3, fig. 10a, b.
1965 *Nodosaria corallina* Gümbel; Gordon, p. 847, text-fig. 7 (6, 7).
1981 *Nodosaria corallina* Gümbel; Barnard, Cordey and Shipp, p. 405, pl. 1, fig. 22.

Diagnosis: An elongate species of *Nodosaria* consisting of a large spherical proloculus and 2-5 sub-globular chambers arranged in an rectilinear series. The second chamber is invariably smaller in diameter than the proloculus. Ornamentation consists of 8-10 vertical ribs, running continuously over the entire test and terminating at the aperture which is produced, terminal and radiate.

Variation: The chamber size varies considerably in the specimens studied and can increase or decrease in size as added. This variation in growth rate produces a variety of test shapes. The majority of forms exhibit a generally constant chamber width.

Remarks: The distinctive smaller second chamber marks this species from the other ornamented nodosariads in the Upper Jurassic.

Material: 31 specimens.

Nodosaria opalini Bartenstein
Pl. 15, Figs 6-7.

1937 *Nodosaria opalini* Bartenstein, Bartenstein and Brand, p. 147, pl. 8, fig. 13a, b, pl 10, fig. 18a, b.

Diagnosis: A minute species of *Nodosaria* consisting of 7-8 chambers in a rectilinear series, with an acuminate initial portion. Chambers increase slowly as added until the 5th chamber after which they remain constant in diameter. Ornament consists of numerous longitudonal striae, sutures flush. Aperture radiate, terminal.

Variation: Variation occurs in the length of the initial tapering section. The chambers of some forms increase rapidly in size after the small proloculus, but in the majority of specimens the increase is gradual until around the 5th chamber. Some forms have a more acuminate initial portion.

Remarks: A very small species. According to Loeblich and Tappan (1950) their species *Nodosaria balteata* is similar to *N. opalini* but is half the size and has a less acuminate initial portion. Cordey (1962) includes *N. balteata* in the synonymy for his renamed species *N. minuta* originally described as *N.* (*Dentalina*) *multicostata* by Wisniowski in 1890. Cordey renamed this species as the name *multicostata* was already used by d'Orbigny (1840). Due to the very small nature of the specimens studied, they may be better refered to *minuta* Cordey (1962). In all other respects the specimens resemble *N. opalina* as figured by Bartenstein and Brand (1937).

Material: 47 specimens.

Nodosaria sp. cf. *N. rudis* d'Orbigny
Pl. 15, Fig. 8.

cf. 1846 *Nodosaria rudis* d'Orbigny, p. 33, pl. 1, figs 17-19.
1965 *Nodosaria* cf. *rudis* d'Orbigny; Gordon, p. 848, text-fig. 7 (20, 21)

Diagnosis: A medium sized species of *Nodosaria* with a distinct chamber arangement. Ovate chambers increase in size as added. Sutures very distinct, constricted and depressed. Chambers narrow sharply towards the sutures. Ornamentation consists of many minute spines giving a hispid appearance. Aperture flush or slightly produced with a thin neck, radiate.

Remarks: Only two specimens are recorded. Both of these specimens are broken and only two chambers are intact. This is a very distinct species although it is not possible to comment on the chamber arangement. This species was originally described by d'Orbigny from the Tertiary of the Vienna Basin. Gordon (1965) expresses doubt as to whether specimens should really be ascribed to this species.

Material: 2 specimens.

Nodosaria simplex (Terquem)
Pl. 15, Fig. 9.

1858 *Dentalina simplex* Terquem, p. 599, pl. 2, fig. 5a, b.
1937 *Nodosaria simplex* (Terquem); Bartenstein and Brand, p. 144, pl. 13, fig. 8.

Diagnosis: A small species of *Nodosaria* with a large proloculus and smooth test. Chambers slightly inflated. Sutures constricted and straight. Aperture not visible.

Remarks: A simple species of *Nodosaria* with a large spherical proloculus. Chambers generally uniform in size. The final chambers are not present in the studied specimens.

Material: 3 specimens.

Nodosaria sp. cf. *N. metensis* (Terquem) *sensu* Gordon
Pl. 15, Fig. 10.

cf. 1858 *Dentalina metensis* Terquem, p. 602, pl. 2, fig. 10a, b.
1965 *Nodosaria metensis* (Terquem), Gordon, p. 848, text-fig. 7 (14).

Diagnosis: An elongate species of *Nodosaria* with a slightly arcuate test. Nine bead-like chambers follow a small proloculus. Chambers increase slowly in size until the 7th chamber, then decrease. A distinctive ornamentation consisting of 10-14 elongated v-shaped depressions, covers the lower 2/3 of each chamber. Sutures distinct and compressed. Aperture simple, terminal.

Variation: Specimens vary in their chamber arrangement, generally increasing in size, although in some specimens a decrease in the size of the final two chambers is observed. Ornamentation varies from a series of elongated v-shaped depressions to elongated arches, generally extending from the base of each chamber and covering the lower 2/3 of each chamber.

Remarks: Specimens resemble those described by Gordon (1965) from the Corallian of the Dorset coast. Gordons remarks that his specimens differ from the type in a number of ways. The ornamentaion consists of fewer, shorter v-shaped depressions and the sutures are more depressed.

Material: 10 specimens.

Genus *Pseudonodosaria* Boomgaart, 1949
Type Species: *Glandulina discreta* Reuss, 1850

Pseudonodosaria vulgata (Bornemann)
Pl. 15, Fig. 11.

1854 *Glandulina vulgata* Bornemann, p. 31, pl. 2, figs 1, 2.

1972 *Pseudonodosaria* ex gr. *vulgata* (Bornemann); Norling, p. 86, pl. 46A-C.
1981 *Pseudonodosaria vulgata* (Bornemann); Barnard, Cordey and Shipp, p. 410, pl. 3, figs 9, 11.

Diagnosis: A small species of *Pseudonodosaria* with a variable growth rate. Small proloculus followed by gently increasing chambers. Chambers sub-globular, final chamber inflated. Sutures slightly impressed. Aperture radiate and terminal.

Variation: Specimens vary in growth rate, generally slowly increasing in width with a final inflated chamber. Outline smooth to slightly lobate.

Remarks: Barnard *et al.* (1981) remark that due to this species' variable growth rate, forms have been assigned to a variety of different species, including *P. humilis* (Roemer), *P. oviformis* (Terquem) and *P. laevis* (Bornemann). These species are synonymous with the present species. Norling (1972) includes an involved synonymy which serves to illustrate the confusion.

Material: 2 specimens.

Pseudonodosaria radiata (Barnard)
Pl. 15, Figs 12-13.

1952 *Pseudoglandulina radiata* (Barnard), p. 347, text-fig. A(2).
1981 *Pseudonodosaria radiata* (Barnard); Barnard, Cordey and Shipp, p. 410, pl. 3, fig. 7.

Description: Test squat to elongate, pupiform, flaring distally, circular in cross-section. 4-6 discoidal chambers arranged uniserially, increasing rapidly in width, after an initial small spherical proloculus. Sutures flush, horizontal and parallel. Periphery smooth or slightly lobate, Final chamber large, spherical and inflated, drawn out to a terminal aperture. Ornamentation consists of numerous oblique striae originating from the first chamber and continuing across the test disapearing mid-way up the final chamber. Aperture circular, terminal, slightly raised, surrounded by a thin lip.

Variation: Variation occurs principly in the different growth rates exhibited by many specimens. A pupiform test with large spherical final chamber is a common variant. In this form the ornament tends to be less well marked with the striae becoming reduced on the final chamber. Forms with a more regular growth rate generally have distinct blade-like ribs which continue almost up to the aperture. Other specimens exhibit irregular growth rates; a common feature is for the final few chambers to be reduced in width.

Remarks: The specimen illustrated by Barnard *et al.* (1981) is a common variant in the studied section.

Material: 4 specimens.

Subfamily LINGULININAE Loeblich and Tappan, 1961
Genus *Lingulina* d'Orbigny, 1826
Type Species: *Lingulina carinata* d'Orbigny, 1826

Lingulina cernua (Berthelin)
Pl. 16, Figs 1-3.

1879 *Frondicularia cernua* Berthelin, p. 32, pl. 1, figs 7-8.
1956 *Lingulina* cf. *cernua* (Berthelin); Barnard, p. 274, pl. 1, figs 6a, b.
1981 *Lingulina cernua* (Berthelin); Barnard, Cordey and Shipp, p. 410, pl. 3, fig. 4, text-fig. 17.

Diagnosis: A compressed elongate species of *Lingulina* consisting of 6-8 chambers. A large spherical proloculus is followed by gradually increasing chambers. Sutures distinct, impressed and straight. Aperture terminal, flush and oval.

Remarks: The specimens vary in size. The second chamber of most specimens tends to be smaller than the proloculus. Many specimens are crushed and broken.

Material: 129 specimens.

Lingulina nodosaria (Terquem)
Pl. 16, Figs 4, 8.

1870 *Frondicularia nodosaria* Terquem, p. 319, pl. 22, figs 25-29, 30.
1981 *Lingulina nodosaria* (Terquem); Barnard, Cordey and Shipp, p. 411, pl. 3, fig. 3, text-fig. 17.

Diagnosis: A compressed species of *Lingulina* that is parallel sided. Initial small proloculus followed by 6-10 chambers. Chambers gradually increasing in size. Sutures arcuate to straight, slightly constricted. Ornament consists of fine longitudinal striae, variable in shape and number. Aperture terminal, produced and slit-like.

Variation: The proloculus varies in size from very small, almost enclosed by subsequent chambers, to large and distinct. Sutures generally arcuate, but in some specimens almost straight. Striae straight or curved following the shape of the periphery.

Remarks: Barnard (1956) states that the variation of suture shape from straight to almost chevron-shaped, may place this species within the genus *Frondicularia* rather than *Lingulina*. The author believes that the slit-like aperture indicates inclusion within *Lingulina*.

Material: 10 specimens.

Lingulina laevissima (Terquem)
Pl. 16, Fig. 5.

1866 *Frondicularia laevissima* Terquem, p. 481, pl. 19, fig. 19a-b.
1956 *Lingulina laevissima* (Terquem); Barnard, p. 272, pl. 1, fig. 5a-b.
1981 *Lingulina laevissima* (Terquem); Barnard, Cordey and Shipp, p. 410, pl. 3, figs 1-2.

Diagnosis: A very thin species of *Lingulina* with 5-7 chambers. Chambers increase slowly in size as added, final chamber can be slightly inflated and pyriform. Sutures faint, slightly impressed, straight to slightly convex up. Aperture flush, terminal and ovate.

Remarks: Specimens are very narrow and fragile-looking; initial proloculus of many forms is often damaged or missing.

Material: 6 specimens.

Lingulina pupa (Terquem)
Pl. 16, Fig. 6.

1866 *Marginulina pupa* Terquem, p. 429, pl. 17, fig. 7a-f.
1971 *Lingulina pupa* (Terquem); Wernli, p. 329, pl. 5, figs 13-16.

Diagnosis: A small species of *Lingulina* with 4 inflated chambers. An initial large spherical proloculus is followed by three inflated chambers increasing in size as added, final chamber inflated and slightly pyriform. Aperture flush and ovate.

Remarks: Only one specimen was found and so the exact identification of this taxon is uncertain.

Material: 1 specimen only.

Lingulina spp. indet.

Remarks: Specimens of *Lingulina* are included in this category when they are not identifiable to species level. This is usually because of broken chambers, a pyritized test or some other reason (i.e. compression) which makes exact identification impossible.

Material: 2 specimens.

Subfamily FRONDICULARIINAE Reuss, 1860

Genus *Frondicularia* Defrance, 1826

Type Species: *Renulina complanata* Defrance, in de Blainville, 1824

Frondicularia franconica sensu lata Gümbel

Pl. 16, Figs 7, 9.

1862 *Frondicularia franconica* Gümbel, p. 219, pl. 3, fig. 13a-c.
1960 *Frondicularia franconica franconica* Gümbel, Lutze, p. 470, pl. 32, figs 4, 6, 14.
1960 *Frondicularia franconica impressa* Gümbel; Lutze, p. 470, pl. 32, figs 3, 5.
1967 *Frondicularia franconica* Gümbel; Gordon, p. 454, pl. 3, figs 2-8.
1981 *Frondicularia franconica* Gümbel; Barnard, Cordey and Shipp, p. 406, pl. 2, fig. 16, text-fig. 13.

Diagnosis: An elongate flaring and smooth species of *Frondicularia*, rounded in cross-section with a lobate periphery. 7-8 chevron shaped chambers arranged rectilinearly after an initial spherical proloculus. Sutures impressed, distinct. Aperture round, terminal, slightly produced and radiate.

Variation: The species is very variable. The test varies from elongate, parallel-sided, to flaring distally. Margins are smooth to extremely lobate with, in some forms, the final chamber being half the width of the penultimate. Sutures are impressed, varying in steepness. Some forms develop a concave-up depressed sulcus on the median line, which have been referred to *F. franconica impressa* by Lutze (1960).

Remarks: Some variants are very similar to species of *Lingulina*, but can be distinguished by a circular and sometimes radiate aperture rather than ovate. Lutze (1960) separated this species into 2 subspecies, *F. franconica franconica* and *F. franconica impressa* for specimens with an impressed central sulcus. The author has included these variants within *F. franconica s. l.* in the present study.

Material: 198 specimens.

Frondicularia sp. cf. *F. lignaria* Terquem

Pl. 16, Fig. 10.

cf. 1866 *Frondicularia lignaria* Terquem, p. 480, pl. 19, fig. 14.
cf. 1971 *Frondicularia lignaria* Terquem; Wernli, p. 319, pl. 6, figs 9-11.

Diagnosis: A small species of *Frondicularia* consisting of an initial large spherical proloculus followed by 10 chevron-shaped chambers. The test is compressed and parallel sided. The chambers increase in size gradually as added until the 5th chamber where there is a sudden increase in growth and the 6th and succeeding chambers are much larger. Sutures are slightly depressed. Final chamber broken, aperture characteristics therefore not visible.

Remarks: Only two broken specimens recorded in the present study which are similar to those figured by Wernli (1970). However, as the specimens are broken, a positive identification is not possible.

Material: 2 specimens.

Genus *Tristix* Macfadyen, 1941
Type Species: *Rhabdogonium liasinum* Berthelin, 1879

Tristix triangularis Barnard
Pl. 16, Figs 11-12.

1953 *Tristix triangularis* Barnard, p. 190, fig. 45.
1965 *Tristix oolithica* (Terquem); Gordon, p. 849, text-figs 8, 10 (3, 4).
1981 *Tristix triangularis* Barnard; Barnard, Cordey and Shipp, p. 427, pl. 3, fig. 19.

Diagnosis: An elongate, smooth species of *Tristix*, triangular in cross-section. Following a variable-shaped proloculus, 4-9 chambers are arranged rectilinearly. Each lanceolate face has compressed arcuate sutures, becoming more impressed distally. Final chamber drawn up to a produced, terminal, radiate aperture.

Variation: The test can vary from elongate and narrow to short and squat. The margins vary from broadly rounded to acute to carinate and the three faces can be concave or flat. Sutures vary from flush to deeeply impressed. Some extreme forms are quadrate in section.

Remarks: Quadrate forms have been previously referred to species *Quadratina* Ten Dam. The author follows Loeblich and Tappan (1952) who in their discussion of the genus *Tristix* included as synonymous the genus *Quadratina* Ten Dam. According to Barnard *et al.* (1981) *T. oolithica* (Terquem) is a juvenile form of this species. The variation of *T. oolithica* described by Gordon (1965) is similar to that exhibited by the studied specimens.

Material: 34 specimens, including 1 quadrate form.

Family VAGINULINIDAE Reuss, 1860
Subfamily LENTICULININAE Chapman, Parr and Collins, 1934
Genus *Lenticulina* Lamarck, 1804
Type Species: *Lenticulites rotalulata* lamarck, 1804

Lenticulina brevispira (Wisniowski)
Pl. 17, Figs 1-2.

1890 *Cristellaria brevispira* Wisniowski, p. 22, pl. 10, fig. 6a, b.
1981 *Lenticulina brevispira* (Wisniowski); Barnard, Cordey and Shipp, p. 411, pl. 2, fig. 26, text-fig. 18.

Diagnosis: A small species of *Lenticulina*, involute, consisting of 5-6 triangular chambers in the final whorl, increasing rapidly in size. The test has a tendancy to uncoil. In peripheral view the final chambers are inflated and flask shaped, the apertural face is broadly rounded. In apertural view the final chamber is globular and triangular. The sutures are distinct, depressed, radial and slightly curved back ventrally. Aperture radiate, terminal, produced on a short neck.

Variation: There is general distinction between two broad groups of specimens. One group is distinctly involute with a small coil, while the other group does not exhibit a coil but a loose curl. This is possibly the difference between the megalospheric and microspheric generations. The majority of coiled specimens show a tendancy to uncoil, with a small uniserial portion, the final chambers in this portion flaring markedly. In a few forms the uniserial portion is compressed distally.

Remarks: A distinctive species of *Lenticulina* due to the inflated triangular nature of the final chamber. Uncoiled specimens become *Marginulina*-like in external morphology.

Material: 175 specimens.

Lenticulina ectypa (Loeblich & Tappan)
Pl. 17, Figs 3-5.

1950 *Astacolus ectypus* Loeblich & Tappan, p. 179, pl. 1, fig. 10.
1960 *Lenticulina* (*Lenticulina*) cf. *ectypa* (Loeblich & Tappan); Lutze, p. 452, text-fig. 11a.
1989 *Lenticulina ectypa* (Loeblich & Tappan); Shipp, p. 256, pl. 6.4.2, fig. 7.

Description: Test biconvex and slightly inflated, planispiral, periphery acute, carinate, thickness one third the greatest diameter of test. Involute, becoming uncoiled with 7-9 chambers in the final whorl, gradually increasing in size as added, becoming twice as wide as high, inflated in apertural view. Sutures strongly arcuate, curving back towards the periphery, strongly depressed. Prominent rib roughly parallel and distal to the suture, raised and distinct. Ribs converge towards umbilicus where they coalesce in an umbilical rib, often undeveloped or present as a collection of small ribs and tubercles. Keel pronounced, extending part-way round the periphery, disappearing distally. Aperture face flat to convex, triangular to sub-triangular. Aperture peripheral, terminal, produced on a short neck, circular, radiate.

Variation: There is a tendency for specimens to become uncoiled. The umbilical ring is developed to a greater or lesser extent. The overall shape is generally inflated with the apertural face wide and triangular, bordered by lateral flanges.

Remarks: This species is quite similar to *L. quentsedti* (Gümbel). It can be distinguished by the presence of deep depressed sutures bordered distally by prominent ribs. In *L. quenstedti* the ribs appear coincident with the sutures and therefore no deep sutural impressions. This is best demonstrated in longitudinal sections (Lutze, 1960 and Cordey, 1962). Most specimens are close coiled. Cordey (1962) recorded a distinct sub-species *L. ectypa cosata* which has additional ornament of 2-4 longitudinal costae on each chamber, this form was not recorded in the present study.

Material: 65 specimens.

Lenticulina major (Bornemann).
Pl. 17, Figs 6-8.

1854 *Cristellaria major* Bornemann, p. 40, pl. 4, fig. 13.
1981 *Lenticulina major* (Bornemann); Barnard, Cordey and Shipp, p. 412, pl. 2, figs 17, 18, text-fig. 19.

Description: Test elongate and compressed, elliptical in cross section, planispiral then uniserial, periphery acute to rounded, thickness approximately one third the greatest diameter of the test. Involute planispiral portion of 3-6 sub-triangular chambers following a large ellipsoid proloculus, periphery acute, sub-angular to lobate, sutures generally flush and curving back, convex distally, sharply recurved at the periphery. Uniserial portion curved or straight, 4-5 chambers increasing in size initially, generally low, 2-3 times wider than high, periphery rounded, entire and smooth dorsally. Sutures depressed ventrally becoming flush towards the dorsal periphery, curved, slightly convex distally, can be oblique, sloping strongly towards the ventral side of the coil. Ornament marked by a distinct sutural rib, distal to the suture, low and rounded in cross section, extending from the ventral margin, increasing in width dorsally not quite reaching the dorsal periphery. Ribs less well pronounced on the more distal chambers, usually absent on the last chamber, may be present on the last few chambers of the initial coil, smaller in size. Apertural face convex, rounded and elongate, size dependant on last chamber. Aperture terminal, peripheral, radiate, produced on a small neck.

Variation: This form is highly variable in its external morphology. The initial coil can be prominent or obscured by the uniserial chambers extending back to join it on the ventral side. Periphery rounded, entire to lobate or sub-angular. Final chamber inflated to a varying degree. Uniserial chambers increase or decrease in width gradually, subsequent chambers can be stepped back from the ventral margin as the chambers decrease in width. This variation changes the outline of the ventral margin. Specimens with marked sutural ribs are the predominant forms in this study. These ribs can extend onto the chambers of the initial coil, although not normally present on final chambers of the uniserial portion. In apertural view the rib cross-section varies from low curved ribs to sharper ones. The lateral view has a crenulated appearance. Previous radiate apertures are sometimes visible through the wall of the test in the last three chambers.

Remarks: This species is similar to certain specimens of *L. varians* (Bornemann); see below for discussion.

Material: 291 specimens.

Lenticulina ex. group *münsteri* (Roemer).
Pl. 17, Figs 9-10.

1839 *Robulina münsteri* Roemer, p. 48, pl. 20, fig. 29.
1981 *Lenticulina münsteri* (Roemer); Barnard, Cordey and Shipp, p. 413, pl. 2, figs 20, 21.

Description: Test large, lenticular to elongate uncoiled, periphery acute to sub-acute, rounded, entire to sub angular, thickness of test varies from 1/3 to 1/2 the greatest diameter of the test. Involute, approximately 1 1/2 whorls with 10-12 chambers in the last whorl. Chambers thin, elongate, sub-triangular, gradually increasing in size as added, reaching 3 times as wide as high, last chamber sometimes inflated reaching back towards coil and enveloping earlier chambers. Sutures sigmoidal, convex distally, but becoming radial at periphery, generally flush but may be slightly raised. Test may become evolute and uncoiled with a series of 2-4 chambers in the uniserial part, sutures reaching back sharply to the coil, becoming depressed in later chambers. Umbilical area covered by large transparent disc, usually flush with the test, may be raised, the earlier chambers can be observed. Periphery sometimes pinched, giving the impression of a keel, occasionally carinate. Apertural face flat or slightly convex, bordered by limbate sutures, giving the impression of lateral flanges, or in the forms with inflated final chamber, completely rounded. Aperture produced on a slight neck, round, radiate, terminal and peripheral.

Variation: Variation occurs in the nature of the sutures, from flush to slightly raised, the presence or absence of a distinct keel, the inflated final chamber and the degree of elevation of the umbilical disc which may also be more or less transparent. A great degree of variation exists in the nature of coiling; from closely coiled thick forms to those with extended last chambers to true uncoiled forms, generally with 2 chambers in the uncoiled portion. In variants with extended final chambers the sutures reach back towards the coil nearly always in contact with the coil ventrally.

Remarks: *Lenticulina münsteri* is by far the most common species of *Lenticulina* encountered in this study, and is almost a ubiquitous component of each sample. In many samples it comprises up to 50% of the total assemblage. The continual variation between the various morphotypes of this species throughout the studied material has allowed its inclusion as a species group or plexus. This species has, however, been recorded as numerous morphotypes in the literature. *L. münsteri* is a very long-ranging species; it is recorded throughout the Jurassic and the early Cretaceous.

Material: 14, 656 specimens.

Lenticulina sp. cf. *L. polonica* var. *glabra* (Wisniowski) *sensu* Cordey
Pl. 17, Fig. 11.

1962 *Lenticulina* cf. *polonica* var. *glabra* (Wisniowski); Cordey, p. 75, pl. 46, fig. 4.

Diagnosis: A compressed species of *Lenticulina*, small with a rounded periphery. Outline in apertural view sub-angular. Eight to nine chambers in the last whorl, increasing rapidly in height as added. Umbilical area broad, flat and smooth. Sutures slightly impressed and swept backwards towards the periphery. Aperture produced, circular and radiate.

Remarks: The periphery is sub-angular. The sutures are markedly swept backwards towards the periphery away from the aperture.

Material: 2 specimens.

Lenticulina polygona (Paalzow)
Pl. 17, Fig. 12.

1917 *Cristellaria polygona* Paalzow, p. 43, pl. 47, fig. 2.

Diagnosis: A large inflated species of *Lenticulina*, with a sub angular periphery. Nine chambers in the final whorl, increasing slowly as added. Sutures incised and distinctly curved backwards away from the apertural end. Umbilicus small and shallow. Aperture produced on a short distinct neck, terminal and radiate.

Remarks: The sutures are very distinct and are markedly swept back towards the periphery and are flush in the earlier chambers becoming depressed towards the later chambers. Some specimens are inflated.

Material: 3 specimens.

Lenticulina protracta (Bornemann)
Pl. 17, Fig. 13; Pl. 18, Figs 1-2.

1854 *Cristellaria protracta* Bornemann, p. 31, pl. 4, fig. 27.
1981 *Lenticulina protracta* (Bornemann); Barnard, Cordey and Shipp, p. 413, pl. 2, fig. 22, text-fig. 20.

Diagnosis: A small highly variable species of *Lenticulina*. Close coiled and uncoiled variants are encountered. The close coiled forms have around 6 chambers in the final whorl, sutures flush initially, becoming impressed by the final chamber. Uncoiling is exhibited and forms vary from *Astacolus*-like to true uncoiled specimens. In the uncoiled specimens the number of chambers vary from 2-5, sutures generally flush, but may be impressed, particularly distally. The section of the uniserial portion varies from near-circular to compressed. Aperture terminal, radiate, produced on the end of a small neck.

Variation: A highly variable species. Specimens vary from close-coiled typical lenticulinid forms through *Astacolas*-like forms to true uncoiled forms. The close-coiled specimens form the majority of specimens.The nature of the sutures is variable and are either flush or slightly impressed throughout or impressed distally; in the latter, specimens of the uncoiled variant have inflated chambers. In a few specimens the sutures are limbate. The cross-section of the uncoiled portion varies from compressed, to compressed with an inflated final chamber to those specimens with an almost circular cross-section.

Remarks: It is obvious from the variation exhibited by the specimens that this species should be regarded as a species group or plexus. The author's concept of this species undoubtedly includes forms which can be referred to a number of different species, but as a complete variation is exhibited between the forms, for the purposes of this study, one species name is applied. Barnard *et al.* (1981) illustrate the variation exhibited by this species from the Oxford Clay and note that the morphological variation embraces several genera, principally *Lenticulina*, *Marginulina* and *Planularia*. The specimens studied by the author exhibit the same variation as those illustrated by Barnard *et al.* (1981), but with less truly uncoiled variants.

Material: 419 specimens.

Lenticulina quenstedti (Gümbel).
Pl. 18, Figs 3-4.

1862 *Cristellaria quenstedti* Gümbel, p. 226, pl. 4, fig. 2a, b.
1981 *Lenticulina quenstedti* (Gümbel); Barnard, Cordey and Shipp, p. 414, pl. 2, fig. 32, text-figs 21, 22

Description: Test biconvex, biumbilicate, planispirally enrolled, periphery acute to subacute, rounded discoidal to elongate, carinate. Thickness of test one third to half the greatest diameter. Involute, approximately 1 1/2 whorls present, test tending to become uncoiled, however later chambers still in contact with the coil on the ventral side. Chambers sub-triangular, increasing gradually as added becoming 3 times high as wide, 7-9 chambers in the last whorl. Sutures arcuate, convex distally ornamented by distinct raised ribs, curving back towards the periphery where they join with the keel. Sutural ribbing strongly marked, converging on the umbilicus where they join with a raised circular umbilical rib, enclosing the umbilicus. Umbilical ring developed to a greater or lesser degree, sometimes degenerating to a series of small tubercles and ribs. Keel distinct, thin and prominent on early chambers to the penultimate chamber, usually absent on the last 2-3 chambers. Apertural face smooth, convex and elongate, bordered by the sutural ribs which become lateral flanges. Aperture terminal, peripherally placed at the apex, extended on a pronounced neck, open, circular, sometimes radiate.

Variation: The nature of coiling varies from tightly coiled to slightly uncoiled with the last few chambers becoming elongate but generally remaining in contact with the coil on the ventral side; few specimens exhibit truly uniserial portions. Apertural face elongate and extended to a greater or lesser degree, can be wider and sub-triangular, almost *Saracenaria*-like. Ornament varies in the nature of the sutural ribs. Generally they are raised and distinct, varying from thickened ribs to thin, sharp "v" shaped ribs, occasionaly becoming crenulated or discontinued, marked by a series of small elongate ribs and or tubercles. Central umbilical ring tends to be discontinued and degenerates similar to the sutural ribbing. Overall the test shape can be compressed or inflated with a more biconvex shape.

Remarks: Similar in appearance to *Lenticulina ectypa* (Loeblich and Tappan), as discussed above.

Material: 208 specimens.

Lenticulina subalata (Reuss)
Pl. 18, Figs 7-8.

1854 *Cristellaria subalata* Reuss, p. 68, pl. 25, fig. 13a, b.
1981 *Lenticulina subalata* (Reuss); Barnard, Cordey and Shipp, p. 416, pl. 2, fig. 33.

Description: Test lenticular, periphery acute to sub-acute, keeled, thickness 1/3 to 1/2 the greatest diameter of the test. Involute, 9-11 chambers in the last whorl, 1 1/2-2 whorls in total. Chambers sub-triangular initially, increasing gradually in size as added, becoming elongate, approximately 3 times as high as wide. Sutures are convex distally, arcuate, curving towards the periphery. Keel sharp to rounded, prominent in early chambers becoming redundant in later chambers. Sutures ornamented by distinct ribs, rounded in cross section. Ribs converging towards umbilicus where they join with a large calcitic umbilical plug or boss, distinct and raised above the surface of the test, particularly evident in apertural view. Apertural face flat to slightly convex, triangular and varying in height, bordered by raised sutural ribs which become lateral flanges. Aperture terminal, rounded produced slightly at the periphery.

Variation: The degree of uncoiling generally observed within other species of lenticulinids is not as marked in this species. Most specimens are closely coiled. Some forms do exhibit elongated final chambers but uncoiling is not observed. The apertural face varies from elongated triangular to wider triangular in shape depending on the thickness of the test which can vary from approximately one half to one third the greatest diameter of the test. The umbilical plug is generally large, raised from the surface of the test and opaque; in some cases the sutural ribs tend to thicken towards the plug, resulting in a star-shaped plug. In some forms the umbilical plug is translucent and in this case they are not dissimilar to *Lenticulina münsteri* (Roemer). The keel is generally distinct becoming less so on the later chambers.

Remarks: This species is similar to *L. münsteri* (Roemer) but it can be distinguished by:

1. The presence of a raised umbilical boss which is generally opaque and distinctive in apertural view.

2. The presence of a keel, generally sharp and distinct; and,

3. The presence of raised sutural ribs.

Some specimens of *L. münsteri* (Roemer) can exhibit slightly raised sutures and/or a slight keel. According to Barnard *et al.* (1981) *L. subalata* and *L. münsteri* may grade into one another.

Material: 86 specimens.

Lenticulina tricarinella (Reuss)
Pl. 18, Figs 5-6.

1863 *Cristellaria* (*Cristellaria*) *tricarinella* Reuss, p. 68, pl. 7, fig. 9; pl. 12, figs 2-4.
1965 *Lenticulina tricarinella* (Reuss); Gordon, p. 840, text-fig. 6 (6-8).
1981 *Planularia tricarinella* (Reuss); Barnard, Cordey and Shipp, p. 422, pl. 2, figs 23-24, text-fig. 25C (1-4).

Diagnosis: A flat parallel-sided *Lenticulina* with a tendancy to uncoil. Around 7-8 chambers in the final whorl. Sutures curved distally, raised and distinct, merging with a distinct marginal rib on both side of the test. Periphery acute to carinate. Apertural face extending back towards initial coil, convex with lateral flanges. Aperture terminal, peripheral.

Variation: In most forms the central keel extends around the entire test on the apertural margin; in some specimens it is absent on the initial chambers. In peripheral view some of the specimens have extended marginal ribs, becoming carinate. The majority of specimens are flat and parallel-sided although some forms flare towards the non-apertural margin, becoming wedge shaped. The apertural face in many specimens extends back towards the coil, almost astacolid-like.

Remarks: A very distinct species which has been recorded throughout the Jurassic. The specimens studied tend to be close coiled with not many properly uncoiled variants.

Material: 10 specimens.

Lenticulina varians (Bornemann) Form B, Lutze
Pl. 18, Figs 9-10.

1854 *Cristelleria varians* Bornemann, p. 41, pl. 4, figs 32-34.
1937 *Cristelleria (Lenticulina) varians* Bornemann Form b, Bartenstein and Brand, p. 176, pl. 2B, fig. 32; pl. 3, fig. 32.
1960 *Cristelleria (Lenticulina) varians* Bornemann Form B; Lutze, p. 450, pl. 28, fig. 10.
1981 *Cristelleria varians* Bornemann Form B Lutze; Barnard, Cordey and Shipp, p. 417, pl. 2, fig. 25, text-fig. 19.

Diagnosis: A compressed species of *Lenticulina* with 6-8 chambers in the final whorl. Triangular chambers gradually increasing in size, final chamber inflated. Sutures distinct and curved back towards the periphery, raised into distinct thin ribs. Final suture impressed. Aperture distinct, radiate, terminal. Apertural face rounded and smooth.

Variation: Specimens vary form those with well marked and strong ribs to those with faint ribs. Some specimens exhibit true uncoiling with 1-2 chambers in the uniserial portion but when showing evidence of uncoiling the majority of specimens are astacolid-like in chamber arrangement.

Remarks: Some specimens are very similar to *L. major* (Bornemann), but in general they are smaller, less likely to exhibit uncoiling, the last suture line is very often impressed rather than raised and the specimens overall are generally more compressed.

Material: 65 specimens.

Lenticulina sp. 1
Pl. 18, Fig. 11.

Description: A small species of *Lenticulina*, with 6-8 chambers in the final whorl. Slightly compressed, periphery lobate with a wide shallow umbilicus. Triangular chambers gradually increasing in size as added; final chambers inflated. Sutures distinct, flush initially, depressed by the final two chambers. Aperture small, produced, radiate and terminal.

Remarks: The final chamber in the specimens studied is generally inflated and the apertural face is rounded.

Material: 1 specimen.

Lenticulina spp. indet. (juvenile)

Remarks: Specimens in this category are mixed species of juvenile *Lenticulina*. Each specimen has only the initial few chambers present following the proloculus, and as such they are difficult to assign to a particular taxon with any certainty.

Material: 49 specimens.

Subfamily MARGINULININAE Wedekind, 1937
Genus *Marginulina* d'Orbigny, 1826
Type Species: *Marginulina raphanus* d'Orbigny, 1826
(non *Nautilus raphanus* Linné, 1758)

Marginulina batrakiensis (Myatluik)
Pl. 19, Figs 1-2.

1939 *Cristelleria batrakiensis* Myatluik, pp. 61, 74, figs 52-53.
1967 *Marginulina batrakiensis* (Myatluik); Gordon, p. 452, pl. 4, figs 24-25.

1981 *Marginulina batrakiensis* (Myatluik); Barnard, Cordey and Shipp, p. 418, pl. 2, fig. 31.

Diagnosis: An elongate species of *Marginulina*, chambers arranged in a curvilinear series, sometimes irregular. The chambers are sub-globular, increasing gradually in size, 7-8 in number. The dorsal margin is generally entire, ventral margin lobate. The sutures are distinct and constricted. The ornament consists of numerous discontinuous sub-vertical costae, extending over the entire test. Aperture distinct, extended on a short neck, peripheral and terminal.

VARAIATION: Some forms exhibit a smaller final chamber, inflated slightly and separated from the remainder of the test by a constricted suture. The dorsal margin is generally entire, curved, but may become lobate in the final few chambers. The ventral margin is lobate; in some forms the final chambers may extend back to the proloculus, which produces a more entire margin.

Remarks: The ornamentaion is resricted to each chamber and is not continuous between chambers.

Material: 10 specimens.

Marginulina undulata Terquem
Pl. 18, Fig. 12.

1858 *Marginulina undulata* Terquem, p. 610, pl. 3, fig. 2a, b.
1950 *Marginulina undulata* Terquem; Barnard, p. 372, fig. 5f.

Diagnosis: A species of *Marginulina* with a distinct ornamentation, and rounded entire periphery. Six to seven chambers slowly increasing in size as added. Sutures flush and indistinct. Ornament consists of 6 strong blade-like ribs originating from the base of the proloculus and curving across each side towards the final chamber. The ribs are parallel to the curved outer margins and branch around midway up the test forming 8-9 ribs on each side by the final chamber. Aperture characteristics not visible.

Remarks: The distinct ornamentation of this specimen make it easy to identify. It also has a narrow keel surrounding the test on both margins, although this is possibly a manifestation of a lateral rib. The final chamber of this specimen is broken.

Material: 1 specimen.

Subfamily VAGINULININAE Reuss, 1860
Genus *Citharina* d'Orbigny, 1839
Type Species: *Vaginulina (Citharina) strigillata* Reuss, 1846

Citharina flabelloides (Terquem)
Pl. 19, Figs 6-7.

1868 *Marginulina flabelloides* Terquem, p. 102, pl. 6, fig. 1a, b.
1960 *Vaginulina flabelloides* (Terquem); p. 459, pl. 30, fig. 11.
1962 *Citharina flabelloides* (Terquem); Cordey, p. 385, pl. 47, fig. 17.
1981 *Citharina flabelloides* (Terquem); Barnard, Cordey and Shipp, p. 422, pl. 2, fig. 9.

Diagnosis: A large species of *Citharina* with a compressed and flaring test, sometimes palmate or elongate triangular. An initial spherical proloculus is followed by 9-12 chambers, sloping or curving gently towards the apertural margin. Generally parallel sided but occasionally triangular. Ornamentation consists of fine ribs, initially continuous but restricted to each chamber later. Apertural margin straight, non-apertural margin sinuous and lobate. Aperture marginal, terminal and radiate.

Variation: The number of ribs varies from around 8 per side to 15. The ornamentation of fine ribs is generally discontinuous later, being restricted to the width of each chamber. In the forms with fewer ribs the ribs are sinuous and continous. Branching is generally restricted to the first few chambers.

Remarks: Most of the specimens studied posses a sigmoidal non-apertural margin, although not as prominant as figured by Barnard, Cordey and Shipp (1981, pl. 2. fig. 9). The specimens are more comparable to the figure of Lutze (1960, pl. 30, fig 11).

Material: 46 specimens.

Citharina heteropleura (Terquem)

Pl. 19, Figs 8-9.

1868 *Marginulina heteropleura* Terquem, p. 117, pl. 7, figs 22, 23, var. C & D, non A & B
1981 *Citharina heteropleura* (Terquem); Barnard, Cordey and Shipp, p. 423, pl. 2, fig. 7, text-fig. 27.

Diagnosis: A compressed species of *Citharina* with 8-11 chambers. An initial curl of 2-3 chambers followed by 6-9 rapidly increasing in size, producing a concave non-apertural margin. Ornament consists of numerous strong ribs continuous over most of the test. Sutures distinct and flush. Keel developed occasionally. Aperture produced, terminal and radiate.

Variation: The overall outline of the test varies depending on the rate of the initial chamber development. A rapid increase in the initial chambers produces specimens with a more markedly concave non-apertural margin. Other specimens have non-apertural margins varying from slightly concave to straight to broadly convex in some forms.

Remarks: The majority of specimens encountered within this study compare favourably with figures 27e and 27f of Barnard *et al.* (1981). The proportion of specimens with distinctly concave non-apertural margins is less than for the forms found by Barnard *et al.* (1981).

Material: 47 specimens.

Citharina lepida (Schwager)

Pl. 19, Fig. 10.

1867 *Cristellaria lepida* Schwager, p. 657, pl. 34, fig. 9.
1960 *Citharina lepida* (Schwager); Lutze, p. 461, pl. 30, figs 2-4, 7, 8, text-fig. 14.

Diagnosis: A distinctive species of *Citharina* with a strongly marked ornament. A small spherical proloculus is followed by 8-9 chambers, rapidly increasing in size initially. Distinctive initial curl with 2-3 chambers. Sutures distinct and slightly depressed. Ornament consists of strong blade-like ribs, up to 8 on each side. Aperture produced, terminal and radiate.

Variation: Ornament consists of a strong thick blade-like ribs running obliquely over the surface of the test. Most ribs start at the base of the proloculus and continue to the final chamber. A single rib is present on the apertural margin forming a keel. On the non-apertural margin a keel is also developed.

Remarks: The specimens encountered in this study are very similar to those figured by Lutze (1960) from the Oxfordian of north-west Germany.

Material: 42 specimens.

Citharina serratocostata (Gümbel)
Pl. 19, Figs 3-5.

1862 *Marginulina serratocostata* Gümbel, p. 222, pl. 3, fig. 23.
1862 *Marginulina flabellata* Gümbel, p. 223, pl. 3, fig. 24.
1981 *Citharina serratocostata* (Gümbel); Barnard, Cordey and Shipp, p. 425, pl. 2, fig. 5, text-fig. 24.

Diagnosis: A compressed species of *Citharina* with a lanceolate to triangular outline. An initial ellipsoidal proloculus is followed by a series of 6-9 parallel-sided chambers curving down towards the non-apertural margin, sutures flush. Ornamentation consists of fine to coarse raised ribs, continuous and branching, sometimes sinuous, fanning out towards the apertural face where they disapear. Aperture raised, terminal and radiate.

Variation: The outline of the test can vary from elongate and thin to broadly triangular. The apertural margin is generally entire and straight whereas the non-apertural margin can be sinuous or lobate. The sutures are flush but the final sutures may be impressed The ornamentation is variable both in the number of ribs and in their size and shape. Some forms exhibit thin sinuous ribs where others have coarse thick ribs, sometimes becoming blade-like, generally originating from the proloculus as approximately 5 ribs which branch towards the apertural face. Additional ribs are inserted between the others and up to thirty ribs reach the apertural margin where they disapear. Gordon (1965) described 3 styles of ornamentation; style 2 is the most common style exhibited in the specimens studied.

Remarks: The author agrees with Gordon (1962) and Barnard *et al.* (1981) in regarding *C. serratocostata* and *Marginulina flabellata* Gümbel, 1862 as being synonymous. Both species are described in the same paper but *C. serratocostata* has priority as it is described first. The original illustration of *C. serratocostata* is very narrow when compared to the majority of specimens encountered in this study. It is however within the range exhibited by this species.

Material: 325 specimens.

Citharina tenuicostata Lutze
Pl. 19, Figs 11-13.

1960 *Citharina tenuicostata* Lutze, pl. 463, pl. 30, figs 5-6.

Diagnosis: A small compressed species of *Citharina* consisting of an initial small spherical proloculus followed by 5-9 chambers. Apertural margin broadly rounded, non apertural margin slightly concave . Sutures flush to occasionally depressed. Ornament consists of up to 9 continuous fine striae running obliquely across each side of the test. Aperture produced on a small neck surrounded by the distal ends of the striae.

Remarks: The specimens are very similar to those figured by Lutze (1960).

Material: 106 specimens.

Genus *Citharinella* Marie, 1938
Type Species: *Flabellina karreri* Berthelin, 1880.

Citharinella exarata Loeblich and Tappan.
Pl. 20, Figs 1-4.

1950 *Citharinella exarata* Loeblich and Tappan, p. 58, pl. 16, figs 4-8.

Diagnosis: Test compressed, elongate and palmate. After an initial ellipsoidal proloculus, 8-12 chambers are added becoming chevron-shaped later increasing gradually in height, initially arranged in a *Citharina*-like curl consisting of 2-6 chambers. Sutures initially impressed becoming flush. Ornamentation consists of numerous arcuate striae, restricted to the height of each chamber. Aperture radiate, terminal, produced on the end of a short neck.

Variation: Ornamentation is very variable within this species. Some forms have continuous fine ribbing while others have numerous arcuate ribs, restricted to each chamber. Some forms exhibit a combination of the two types of ornamentation, the discontinuous striae occuring on the later chambers. The nature of the initial chamber arrangement is also variable. In some forms the chevron-shaped chambers begin immediately after the proloculus, while in the majority, an initial spherical proloculus is followed by 2-6 chambers arranged in an initial *Citharina*-like curl, the chevron-shaped chambers are present only after the 6th chamber. This difference in initial chamber arrangement produces forms which can be assigned to *Frondicularia* or *Citharinella*. Some specimens exhibit a large bulbous proloculus and these are possibly the megalosperic form of this species.

Remarks: The variation in initial chamber arrangement is such that some forms are better placed in *Frondicularia*. Due to the fact that a continuous variation is observed from the true *Citharinella*-type forms through to *Frondicularia*-types the author believes that all forms are suitably placed within this species. The majority of specimens are typically *Citharinella*-like in their initial chamber arrangement. Barnard *et al.* (1981) illustrate specimens from the Oxford Clay which they refer to *Frondicularia nikitini* Uhlig, 1883 and indicate that initial chamber arrangement varies from *Frondicularia* to *Citharinella*. They mention that *Citharinella*-like variants of *F. nikitini* are identical to *C. exarata*. Due to the fact that only a small number of specimens have a typical frondicularid initial portion with continuous variation to citharinid initial portion, all specimens are included within *Citharinella*. These two species may in fact be variants of the one taxon.

Material: 76 specimens.

Genus *Planularia* Defrance,1826
Type Species: *Peneroplis auris* Defrance in de Blainville, 1824

Planularia angustissima (Wisniowski)
Pl. 20, Fig. 5.

1891 *Cristellaria angustissima* Wisniowski, p. 212, pl. 9, fig. 15.
1981 *Planularia angustissima* (Wisniowski); Barnard, Cordey and Shipp, p. 418, pl. 3. fig. 8.

Diagnosis: An elongate species of *Planularia* with a compressed and narrow test. An initial small coil of 3-4 chambers is followed by a rectilinear series of between 4-5 similar sized chambers. The last chamber is drawn out to the aperture and is slightly inflated. Sutures are steeply sloping and are depressed. Aperture terminal, marginal and extended on a short neck.

Variation: The non-apertural margin varies from almost entire to lobate. The chambers after the coil remain constant in size, the final chamber however is drawn out to the terminal aperture, and in some forms is slightly inflated.

Remarks: A very distinctive small, narrow species of *Planularia*.

Material: 9 specimens.

Planularia beierana (Gümbel)
Pl. 20, Figs 6-8.

1862 *Marginulina beierana* Gümbel, p. 221, pl. 3, fig. 20a, b.
1959 *Planularia beierana* (Gümbel); Cifelli, p. 299, pl. 3, figs 1-10, text-fig. 3.

1981 *Planularia beierana* (Gümbel); Barnard, Cordey and Shipp, p. 419, pl. 2, fig. 28, text-fig. 24.

Diagnosis: A small compressed species of *Planularia,* consisting of 6-10 chambers. Initial large ovoid proloculus, followed by 5 chambers arranged in a planispiral coil. Later chambers increasing slowly in size, sometimes reaching back towards the proloculus. Sutures impressed. Aperture radiate, and terminal.

Variation: The test outline of many specimens varies depending on the orientation of the later chambers, some chambers reaching back towards the proloculus. There is also a variable number of chambers in contact with the proloculus, creating a variety of initial outlines. Some specimens have falsopalmulid-like final chambers. Sutures generally impressed but may be flush in some specimens. An initial keel is observed in some specimens.

Remarks: Barnard *et al.* (1981) illustrate the range of variation observed within this species. Gordon (1965) records smooth planularids as *P. fraasi* (Schwager). The original illustrations of *P. fraasi* show a more inflated cross-section than the present specimens. The specimens of *Lenticulina (Planularia) cordiformis* (Terquem) as figured by Lutze (1960, p. 456, pl. 29, figs 14-15) are possibly synonymous. A distictive species due to its flat, compressed and parallel sided nature. The test wall often transparent.

Material: 85 specimens.

Planularia eugenii (Terquem)
Pl. 20, Fig. 9.

1864 *Cristellaria eugenii* Terquem, p. 414, pl. 9, fig. 16a-b.
1981 *Planularia eugenii* (Terquem); Barnard, Cordey and Shipp, p. 420, pl. 2, fig. 27, text-fig. 25A.

Diagnosis: A compressed species of *Planularia* with distinctive ornament. An initial coil of 3-5 chambers following a sub-spherical proloculus, with 9-11 chambers in total. Sutures slightly depressed. Ornament consists of a series of oblique striae which are variable in number. A keel is frequently developed on the non-apertural matgin. Aperture produced, terminal and radiate.

Variation: The ornametation varies from 3 strongly marked striae to a number of faint striae continuous over most of the test but dissapearing towards the apertural face in the majority of specimens. A keel is often present in some specimens but is generally not complete. Chambers in contact with the proloculus vary from 2 to 5.

Remarks: The number and definition of the striae could be used to divide the specimens that have been assigned to this taxon. Barnard *et al.* (1981) divide the species into 3 broad groups depending on the character of the ornament. In this study most of the specimens fall within group (3) as defined by Barnard *et al.* (1981). The periphery is broadly rounded at the proximal end of the test, distinguishing this species from specimens of *Citharina.*

Material: 16 specimens.

Planularia listi (Bornemann)
Pl. 20, Figs 10-11.

1854 *Cristellaria listi* Bornemann, p. 40, pl. 4, fig. 28a-c.

Diagnosis: A small species of *Planularia* with up to 9 chambers. Concave non-apertural margin lobate, apertural margin broadly rounded. A small initial spherical proloculus is followed by low, wide triangular chambers increasing rapidly in size at first. Sutures flush becoming impressed distally, swept backwards towards the periphery. Aperture produced, radiate and circular.

Remarks: In many specimens the size of the proloculus varies and the number of chambers in contact is also variable, from 2 – 5. The difference is probably the distinction between the microspheric and megalospheric generations.

Material: 23 specimens.

Planularia suturalis (Terquem)
Pl. 20, Figs 12-14.

1866 *Cristellaria suturalis* Terquem, p. 441, pl. 8, figs 11a-c.
1981 *Planularia suturalis* (Terquem); Barnard, Cordey and Shipp, p. 421, pl. 2, fig. 30, text-figs 25B, 26.

Diagnosis: A compressed species of *Planularia* with 9-10 chambers. Up to 5 chambers in the initial coil followed by 4-5 chambers increasing in height as added. The final chambers reach back and are in contact with the initial coil. Last chamber is less wide than than the previous and is stepped back from the non-apertural margin. Sutures distinct, deeply impressed and swept back towards the periphery. Aperture terminal, radiate, marginal and produced on a small neck

Variation: The number of chambers in contact with the initail coil is variable. Some specimens have all of the later chambers in contact, including the final chamber which becomes very wide and extends all the way down across previous chambers to the coil. In other specimens the final chambers become progressively stepped back from the non-apertural side producing a lobate margin.

Remarks: A very distinctive species.The chambers are as wide as the coil and in some specimens reach over the width of the coil.

Material: 20 specimens.

Genus *Vaginulina* d'Orbigny, 1826
Type Species: *Nautilus legumen* Linné,1758

Vaginulina anomala Blake
Pl. 21, Figs 1-4.

1876 *Vaginulina anomala* Blake, p. 464, pl. 17, fig. 23.
1965 *Vaginulina anomala* Blake; Gordon, p. 852, text-fig. 7 (30, 31).
1966 *Vaginulina anomala* Blake; Gordon, p. 328, pl. 1, figs 1-5.

Diagnosis: An elongate species of *Vaginulina* with a rectilinear or curvilinear test, initially compressed, becoming inflated towards the non-apertural margin, later chambers inflated. The initial small spherical to ellipsoidal proloculus is followed by 6-7 irregular chambers, increasing in length slowly at first then rapidly. Sutures flush, sloping gently at first then steeply towards the proloculus, away from the apertural margin. Sutures can be sigmoidal and irregular. Final chamber inflated, sub-vertical. Aperture large, marginal, terminally produced on a short neck with up to 15 coarse radiating slits.

Variation: Gordon (1965, 1966) reports that this species is extremely variable. The specimens in this study tend to conform to a distinct outline, the periphery varying very little. The suture pattern and chamber arrangement does, however, vary in accordance with that mentioned by Gordon (1966).

Remarks: Some of the more elongate and narrow specimens are very similar to *Vaginulina* *jurassica* (Gümbel). They can be distinguished by their generally large size and irregular chamber arrangement. Specimens closely resemble figures 1 and 5 of Gordon (1966).

Material: 26 specimens.

Vaginulina barnardi Gordon
Pl. 21, Fig. 5-6.

1965 *Vaginulina barnardi* Gordon, p. 852, text-fig. 7 (9, 24-25).
1989 *Vaginulina barnardi* Gordon; Shipp, p. 260, pl. 6.4.3, fig 7.

Diagnosis: A variable species of *Vaginulina*, generally parallel-sided and ovoid in cross-section. Approximately 8-12 chambers arranged initially in loose coil followed by a rectilinear series. Chambers are parallel-sided, gently sloping to the non-apertural margin; sutures flush. A distinct ornamentation of very fine striae running continuously and obliquely across the test towards the aperture. Aperture marginal, terminal, produced and radiate.

Variation: The outline of the test is generally parallel-sided, straight or arcuate. The apertural margin is always entire, curving towards the aperture. The non-apertural margin can vary from straight to concave to convex or lobate especially close to the final chamber. The sutures are flush, but the last few may be impressed. The sutures slope gently at first, becoming steeper distally. The test is ovate and rounded in cross-section, but may be compressed or carinate; some forms exhibit an almost circular cross-section.

Remarks: The very fine striated surface of the test distinguishes these specimens from other Upper Jurassic vaginulinids.

Material: 221 specimens.

Vaginulina contracta (Terquem)
Pl. 21, Figs 7-9.

1868 *Marginulina contracta* Terquem, p. 125, pl. 8, figs 13-24.
1954 *Vaginulina contracta* (Terquem); Bielecka and Pozaryski, p. 174, pl. 6, fig. 24.
1959 *Vaginulina contracta* (Terquem); Cifelli, p. 321, pl. 5, fig. 17.

Diagnosis: A small species of *Vaginulina*, consisting of 5 chambers increasing in size slowly, final chamber inflated. Sutures impressed, sloping towards the non-apertural margin. Straight apertural margin, lobate non-apertural margin.

Remarks: Specimens similar to *Vaginulina legumen* (Linné) but smaller and less inflated.

Material: 19 specimens.

Vaginulina jurassica (Gümbel)
Pl. 21, Fig. 10.

1862 *Vaginulina jurassica* Gümbel, p. 222, pl. 3, fig. 21a, b.
1960 *Vaginulina jurassica* (Gümbel); Bielecka, p. 138, pl. 6, fig. 49.
1981 *Vaginulina jurassica* (Gümbel); Barnard, Cordey and Shipp, p. 422, pl. 3, figs 5, 6.

Diagnosis: A compressed species of *Vaginulina*, elongate to sub-triangular in shape, consisting of 5-6 chambers following a small spherical proloculus. Chambers increasing in length but remaining constant in height, final chamber slightly inflated. Sutures impressed and sharply sloping. Aperture radiate, marginal and terminal.

Variation: Variation occurs in the width of the specimens. Most are elongate triangular, but some specimens are thinner and more elongate. Sutures generally impressed, especially towards the final chambers.

Remarks: Similar to *V. anomala* Blake but much smaller and with regular chamber arrangement.

Material: 14 specimens.

Vaginulina sp. 1
Pl. 21, Fig. 11.

? 1962 Vaginulina sp., Cordey, p. 384, pl. 47, fig. 18.

Description: Test elongate, ovate in section, consisting of a rectilinear series of 6-8 parallel-sided chambers following a spherical proloculus. Chambers gradually increasing in size, sloping gently towards the non-apertural margin. Apertural margin entire, gently curving, non-apertural margin slightly lobate. Ornament consists of up to 14 blade-like ribs, continuous over the entire test, originating from a small spine below the proloculus, continuing up to the raised aperture. Sutures flush. Aperture raised on a short neck surrounded by radiating slits in between the distal ends of 8 ribs. Apertural face smooth, as the distal ends of the ribs on the non-apertural margin become obsolete.

Variation: The outline of the specimens varies according to the growth rate. In the majority of the specimens the chambers increase gradually but in some forms an initial rapid increase in growth produces a triangular early stage.

Remarks: Cordey (1962) recorded this species from the Oxford Clay of Skye.

Material: 11 specimens.

Family LAGENIDAE Reuss, 1862
Genus *Lagena* Walker and Jacob, 1798
Type Species: *Serpula (Lagena) sulcata* Walker and Jocob, in Kanmacher, 1798

Lagena globosa (Montagu)
Pl. 22, Fig. 1.

1803 *Vermiculum globosum* Montagu, p. 523.
1967 *Lagena globosa* (Montagu); Gordon, p. 456, pl. 3 fig. 19.

Diagnosis: An unornamented species of *Lagena* with a simple radiate aperture, terminal on a short neck.

Remarks: Specimens vary from almost spherical to more elongate.

Material: 36 specimens.

Lagena sp. 1
Pl. 22, Fig. 2.

Description: Test small, unilocular, globular with a short elongated apertural neck. Ornamentation consists of numerous longitudonal striae, around 12 in number. The striae originate from a small spine below the lower margin of the test and continue verticaly across the surface reaching to the aperture. The aperture is extended on a small thin neck, circular, terminal and radiate.

Remarks: The specimens of this taxon are variable in size and can be more globular than ovate. The aperture is generally extended and produced on a small neck, although in some specimens the neck is almost absent.

Material: 6 specimens.

Lagena sp. cf. *Lagena* sp. 3 Bartenstein and Brand
Pl. 22, Fig. 3.

1951 *?Lagena* sp. 3 Bartenstein and Brand, p. 319, pl. 13, fig. 357

Diagnosis: A distinct species of *Lagena*. Ornamentation consists of three thin ribs, evenly spaced across the test, starting at the base of the chamber and continuing across the test to the aperture. Aperture radiate, extended on a small neck.

Remarks: Similar to the specimen illustrated by Bartenstein and Brand (1951). They remark that their specimen may represent the proloculus or chamber of a species of *Tristix*, or could be a distinct species of *Lagena* with triradiate ornamentation. As there is only one specimen found it is difficult to assign it to a particular taxon with any certainty.

Material: 2 specimen.

Family POLYMORPHINIDAE d'Orbigny, 1839
Subfamily POLYMORPHININAE d'Orbigny, 1839
Genus *Eoguttulin*a Cushman and Ozawa, 1930
Type Species: *Eoguttulina anglica* Cushman and Ozawa, 1930

Eoguttulina anglica Cushman and Ozawa

1930 *Eoguttulina anglica* Cushman and Ozawa, p. 16, pl. 1, fig. 3a-c.
1962 *Eoguttulina anglica* Cushman and Ozawa; Lloyd, p. 374, pl. 1, fig. 10a-c.

Diagnosis: An elongate species of *Eoguttulina* with a lobate periphery. Initial small proloculus followed by 4-5 chambers. Sutures impressed and distinct. Aperture flush with the periphery and radiate. Apertural end sub-angular, initial end rounded.

Remarks: Lloyd (1962) records this species from the Kimmeridge Clay of the Dorset coast.

Material: 1 specimen.

?Eoguttulina inovroclaviensis (Bielecka and Pozaryski)
Pl. 22, Fig. 7.

1954 *Sigmomorphina inovroclaviensis* Bielecka & Pozaryski, p. 192, pl. 9, fig. 47a-c.
1962 *Eoguttulina inovroclaviensis* (Bielecka and Pozaryski); Lloyd, pl. 1, fig. 7a-c; text- fig. 4A-B.

Diagnosis: An elongated species of *Eoguttulina* consisting of 4 or 5 chambers following a small sub-spherical proloculus. Later chambers narrow and elongate, initial chambers exposed. Sutures depressed. Aperture radiate produced on a short neck.

Remarks: Lloyd (1962) notes that the later chamber arrangement in this species is similar to that of *Sigmomorphina* Cushman and Ozawa, to which Bielecka and Pozaryski (1954) originally referred this species. Lack of material precludes a decision on the generic position.

Material: 2 specimens

Eoguttulina liassica (Strickland)
Pl. 22, Fig. 8.

1846 *Polymorphina liassica* Strickland, p. 31, text-fig. b.
1962 *Eoguttulina liassica* (Strickland); Lloyd, p. 370, pl. 1, figs 1a-d, 2a-c, 3a-c, text-fig 2A-E
1981 *Eoguttulina liassica* (Strickland); Barnard, Cordey and Shipp, p. 426, pl. 3, fig. 20; text-fig. 29a.

Diagnosis: A teardrop-shaped species of *Eoguttulina* with a lobate periphery. Approximately 5-6 chambers initially sub-globular and triserially to quadriserially arranged, becoming elongate later and added biserially. Final chamber large and reaching almost to the proloculus. Sutures depressed, distinct. Aperture radiate, terminal and flush.

Variation: The microspheric generation is much larger with more chambers. Some specimens have a large final chamber approximately 2/3 the length of the test, reaching back almost to the proloculus. These forms can be separated from other forms with a smaller final chamber, and a shorter stouter test. Lloyd (1962) distinguishes two variant groups based on these criteria.

Remarks: Similar to *Eoguttulina oolithica* (Terquem) but with a lobate periphery, distinctly impressed sutures and a flush aperture.

Material: 135 specimens.

Eoguttulina oolithica (Terquem)
Pl. 22, Fig. 4.

1874 *Polymorphina oolithica* Terquem, p. 299, pl. 32, figs 1-5, 8, 10.
1962 *Eoguttulina oolithica* (Terquem); Lloyd, p. 373, pl. 1, figs 5a-c, 8a-c, text-fig. 5A, B

Diagnosis: A smooth ovoid *Eoguttulina*, tapering to a point distally. Approximately 5 chambers, initially triserially arranged, later biserial, final chamber overlapping and reaching the proloculus. Sutures flush. Aperture terminal radiate, produced to a point on a short neck.

Variation: Specimens can have from 3 to 5 chambers. The outline can vary from elipsoidal to occasionally teardrop shaped. Microspheric forms are larger with more chambers.

Remarks: The sutures, although appearing flush, are actually incised very slightly, and as Lloyd (1962) remarks "the depressed area is so narrow that it may easily be overlooked". The smooth nature of the test, with an entire periphery and flush sutures, separates this species form *Eoguttulina liassica* (Strickland).

Material: 109 specimens.

Eoguttulina oolithica (Terquem) Form A.
Pl. 22, Figs 5-6.

1962 *Eoguttulina oolithica* (Terquem); Lloyd, p. 373, pl. 1, figs 5a-c, 8a-c, text-fig. 5A, B.

Diagnosis: Test small, ovate with a smooth outline. Slightly flattened egg-shaped test with no evidence of chamber development. Test with a smooth surface, sutures not visible. Aperture at the open end of the test, circular, slightly produced and often radiate.

Remarks: Lloyd (1962) notes that in specimens of *E. oolithica*, sutures may be very difficult to observe. The specimens studied have no visible sutures and have the appearance of a unilocular test. They may represent a species of unilocular foraminifera (e.g. *Oolina*) but the author believes that they represent the megalospheric form *of E. oolithica*. This form is generally smaller than the microspheric form and is less ovate with a more rounded periphery (Lloyd, 1962).

Material: 68 specimens.

Subfamily RAMULININAE Brady, 1884.
Genus *Ramulina* Jones, 1875
Type Species: *Ramulina laevis* Jones, in Wright, 1875.

Ramulina spandeli Paalzow
Pl. 22, Figs 9-10.

1917 *Ramulina spandeli* Paalzow, p. 246, pl. 47, fig. 15.
1937 *Ramulina spandeli* Paalzow; Bartenstein and Brand, p. 180, pl. 11B, fig. 25a-b.
1960 *Ramulina spandeli* Paalzow; Bielecka, p. 144, pl. 8, fig. 63.

Diagnosis: A species of *Ramulina* with rounded elongated chambers, connected by stolon-like tubes or necks. Ornament consists of small spine-like projections. Aperture simple, circular at open end of the tube.

Variation: In the majority of specimens the chambers are elongate cyclindrical, but in some forms can vary from near spherical to mere swellings in the tube. The ornament is generally spinose but some specimens exhibit a more hispid ornamentation. The ornamentation becomes reduced towards the necks of the chambers.

Remarks: Specimens are only ever found as single chambers, so the exact nature of the complete test is difficult to ascertain.

Material: 14 specimens.

Suborder ROBERTININA Loeblich and Tappan, 1984
Superfamily CERATOBULIMINACEA Cushman, 1927
Family CERATOBULIMINIDAE Cushman, 1927
Subfamily REINHOLDELLINAE Seiglie and Bermúdez, 1965
Genus *Reinholdella* Brotzen, 1948
Type Species: *Discorbis dreheri* Bartenstein, in Bartenstein and Brand, 1937

Reinholdella cf. *lutzei* Barnard, Cordey and Shipp
Pl. 23, Figs 1-3.

cf. 1981 *Reinholdella lutzei* Barnard, Cordey and Shipp, p. 432, pl. 4, figs 3, 7.

Diagnosis: A plano-convex species of *Reinholdella*, trochospirally coiled, with a lobate periphery and 5-6 chambers in the final whorl. Sutures convex dorsally, merging to form an apical disc. Ventrally sutures impressed, straight and narrow. Aperture loop-shaped.

Variation: Most specimens are plano-convex but vary in the height of the convex dorsal side. Some specimens have a concave ventral side. The chambers appear as depressions on the dorsal side and the sutures are generally raised slightly.

Remarks: First described by Barnard *et al.* (1981) from the Oxford Clay of England. In all respects the specimens recorded here are very similar to those figures by Barnard *et al.* (1981) which has not been recorded above the Oxford Clay. The specimens in this study occur in a flood abundance in only two samples (26 and 24) in the Sandsfoot Formation from the Hallett's Farm Borehole. These specimens may represent a re-occurrence of the species recorded by Barnard *et al.* (1981), or possibly a new species.

Material: 140 specimens.

Reinholdella sp. 1
Pl. 23, Fig. 4.

Diagnosis: A compressed species of *Reinholdella* with 5 chambers per whorl. Test concavo-convex with flush sutures. Aperture obscure.

Remarks: Only one specimen precludes a definite identification.

Material: 1 specimen.

Family EPISTOMINIDAE Wedekind, 1937
Subfamily EPISTOMININAE Wedekind, 1937
Genus *Epistomina* Terquem, 1883
Type Species: *Epistomina regularis* Terquem, 1883

Epistomina mosquensis Uhlig
Pl. 23, Figs 5-6, 9.

1883 *Epistomina mosquensis* Uhlig, p. 776, pl. 7, figs 1-3.
1954 *Brotzenia mosquensis* (Uhlig); Hofker, p. 178, figs 1-3.
1988 *Epistomina mosquensis* Uhlig, Williamson and Stam, p. 142, pl. 1, figs 2, 3.

Description: Test trochospiral, biconvex, generally more convex ventrally, periphery round, entire, 16 chambers arranged in approximately 2 1/2 whorls, 6-8 chambers visible in the last whorl, all chambers visible on the dorsal side. Dorsally, initial chambers are of equal proportions, rounded and circular to oval, becoming gradually larger, wider than high. Sutures on the dorsal side are strong, thin and elevated, distinct, arcuate, swept back to the periphery joining and forming a keel. Spiral suture also elevated, distinct, regular, initial chambers occasionally become circular depressions, loosing their spiral arrangement as the spiral suture thickens and the chambers take on the appearance of a collection of deep pits. Last few chambers forming the distinct inner "v" as described by Williamson & Stam (1986). Later chambers also exhibit an ornamentation of small pustules. Ventrally the sutures are essentially radial and straight, elevated, converging on a thick raised horse-shoe shaped umbilical collar. Peripherally they run towards the raised thickened line that describes the junction between the internal partition and the ventral test wall, which is parallel to the periphery and forms a weakly developed secondary keel. In many specimens this ventral ornament is altered and can be obscured. This alteration varies from the occasional perpendicular connecting rib between the radial sutures through more ribbed forms to forms whose ventral surface is entirely an irregular network of interconnecting ribs and cells. Primary aperture is not visible, secondary aperture is long, crescentic, slit-like with a raised lip, length the entire width of the chamber, roughly between the peripheral keels, occasionally present and only in the last few chambers.

Variation: The main variation within this species is the ventral ornament. The ornament varies from the basic radial sutures and weakly developed secondary keel surrounding a strong, elevated horseshoe-shaped umbilical collar, to forms with occasional connecting ribs to those with a network of ribs over the entire ventral surface. The secondary keel is sometimes very well developed but can be absent with the secondary apertures covered over with calcite

Remarks: A high degree of variation exists within this form not least because the author's concept of this species includes those forms referred to the species *E. regularis* Terquem (1883) by other authors. According to Williamson & Stam (1986) *E. regularis* is very similar to the species of *E. mosquensis* Uhlig (1883) with a heavily ornamented ventral side. Loeblich and Tappan (1964) did not locate the type *of E. regularis* when visiting the French Museums and considered it lost, but stated that it is "almost certainly identical to *E.*

mosquensis Uhlig, 1883". Williamson & Stam (1986) distinguish between the two species; those forms of *E. mosquensis* with a heavily ornamented ventral side and lacking the central umbilical collar and depression are considered to be *E. regularis* due to the fact that in Terquem's 1883 description the central depression with umbilical ring is not mentioned.

Material: 1390 specimens.

Epistomina mosquensis Uhlig Form A.
Pl. 23, Figs 7-8.

1883 *Epistomina mosquensis* Uhlig, p. 776, pl. 7, figs 1-3.

Remarks: A variant of *E. mosquensis* which has a more convex dorsal side with lower, less distinctive sutural ribs, especially in the final whorl. The ventral side shows the same degree of variation as *E. mosquensis s. s.*

Material: 18 specimens.

Epistomina parastelligera (Hofker)
Pl. 23, Figs 10-11.

non 1854 *Rotalia stelligera* Reuss
1954 *Brotzenia parastelligera* Hofker, p. 180, text-figs 4-6.
1960 *Epistomina parastelligera* Hofker; Bielecka, pl. 10, fig. 76.

Description: Test trochoid, bi-convex, periphery circular, rounded, entire, sometimes slightly polygonal. Approximately 18 chambers arranged in a sinistral spiral of 21/4 to 2 1/2 whorls, around 7-8 chambers in final whorl. Chambers increasing gradually in size, polygonal becoming slightly higher than wide, final chamber inflated and hemispherical in nature from the dorsal side. Initial chambers not visible due to an almost boss-like covering of calcite. Chambers in final whorl have a tendency to become depressed emphasising the sutures, and in some cases the whole of the last whorl can become flattened and elevated below the previous whorl. Ventrally, chambers are visible as triangular areas separated by thickened sutures. Dorsally the sutures are short, radial, straight, curving back slightly at their distal ends, occasionally visible surrounding initial chambers, though usually obscured by the calcite covering; emphasised later by the depressed nature of the chambers. Ventrally the sutures are slightly raised, thickened, radial, emanating from a slightly thickened umbilical boss, distally joining up with the secondary keel. Keel thickened and slightly raised, with a stepped back ventral periphery as described by Williamson & Stam (1986). Secondary apertures crescentic, between keels, sometimes peripheral, open in the last few chambers, elongated and as long as chamber width. Primary aperture a small comma-shaped opening, areal, medially placed towards the base of the final chamber.

Variation: This species varies from having a completely smooth dorsal side with sutures not visible to forms with visible sutures and a "dropped" last whorl with depressed sutures. The periphery varies in shape from circular in outline to polygonal. The size of the umbilical boss varies from small to large, a small boss being the most common.

Remarks: This is the most common species of *Epistomina* encountered in this study. Some specimens are quite similar to *E. tenuicostata* Bartenstein and Brand, especially when degraded. When the two species occur together and are badly preserved it is very difficult to distinguish between them. *E. parastelligera* tends to have a straighter radial sutures on the dorsal side which are not raised, and in general has a distinctive calcite covering. This species is known by some authors as *E. stelligera* (Reuss, 1854), although Hofker (1954) believed that his specimens of *E. parastelligera* were sufficiently different from those figured by Reuss from the Upper Cretaceous as to merit a new species. Bielecka (1960) agrees with Hofker's view but notes that there is a lack of Reuss's original material to make a definite standpoint. In agreement with previous authors the species *B. porcellanea sensu* Lloyd

(1962) is considered to represent *E. parastelligera* of this study and that *E. parastelligera* as figured by Lloyd (1962) represents another species due to its coarse ribbing.

Material: 10, 123 specimens

Epistomina stellicostata Bielecka & Pozaryski
Pl. 24, Figs 1-2.

1954 *Epistomina stellicostata* Bielecka & Pozaryski, p. 71, pl. 12, fig. 60a-c.
1981 *Brotzenia stellicostata* (Bielecka & Pozaryski); Barnard, Cordey and Shipp, p. 432, pl. 4, figs 10,11; text-fig. 31A.
1988 *Epistomina stellicostata* (Bielecka & Pozaryski); Williamson and Stam, p. 146, pl. 4, figs 1,2.

Description: Test trochospiral, biconvex, periphery round, entire to slightly lobate, predominantly sinistral coiling. 17-19 chambers arranged in approximately 2 and a half whorls, 7-8 chambers in the last whorl. Chambers are slightly raised, swollen to the height of the raised sutures, especially on the ventral side. Dorsally the chambers gradually increase in size becoming wider than high in the last few chambers. Sutures on the dorsal side are marked by raised ribs, distinct, radial then arcuate, sweeping back towards the periphery to form a keel. Ribs thicken towards the centre of the dorsal face and join up, initial chambers taking on the appearance of a collection of circular pits. Sutural ribs are generally pitted. Spiral sutures raised and distinct but somewhat irregular, pitted towards the initial chambers. Ventrally sutures are raised slightly, distinct and radial, leading to an irregular network of sutures covering the umbilicus, becoming an umbilical boss. This boss is frequently covered in irregular pits, which extend upwards on the sutures towards the periphery. Towards the periphery the sutures join with a secondary keel which is raised and distinct, parallel to the periphery with a marked keel band, crescentic, curving between sutures. Primary aperture difficult to discern, secondary apertures crescentic, between keels, as wide as chambers.

Variation: Bielecka & Pozaryski (1954) describe this species as "coiled in a counter-clockwise direction" although the vast majority of the specimens studied have a sinistral coiling, a few specimens exhibit dextral coiling and, therefore, the author believes the concept of this species should allow for both coiling directions. The specimens vary from being bi-convex (the ventral side tending to be more convex) to plano-convex; the majority bi-convex. The ventral umbilical area varies from having a strongly pitted boss, with pits extending up the sutures, to an umbilical area of suture ends joining in an irregular network, in most cases the radial nature of the sutures is still visible especially towards the periphery and the secondary keel. All specimens exhibit the stepped back ventral periphery (type c) as described by Williamson & Stam (1986). Dorsally the initial chambers are reduced to a series of circular - oval rounded pits surrounded by the thickened sutures which cover the initial chambers. Occasionally pustulose ornament is exhibited on the final chambers.

Remarks: This species is similar to *E. mosquensis* Uhlig in some aspects but differs in having pitted dorsal sutures; a pitted ventral boss; and at least a remnant of regular radial sutures on the ventral side; in having sutural ribbing with lower relief and in having a regular secondary keel. Some specimens are similar to *E. tenuicostata* Bartenstein and Brand but tend to have an irregular central network of pits instead of a regular dorsal chamber arangement.

Material: 3265 specimens.

Epistomina tenuicostata Bartenstein and Brand
Pl. 24, Figs 3-5.

1951 *Epistomina tenuicostata* Bartenstein and Brand, p. 327, pl. 12A, fig. 325.
1954 *Voorthuysenia tenuicostata* (Bartenstein); Hofker, p. 186, text-fig. 19.

1988 *Epistomina tenuicostata* Bartenstein and Brand; Williamson and Stam, p. 146, pl. 4, figs 1, 6.

Diagnosis: A biconvex species of *Epistomina*, with a keeled periphery. Two whorls visible with 7-8 chambers in the final whorl. Dorsally the sutures surrounding the initial chambers have a tendncy to coalesce sometimes forming a smooth central area. Sutures later are strongly curved and swept back, thickened and raised. Ventral sutures radial merging towards the umbilicus. Aperture areal, oral. Secondary apertures are infilled.

Remarks: The final chamber is often inflated and overlaps part of the umbilical area on the ventral side. Differs from *E. stellicostata* Bielecka and Pozaryski in having an initial area of regularly arranged chambers rather than a series of pits.

Material: 5775 specimens.

Epistomina spp. indet.

Diagnosis: Many specimens of *Epistomina* encountered in this study are very badly preserved. Pyritized, damaged, abraded and dissolved specimens are very difficult to assign with any certainty to a specific taxon. While it is often possible to recognise specific diagnostic features in some poorly preserved specimens, forms which are indistinguishable are included within this category. The majority of specimens included here are pyritized casts, which are generally broken and damaged.

Material: 154 specimens.

Superfamily DISCORBACEA Ehrenberg, 1838
Family PLACENTULINIDAE Kasimova, Poroshina and Geodakcham, 1980
Subfamily ASHBROOKIINAE Loeblich and Tappan, 1984
Genus *Paalzowella* Cushman, 1933
Type Species: *Discorbis scalariformis* Paalzow, 1917

Paalzowella feifeli (Paalzow)
Pl. 24, Figs 6-7.

1932 *Trocholina feifeli* Paalzow, p. 140, pl. 9, figs 6-7.
1960 *Paalzowella feifeli feifeli* (Paalzow); Lutze, p. 485, text-fig. 19, figs 5-15.
1960 *Paalzowella feifeli seiboldi* (Paalzow); Lutze, p. 486, text-fig. 19, figs 20-34, pl. 33, fig. 12.
1960 *Paalzowella feifeli* aff. *elevata* (Paalzow); Lutze, p. 487, text-fig. 19, figs 16-19, pl. 33, fig. 11.
1960 *Paalzowella feifeli feifeli* (Paalzow); Seibold and Seibold, p. 378, text-fig. 8h, l, p, q, pl. 7, fig 2.
1960 *Paalzowella feifeli elevata* (Paalzow); Seibold and Seibold, p. 379, text-fig. 8u, pl. 7, fig 3.
1989 *Paalzowella feifeli* (Paalzow); Shipp, p. 255, pl. 6.4.1, figs 19, 20.

Diagnosis: A variable-shaped, conical species of *Paalzowella*, consisting of 4 to 5 low chambers per whorl trochospirally enrolled with an involute umbilical side and evolute dorsal side. Radial striations on the umbilical surface. Aperture, interiomarginal, a long, low arch extending across the concave umbilical side.

Variation: Apical angle varies from around 70-110° and the height of the test varies from low conical to high conical.

Remarks: Variation occurs in the height of the spire. Lutze (1960) recorded 2 species and one subspecies based on spire height. *Paalzowella feifeli* for the majority of forms with a medium - high spire with an angle of around 90°; *Paalzowella feifeli seiboldi* for specimens with a slightly higher spire and *Paalzowella feifeli* aff. *elevata* for the high spired forms. Seibold and Seibold (1960) recorded two subspecies *Paalzowella feifeli elevata* and *Paalzowella feifeli feifeli*. Although the difference in spire height and angle is visible in the specimens studied the small number precludes the division into separate species or subspecies.

Material: 7 specimens.

Paalzowella sp. 1

cf. 1971 "*Paalzowella* sp. A" Wernli, p. 340, pl. 8, figs 5-8, 10-11, 13.

Diagnosis: A very compressed species of *Paalzowella* with 3-4 long low chambers per whorl. Ventral side involute, 4 triangular chambers visible. Aperture not visible.

Remarks: Distinct from *P. feifeli* (Paalzow) in the compressed nature of the test. Very similar to "*Paalzowella* sp. A" as figured by Wernli (1971) but more compressed (greatest similarity with figs 7 and 13).

Material: 2 specimens.

5. Holothurian Sclerites.

5.1. Introduction.

Although the research is primarily concerned with foraminifera, some well-preserved holothurian sclerites are present as a common constituent of the assemblage. In order to further evaluate the distribution and relative abundance of the sclerites fourteen samples from the East Stour Borehole were examined and all holothurian elements were removed. See Figures 3.17 and 7.3 for borehole and sample location.

The Holothuroidea, more commonly known as Sea Cucumbers, are a class of the Echinodermata which, according to Smiley and Pawson (1991), consist of 1400 extant species. Although holothurian body fossils are very rare due to the soft nature of the tissue, the skeletal elements are often fossilised. This fossil material consists of two distinct components, the calcareous ring (circum-oesophagael ring) which consists of numerous calcareous platelets, and sclerites which are embedded in the body wall and tentacles of the Sea Cucumber. It is the sclerites with which this section is concerned.

5.2. Holothurian biology.

Holothurians (Sea Cucumbers) are typically elongate and cylindrical reaching an adult size which varies from 3 mm to 2 m in length, with an average of around 0.5 m. The body of the holothurian tapers from a large end which comprises the buccal tentacles and mouth to a smaller end where the anus is situated. Holothurians exhibit the fundamental echinoderm pentameral symmetry which is manifested as 5 ambulacral longitudinal lines with double rows of podia, tube feet or tentacles.

The body of the holothurian is generally soft when relaxed but becomes hard and rigid when contracted. The holothurians do not exhibit the external plates that are common in other echinoderms, but their supporting structure is composed of many minute calcareous platelets of varying size and shape which are referred to as sclerites. Hampton (1959) estimates that the number of sclerites in one holothurian can be as many as 20, 600,000. The holothurian body wall is composed of three elements:

1. The leathery external cuticle;
2. A layer of connective tissue; and
3. An internal muscle layer.

The sclerites are found in layer two, and form the skeletal structure.

5.3. Holothurians as fossils.

Due to the soft-bodied nature of holothurians they rarely fossilise as impressions. Prior to the discovery of holothurian fossils from the Middle Triassic of northern Spain, complete fossil holothurians had been reported from only six localities (Smith and Gallemí, 1991).

Sclerites, and to a lesser extent the calcareous ring, are the only abundant fossilised material of holothurians. These are a component of many different assemblages but are more often found in association with the fragmental remains of other echinoderms (ophiurids, crinoids etc.) and most frequently found in lithologies comprising clays, marls, shales or sandy shales.

Sclerites are microscopic objects varying from 0.05 mm to 1 mm in size and are composed of clear or opaque calcite. As with other echinoderm fragments they are composed of a single crystal of calcite, the optical axis of which has been utilized as a feature of taxonomic importance by some authors. They exhibit a wide variety of shapes (morphotypes) and are described by the self-explanatory names of common objects (e.g. anchors, hooks, wheels, tables, plates, etc.).

5.4. History of Research.

This section is concerned with records from the Jurassic only; for a more complete history of the research into holothurian sclerites see Croneis and McCormack (1932), Bartenstein (1936), Mortensen (1937), Frizzell and Exline (1955, 1966), Deflandre-Rigaud (1962) and Gilliland (1993).

Holothurian sclerites as a group have received little attention in this country. Published works from the Jurassic include Hodson *et al.* (1956) who studied specimens from the Oxford Clay of the Dorset Coast; Hampton (1957-1960) examined Upper Bathonian forms from the Dorset Coast and published papers concerned with the taxonomy and statistical analysis of holothurian sclerites. Fletcher (1962) describes forms from the Ampthill Clay of Melton, near Hull, and Lord & Senior (1973) re-describe two holothurian species from the Middle Jurassic of South Dorset. Soodan & Whatley (1987, 1988) published a two-part paper titled "Fossil Holothuroidea from the Jurassic of Great Britain". These papers illustrate and describe species from various Jurassic outcrops throughout Britain. More recent contributions from Gilliland are concerned with the holothurians from the Blue Lias of southern Britain (Gilliland, 1992a) and the assemblagel changes of holothurians at the Triassic-Jurassic boundary (Gilliland, 1992b). More importantly Gilliland (1993) has also published a Palaeontological Association Special Paper which is concerned with the skeletal morphology, systematics and evolutionary history of the holothurians. This paper represents the most recent work on fossil holothurians and includes a review of all relevant publications on fossil holothurian sclerites. Gilliland (*op. cit.*) classifies the skeletal elements of recent holothurians with a view to place fossil sclerites into a natural biological classification scheme based on Recent holothurians.

5.5. Sample Preparation.

The samples have not been prepared solely for the examination of holothurian sclerites, but using standard micropalaeontological processing techniques, which are not ideal for their preservation. Inherently, sclerites have a far more delicate structure than most foraminifera or ostracods, even the action of separating residues, in standard nesting sieves can damage the more fragile specimens. The presence of matrix adhering to the specimens and/or the growth of secondary calcite coupled with the minute size of most of the specimens, further hampers the identification of forms. Over 200 sclerites were counted in total from the 14 samples.

5.6. Taxonomy of holothurians.

The taxonomy of holothurian sclerites has inherent difficulties as with all groups of fragmental microfossils. Hampton (1959) points out that many different forms of sclerites can occur within the same species and conversely, many similar forms are found in distantly related taxa. They outnumber the complete specimen many fold, and are very difficult to identify with the complete fossils of their parent animals. They are the disjunct fragments of numerous holothurian parents. The first attempt to classify the holothurians was by Frizzell and Exline (1955). In this comprehensive paper the problems of classification of fragmental microfossils are discussed. The classification utilised is based only on the sclerites, and discrete isolated sclerites are treated as the taxonomic unit, a separate classification scheme is advocated for body fossils. Around the same time Deflandre-Rigaud (1950) published the *ordo militaris* scheme as applied to sclerites. Not until Frizzell and Exline (1966) was a classification scheme accepted. This scheme, published in the Treatise on Invertebrate Palaeontology, combined some of the ideas of Deflandre-Rigaud but generally builds upon their earlier classification. It is based entirely on disjunct components and is therefore basically artificial. In general, following the "parataxa" proposals of Moore and Sylvester-Bradley (1957), species of fossil holothurian sclerites are alluded to in terms of parataxa or form species. Sclerites are grouped together into Families based on morphology. The desire to incorporate both sclerites and Recent holothurians was important and both Pawson and Fell (1965) and Pawson (1966) attempted an integrated classification. The most recent attempt to group fossil sclerites within the framework of Recent holothurian taxonomy was presented by Gilliland (1993) who states that "there is clearly a need to reassess and update the fossil record of holothurians within a palaeobiological paradigm in order to relate fossil and Recent taxa, and to develop the view that both Recent and fossil material provide complementary sources of information on the same group of organisms".

5.7. Systematic Descriptions.

Although Gilliland (1993) has set the basis for a unified systematics between fossil and Recent holothurians, there are still problems to be overcome. Due to the limited scope of the present study the taxonomy of the holothurians will be referred to purely in terms of parataxa and form species and is based on the classification scheme of Frizzell and Exline (1955 and 1966). In this section the taxonomy will be restricted to a remarks section. Synonymies and detailed description by other authors will be referred to whenever possible.

Phylum: ECHINODERMATA.

Non-Holothurian 'Holothurian Sclerites"

Following Gilliland (1992a), certain sclerites recorded in this study have been placed under this heading. Sclerites which had previously been referred to the holothurians have subsequently been reclassified as echinoderm in origin rather than specifically holothurian.

Frizzellus-type elements.

Plate 25, Figs T, U.

Remarks: Flattened disc-shaped sclerites are included under this heading. The forms compare well with those described by Hampton (1958b) as *Frizzellus iregularis*, but differ in being perforated towards the outer margin. The surface ornamentation is granular becoming almost reticulate nearer the centre, where the sclerite thickens slightly. The sclerites vary in morphology in accordance with forms (a) to (d) of Gilliland (1992a): the majority of specimens being type (a) forms.

Previous authors have expressed doubt as to whether the genus *Frizellus* Hampton, 1958, formally in the Family Etheridgellidae Frizzell and Exline, 1955, is definitely Holothurian in origin. The forms encountered in this study are very similar to *F. irregularis* Hampton, 1958, and as Gilliland has shown, precludes assigning them to the holothurians.

Distribution: This form is the most common, occurring in all the samples.

Eocaudina-type plates.

Plate 25, Figs F, G.

Remarks: Flattened perforated plate-like sclerites are include in this taxon. Unfortunately, all the perforated plate forms examined have a tendency to be broken with the perforations filled with matrix and/or secondary calcite. This makes identification difficult.

When considered holothurian in origin the genus *Eocaudina* Martin, 1952 belonged to the Family Calclamnidae Frizzell and Exline, 1955, and formally incorporated all perforated plate forms which are discoidal or hexagonal in outline. As noted by Frizzell and Exline, and by subsequent authors, *Eocaudina* cannot be considered unequivocally as holothurian in origin, since the plates are also found in other echinoderms. The assemblage encountered here compares well with that of the Blue Lias (Gilliland, 1992a), in that *Eocaudina*-type plates co-occur with holothurian and various echinoderm skeletal elements. The author agrees with Gilliland that it seems preferable not to accept these plates as holothurian.

Distribution: These plates are common; occurring in all the samples studied.

Class: HOLOTHUROIDEA.
Family: STICHOPITIDAE Frizzell & Exline, 1955.
Genus: *Rhabdotites* Deflandre-Rigaud, 1952.

Rhabdotites dorsetensis Hodson, Harris & Lawson 1956, *emend.* Hampton 1960.
Plate 25, Figs A-E.

Remarks: These sclerites are variously shaped thin and thickened rod-like sclerites. The surface is smooth or covered in minute nodules. Branching forms are also observed and those with large pustules. This species was revised by Hampton (1960) who concludes that previously separate species are in fact "variational aspects of a single sclerite morphogroup" and are to be included in the single species *Rhabdotites dorsetensis*. The variety of forms encountered in the present study all fall within these "variational aspects".

Gilliland (1993) regards *Rhabdotites*-type rods as being non-holothurian in origin and comments on their structure. He mentions that they are "...not solid throughout but composed of stereom meshwork in part". He attributes these sclerites to the pedicellarial stalks of echinoids. In the studied samples many echinoid pedicellaria are encountered which, structurally bare no resemblance to the specimens of *Rhabdotites dorsetensis*. These specimens are identical in composition to unequivocal holothurian sclerites (ie. species of *Achistrum*) and the author therefore prefers to retain these specimens as holothurian in origin.

Distribution: Samples 30447, 30450, 30452. Very common, 31 specimens. The preservation of all specimens is exceptional.

Family: ACHISTRIDAE Frizzell & Exline, 1955.

Remarks: Aside from those belonging to the genus *Frizzellus* the majority of sclerites encountered in this study belong to this Family (hooks), and all but one of the specimens belongs to the genus *Achistrum*.

Genus: *Achistrum* Etheridge, 1881, *emend.* Frizzell & Exline, 1955.

Remarks: This taxon is reserved for hook-shaped sclerites with a distinct loop, shaft and spear. The author does not follow Hampton (1958) in splitting the genus *Achistrum* into the subgenera *Achistrum s. s.*, *Spinrum*, *Cancellrum* and *Aduncrum* but follows Frizzell and

Exline (1966). The preservation of the specimens is generally very good, but some forms have the eye wholly or partially filled with matrix and/or secondary calcite. In the latter case it becomes difficult to identify the forms to specific level, so they are placed in open nomenclature under the genus *Achistrum*. Almost all of the specimens are incomplete, in that the spear of each is lacking.

Achistrum spp.

Remarks: There are a moderate number of indeterminable species of *Achistrum* in the study, occurring in samples 30442, 30447, 30451, 30452. 13 specimens.

Achistrum cf. *issleri* (Croneis, 1932).

Plate 25, Fig. H.

Remarks: Hook-shaped sclerites in which the terminal loop is empty. All specimens are incomplete (lacking a spear), but otherwise agree closely with those figured by Hodson *et al.* (1956), as *A.* sp. cf *issleri.*

Distribution: The second most common *Achistrum* species in the samples studied; occurring in samples 30434, 30447, 30450, 30452, 30453. 13 specimens.

Achistrum monochordata Hodson, Harris & Lawson, 1956.

Plate 25, Fig. I, J.

Remarks: A species of *Achistrum* in which there is a single bar across the terminal loop. This is the most common species of this genus and, aside from *Frizzelus* type elements, is the single most common species encountered in this study. The crossbar varies in its position within the eye, and in many cases is broken, resulting in two small protrusions which have been interpreted as spine-like processes by previous authors and recorded as the distinct species *A. bartensteini* Frizzell and Exline, 1955. This species is regarded as synonymous in this study following Rioult (1961). All specimens are lacking the spear. Gilliland (1992a) gives a comprehensive reference list for *Achistrum monochordata.*

Distribution: This form is very common in the samples studied occurring in samples 30427, 30434, 30439, 30442, 30447, 30450, 30452, 30453, 30454. 73 specimens.

Achistrum gamma Hodson, Harris & Lawson, 1956.
Plate 25, Fig. K.

Remarks: A species of *Achistrum* with a bifurcated bar within the terminal loop. The majority of the specimens have the "Y"-shaped crossbar intact. All specimens are lacking the spear. The specimens are similar to those figured by Hodson *et al.* (1956) from the Oxford Clay.

Distribution: Relatively rare in the samples studied. Occurring in samples 30434, 30452, 30454. Six specimens.

Achistrum sp. cf. *A. bichordata* Fletcher, 1962.
Plate 25, Fig. M.

Remarks: A species of *Achistrum* with two crossbars in the terminal loop. As the eye of this form is partially infilled with matrix, the nature of the crossbar is difficult to ascertain and hence assigning it to this species is uncertain. The specimen seems to have only two crossbars but a bifurcation of one of these bars could easily be obscured. The form would then be assigned to *A. trichordata* Fletcher, 1962.

Distribution: Only one specimen occurring in sample 30447.

Genus: *Aduncrum* Hampton, 1958.

?Aduncrum sp.
Plate 25, Fig. L.

Remarks: This genus includes hook-shaped sclerites with the terminal loop replaced by two small, incurved, hook-like projections. Due to the specimen's relatively bad preservation, positive identification is difficult.

Distribution: One specimen only. Sample 30447.

Family: PRISCOPEDATIDAE Frizzell & Exline, 1955.
GENUS: *Priscopedatus* Schlumberger, *emend.* Frizzell & Exline, 1955.

Priscopedatus spp.

Plate 25, Fig. N, O.

Remarks: Sclerites with a flat or slightly curved perforated base plate with a central raised spire are included in this taxon. These forms are often referred to as table-like sclerites. One of the major characteristics for identification of taxa within this Family is the position and nature of the central spire, lattice cross and primary pore(s). Due to the common occurrence of secondary calcite on perforated plate forms, coupled with the invariable damaged outline, it is difficult to assign these specimens to an individual taxon. Some forms resemble *Helfriedella mesojurassica* Kozur & Sadeddin from the Upper Bathonian and Callovian of Jordan.

Gilliland (1993) further subdivides the family Priscopaedatidae into 7 groups based on differing morphology. For simplicity the author refers to the specimens as *Priscopedatus*. The specimens probably belong to Gilliland's "*Priscopedatus/Feddenella*" group.

Distribution: Common in the samples studied. Occurring in Samples 30442, 30447, 30450. 12 specimens.

Family: THEELIIDAE Frizzell & Exline, 1955.

GENUS: *Theelia* Schlumberger, 1890.

Remarks: Sclerites with a distinct wheel-like appearance are included in this genus.

Theelia convexa (Whidborne, 1883).

Plate 25, Figs P-R.

REMARKS. Small circular wheels with an incurved and denticulate inner rim on the dorsal side and a distinctive "star" arrangement of the spokes at the hub on the ventral side. All of the forms in this Family belong to this species. The specimens compare well with the forms figured by Lord and Senior (1973). The specimens all have only 7 spokes which is in keeping with the sclerites recorded by Soodan & Whatley, 1988, and is unusual for this species which tends to have a variable number of spokes with an average of six. For a detailed description and synonymy of this species see Lord and Senior (1973) and Gilliland (1992a).

Distribution: Frequent in the samples studied. Occurring in Samples 30439, 30447, 30450, 30452, 30453. 18 specimens.

Family: SYNAPTITIDAE Frizzell & Exline, 1955.
GENUS: *Synaptites* Deflandre-Rigaud, *emend.* Frizzell & Exline, 1955.

Synaptites sp.
Plate 25, Fig. S.

Remarks: Sclerites with a perforated plate and small socket and bar at one end are included in this genus. These plates are usually associated with anchor-like sclerites. Due to poor preservation it is only possible to classify this specimen to generic level. The genus *Synaptites* has not been previously described from the Upper Jurassic of Britain.

Distribution: Only one specimen. Sample 30450.

5.8. Palaeo-ecology.

Fossil holothurian sclerites are widely distributed in marine sedimentary strata of moderate to shallow depths, and are found most frequently in clays, marls, shales and sandy shales. They are found less commonly in limestones and marly limestones, and rarely in sandstones. Palaeo-environments range from marine and tropical to sub-arctic, suggested bathymetry ranges from sublittoral to moderate depths. Although Recent holothurians are abundant and varied in the depths of the seas, fossil sclerites are rare in deep-sea deposits due to dissolution after deposition.

As Gilliland notes the comparison with the distribution of Recent taxa to elucidate palaeo-environments is limited by the uncertain affinity of some of the morphotypes and the difficulty of assigning others to a taxonomic level below that of the Recent family. However, although there is a diverse and widely distributed extant fauna on which to base palaeontological distributions, there is still work needed to help determine the relationships between fossil and Recent taxa.

In a general sense certain sclerite morphotypes can be assigned to Recent families. The species *Theelia convexa* encountered in this study is almost certainly a member of the family Chiridotidae. Species of holothurian from this family have an infaunal or burrowing mode of life. It is only certain generalisations such as these which can help towards palaeo-environmental or palaeo-ecological interpretations.

Some of the generalised palaeo-environments are listed below for the various morphotypes encountered in this study (Table 5.1, summarised from Gilliland, 1993).

5.9. Biostratigraphy.

The distribution of the sclerites throughout the samples does not indicate any particular useful biostratigraphic marker morphotype. With more samples and a more detailed study more information may be derived.

Although there are published biostratigraphical schemes based on sclerites (e.g. Rioult, 1961) their use at present is limited. For a more detailed discussion of sclerites as biostratigraphical tools see Gilliland (1992a, b and 1993). Biometric studies may, potentially, provide useful biostratigraphical indications.

Sclerite Morphotype.	Implied Palaeo-environment	After authors.
Achistrum spp.	coral-stromatoporoid reef or near-reef community	Beckmann (1965)
	"moderately deep"	Said and Barakat (1958)
	low energy, nearshore shallow water shelf	Gutschick *et al.* (1967)
	"deep neritic/shallow bathyal"	Zawidzka (1971)
	algal dominated shallow water sediments	Gramann *et al.* (1972)
	mid-basinal position with quiet sedimentation	Michelson (1972)
	very shallow, warm water platform	Patterson (1978)
	shallow, quiet warm water, soft bottom, shelf	Fischer *et al.* (1986)
	turbid, nearshore, euryhaline estuarine/deltaic environment	Skroka (1988)
	shallow (<150 m) warm water (tropical/subtropical)	Gilliland (1992a) after Hallam 1960.
Thelia convexa -type species.	proximal reef slope	Donofrio *et al.* (1980)
	shallow (40-60 m), warm water with a soft, unstable substrate	Fischer *et al.* (1986)
	shallow (<150 m) warm water (tropical/subtropical)	Gilliland (1992a) after Hallam 1960.
Synaptidae	less than 10m depth	Frizzell and Exline (1955)
	open water, shallow shelf, tropical-subtropical	Tandon and Saxena (1977)
	shallow (less than 210 feet)	Jafar (1970)

Table 5.1. Generalised palaeo-environments for sclerite morphotypes encountered in this study. (Summarised from Gilliland, 1993).

Chapter 6. Statistical analysis of the samples.

6.1. Introduction.

A number of methods have been employed to interpret the assemblage encountered in the studied boreholes. These vary from simple abundance counts to complex multivariate statistical methods. The statistical methods employed were selected to produce interesting and meaningful results for the assemblage studied and do not represent an exhaustive statistical analysis. There is a vast array of sophisticated statistical methods available for dealing with species/sample data, ranging from simple diversity indices, through distributional representations of richness, dominance and evenness to the more complex multivariate clustering and ordination techniques; only a few are employed in this study. Many of the following techniques utilise the computer software package PRIMER (Plymouth Routines In Multivariate Ecological Research), and parts of the following discussion of techniques are summarised from Clarke and Warwick (1994).

6.1.1. Techniques employed.

6.1.1.1. Simple techniques

Simple techniques include assemblage counts, wall structure ratios, % abundance of species, % abundance of families etc. The results from these methods are included in Chapter. 7.

6.1.1.2. Univariate techniques:

Univariate methods collapse the full set of species counts for samples into a single coefficient; methods employed to analyse the data are the simple measurement of the number of species (richness) per sample, the richness indices, Fisher *et al.* (1943; the α: index) and Margalef 's Richness Index, Simpson's Dominance Index, Pielou's Evenness Index and the Shannon-Weiner Information index are also used.

6.1.1.3. Multivariate techniques.

These techniques compare two or more samples depending on the extent to which these samples share particular species, at comparable levels of abundance. Multivariate techniques are founded on these similarity coefficients calculated between each pair of samples. This in turn facilitates the clustering or classification of samples into groups which are mutually similar. Ordination plots are also produced in which, for example, the samples are "mapped" in two or three dimensions in such a way that the distances between pairs of samples reflect their relative dissimilarity of species composition (Clarke and Warwick, 1994). The multivariate methods employed in this study are hierarchical agglomerative clustering and the ordination technique non-metric multi-dimensional scaling (MDS) first introduced by Shepard (1962) and Kruskal (1964) for applications to problems in psychology.

In the following sections the techniques will be summarised and the basic theory discussed. The author does not attempt to provide an in-depth critique of each technique as this is beyond the scope of the present study but, where appropriate, will reference the more authoritative texts for each method.

The samples from each of the four boreholes were analysed in turn according to the above methods, and the results are interpreted in the following section.

6.2. Statistical Techniques.

6.2.1 Univariate techniques.

In each of the following methods the following abbreviations are used:

S: Number of species.

N: Total number of individuals

R: Margalef's Richness Index.

α: Fisher's Alpha Index.

$H(S)$: Shannon-Weiner Information Function.

λ: Simpson's Dominance Index.

J: Pielou's Equatibility Index.

p_i: the proportion of the *i*th species

Species Richness:

Richness is an indicator of the relative abundance of species within a community. At its simplest level it is the measure of the number of species in a sample. The concept is simple, but as Peet (1974) notes, it is difficult to apply a formal definition. The problem stems from an inherent dependence of any richness measure on sample size; the larger the sample the greater the number of species would be expected to be encountered. Two richness indices are measured in this study.

Margalef's Richness.

Margalef suggested a logarithmic relationship:

$$R = \frac{(S - 1)}{\log N} \text{..........} (1)$$

Fisher α index.

One of the most frequently used and thoroughly investigated models of the relationship between species richness and relative abundance of species is the α: index, first described by Fisher *et al.* (1943):

$$S = \alpha \log(1 + \frac{N}{\alpha}) \text{..........} (2)$$

This can be abbreviated to:

$$\alpha = \frac{n^1}{x} \text{..........} (3)$$

where x is a constant having a value of <1 (which can be read from fig. 125 of Williams, 1964) and n^1 can be calculated from $N(1 - x)$, N being the size of the sample (number of individuals). This index assumes that the number of individuals of each species follow a logarithmic series. Murray (1968) tested the variation of the index with increasing sample size and while the variation was not great, there was a tendency for α: to increase with sample size. The α index has the advantage that the values can be read off a base graph by plotting the number of species against the number of individuals in a sample (Murray, 1973, 1991).

Heterogeneity Indices.

Simpson's Index or Simpson's Dominance measures the probability that two individuals selected at random from a sample will belong to the same species. For an infinite sample this index is:

$$\lambda = \sum_{i=1}^{S} p_i^2 \,\ldots\ldots\ldots(4)$$

When all individuals belong to the same species then λ = 1. Most diversity indices increase as S increases, Simpsons Index decreases however, because there is less probability of finding 2 individuals that belong to the same species for greater values of S. For this reason some authors have used the reciprocal of l.

Buzas (1979) mentions that l is an attractive measure of diversity because it does not assume any particular distribution of the species abundances and is of some biological significance.

The most popular heterogeneity indices are those based on information theory (H). These can be thought of as a measure of uncertainty. The expression for the information content per individual within an infinite population is given by the Shannon-Weiner (Shannon-Weaver) formulation:

$$H(S) = -\sum_{i=1}^{S} p_i \log p_i \ldots\ldots\ldots(5)$$

where S is the number of species and p_i the proportion of the ith species. The maximum value of H for any given number of species is attained when all S species have equal abundances; then:

$$H(S)_{\max} = \log S \,\ldots\ldots\ldots(6)$$

Within the concept of heterogeneity is a component concept concerning the evenness with which importance is divided among species. Pielou's Equitability index *J:*

$$J = \frac{H(S)}{\log S} \text{..........}(7)$$

or substituting (6) above:

$$J = \frac{H(S)}{H_{\max}} \text{..........}(8)$$

6.2.2. Multivariate techniques.

Multivariate techniques used in this study are hierarchical agglomerative clustering and non-metric multi-dimensional scaling (MDS).

6.2.2.1. Cluster analysis.

Cluster analysis (or classification) seeks to find "natural groupings" of samples. Within these groups samples are more similar to each other, generally, than samples from other groups. There are many different clustering methods in use of which Cormack (1971) and Everitt (1980) present thorough reviews. Clustering methods can be split into 5 classes following the categories by Cormack (1971) and Clarke and Warwick, (1994).

1. Hierarchical methods.
2. Optimising techniques.
3. Mode-seeking methods.
4. Clumping techniques.
5. Miscellaneous techniques.

Cormack (1971) mentions "that the availability of computer packages of classification techniques has led to the waste of more valuable scientific time than any other "statistical" innovation". Therefore, the clustering technique used here is the hierarchical agglomerative method which, according to Clarke and Warwick (1994), is the most commonly used technique and has been found to be of widespread utility in ecological studies. It must be mentioned, however, that clustering analysis has the potential arbitrariness of all classification methods and must be performed in conjunction with other techniques. This will hopefully produce balanced and reliable conclusions.

The basic procedure begins with the computation of (usually) a similarity matrix between the samples and ends with a dendrogram showing the successive fusions of samples. Samples are fused into groups and these groups are successively fused into clusters. This culminates in a stage where all the samples are in one group. At any particular stage, the method fuses samples which are most similar (closest). The results are represented as a tree diagram or dendrogram The y-axis represents the full set of samples and the x-axis defines the similarity level at which pairs of samples (or groups) have been linked. There are many linkage options within hierarchical agglomerative clustering but "group-average linkage" is used in this study. Clarke and Warwick (1994) state that hierarchical clustering with group-average linking, based on sample similarity matrices such as Bray-Curtis, has proved a useful technique in a number of ecological studies within the last two decades.

Some points about the use and appearance of dendrograms need to be addressed.

1. It is always possible to arrange the samples along the y-axis of a dendrogram in such a way that no dendrogram branches cross each other.
2. The resulting order of the samples along the y-axis is not unique. Clarke and Warwick (1994) present a simple analogy to illustrate this. If the dendrogram is envisaged as a child's "mobile" then the horizontal lines are the strings and the vertical lines are the rigid bars. When the whole structure is "suspended" by the top string then the bars can rotate freely, generating many possible re-arrangements of samples on the y-axis. Caution must me excersied when regarding the y-axis sequence as an ordering of samples.
3. Clustering analysis attempts to group samples into discrete clusters and does not display the inter-relationship of samples on a continuous scale; this is the province of ordination (see below).

4. The nature of this clustering procedure is hierarchical and as such once a sample is grouped with others it remains so grouped throughout the process. It follows, that early "borderline" decisions which may be somewhat arbitrary in nature are perpetuated through the analysis and may have a significant effect on the shape of the completed dendrogram.

It is important to realise that even for samples which are strongly grouped, cluster analysis is often best used in conjunction with ordination. The superimposition of the cluster (at various levels of similarity) on an ordination plot will allow any relationships between the groups to be more informatively displayed. Clarke and Warwick (1994) indicate that agreement between the two representations strengthens belief in the adequacy of both methods. In the present study the ordination technique employed is MDS.

Clustering may be misleading if there is a steady gradation in community structure from sample to sample. This is probably more relevant when examining samples temporarily distributed within a heterogeneous lithology, as in this study, rather than when comparing sites of different geographical position, as in modern ecological studies. Again it is important to stress that clustering techniques are useful but their limitations must always be recognised.

6.2.2.2. Ordinations.

Clarke and Warwick (1994) define an ordination as a map of the samples, usually in two or three dimensions, in which the placement of samples, rather than representing their simple geographical location, reflects the similarity of their biological communities. The distances between the samples on the ordination attempt to match the corresponding dissimilarity of their community structure, i.e. close points have very similar communities and sample points which are far apart have either few species in common or the same species but with differing abundances. Clarke and Warwick stress that there is no uniquely defined way in which this can be achieved. As with cluster analysis there are many methods used in the literature.

1. Principle Components Analysis, PCA

2. Principle Co-ordinates Analysis, PCoA
3. Correspondence Analysis and Detrended Correspondence Analysis, DECORANA
4. Multi-Dimensional Scaling, MDS

In this study, Multi-Dimensional Scaling (in particular non-metric MDS) is applied throughout. MDS will be used as the abbreviation and will represent non-metric rather than metric multi-dimensional scaling. Clarke and Warwick (1994) state that MDS is a more recent development, realised by the advent of advanced computational power. Its rationale can be very simply described and understood. The need to make few (if any) assumptions about the data make it the most widely applicable and effective method available.

6.2.2.3. Ordination by Non-Metric Multi-Dimensional Scaling (MDS).

The method of non-metric MDS was introduced by Shepard (1962) and Kruskal (1964). Kruskal and Wish (1978) provide an introductory text although applications are not ecological. Kenkel and Orloci (1986) applied metric and non-metric multi-dimensional scaling to ecological studies.

The starting point of MDS is the similarity matrix, which can be any similarity matrix that is biologically relevant to the questions being asked of the data.

Clarke and Warwick (1994) simply state the purpose of MDS as follows: “it constructs a “map” or configuration of the samples, in a specified number of dimensions, which attempts to satisfy all the conditions imposed by the rank (dis)similarity matrix, e.g. if sample 1 has higher similarity to sample 2 than it does to sample 3 then sample 1 will be placed closer on the map to sample 2 than it is to 3”.

The MDS algorithm is an iterative procedure which is complex and an in-depth discussion is beyond the scope of this study. For a full description see Kruskal (1964) or Clarke and Warwick (1994) for reference to its use with the PRIMER package.

The MDS Algorithm follows the following steps:

1. Specify the number of dimensions for the final ordination plot (*m*)
2. Construct a starting configuration of the *n* samples
3. Regress the interpoint distances from this plot on the corresponding dissimilarities.
4. Measure goodness of fit of the regression by calculating the stress value.
5. Perturb the current configuration in a direction of decreasing stress.
6. Repeat steps 3 to 5 until convergence is achieved.

Convergence to the lowest stress value (global minimum) is desired. However, because of a number of reasons, a local minimum may be reached instead. There is no guaranteed method of ensuring that a global minimum of the stress function has been reached; the practical solution is to repeat the MDS analysis several times starting with different random positions of samples in the initial configuration (step 2 above). Clarke and Warwick (1994) state that if the same (lowest stress) solution re-appears from a number of different starts, then there is a strong (although not guaranteed) assurance that this is the best solution.

A rough rule-of-thumb for 2-dimensional ordinations, using the stress function in step 4 above, is given below (after Clarke and Warwick,1994):

- Stress < 0.05 gives excellent representation with no prospect of misinterpretation.
- Stress < 0.1 corresponds to a good ordination with no real prospect of a misleading interpretation.
- Stress < 0.2 still gives a potentially useful 2-dimensional picture, though for values at the upper end of this range, too much reliance should not be placed on the detail of the plot; a cross check of any conclusions should be made from those of an alternative technique (e.g. the superposition of cluster groups)
- Stress > 0.3 indicates that the points are close to being arbitrarily placed in the 2-dimensional ordination space. Values of stress in the range 0.2 – 0.3 should therefore be treated with a great deal of scepticism.

The strengths of MDS are listed below (after Clarke and Warwick, 1994)

1. MDS is simple in concept.
2. It is based on the relevant sample information. MDS works on the sample dissimilarity matrix, not the original data array, so there is complete freedom of choice to define similarity of community composition in whatever terms are biologically most meaningful.
3. Species deletions are unnecessary. In some ordination techniques it is necessary to delete species, either to obtain realistic low-dimensional ordinations or to make calculations viable.
4. MDS is generally applicable. MDS can be validly applied in a wide variety of situations; fewer assumptions are made about the nature and quality of the data than for (arguably) any other ordination method.
5. Similarities can be given unequal weight. If some samples are inherently less reliable than others then similarities involving these samples can be given less influence.

MDS Weaknesses.

1. MDS is computationally demanding. With the speed of new manufactured CPU's increasing almost monthly, this is now less of a problem than it once was.
2. Convergence to the global minimum of stress is not guaranteed.
3. The algorithm places most weight on the large distances. For MDS, the largest contributions to stress will come from incorrect placement of samples which are very distant from each other.

6.3. Interpretation of borehole data.

All samples in this study were analysed according to the above techniques. The set of samples from each borehole were analysed as a group There are 4 boreholes in this study; these are Hartmoor Hill, Bowden Farm, East Stour and Halletts Farm. Each group of samples are discussed in turn according to the different methods. At this stage no attempt is made to interpret the boreholes with respect to lithological change or to palaeo-environment or palaeo-ecology. The following section is purely a discussion of the results as given by the various statistical methods. In the final section all results will be compared. At this stage interpretation of samples from individual lithologies will be attempted, and any palaeo-ecological or palaeo-environmentalogical interpretations discussed..

Graphs of diversity are presented in the following sections. Each of the various univariate indices indicate trends which in some cases are similar or related. Most major peaks or troughs occur at the same positions for Species Richness, Shannon-Weiner, Evenness and Dominance. Buzas (1979) states that if populations are to be compared in terms of number of species present and distribution of their proportions, no single index will suffice. Buzas mentions that *S*, *H(S)* and *J* or some other counterparts must be all examined to ascertain the nature of differences. It is for this reason that a number of different indices are utilised. To ease interpretation the Shannon-Weiner Information index will be discussed initially, with any other important information provided by the other indices referred to at the appropriate time.

6.3.1. Hartmoor Hill Borehole samples - statistical analysis.

6.3.1.1. Univariate methods.

The diversity indices for the Hartmoor Hill borehole were measured for samples 169 to 225 and the results are plotted in Fig. 6.1, and tabulated in Table 6.1.

An initial examination of the graph for the Shannon-Weiner Information Index reveals a distinct division of the samples into two groups, samples 225 to 209 and samples 203 to 169. These broad groups are divided by a distinct dip in the diversity index troughing at sample 205. The samples prior to sample 209 have a relatively high value when compared to the rest of the borehole values, fluctuating from 2.45 to 2.82. Following the distinct trough the samples from 203 to 169 have a generally lower diversity and fluctuate from around 1.5 to 1.7.

The Simpson Dominance index shows 5 peaks. These peaks indicate samples with a higher relative dominance. The peak at sample 205 has a value of 0.702 which indicates a

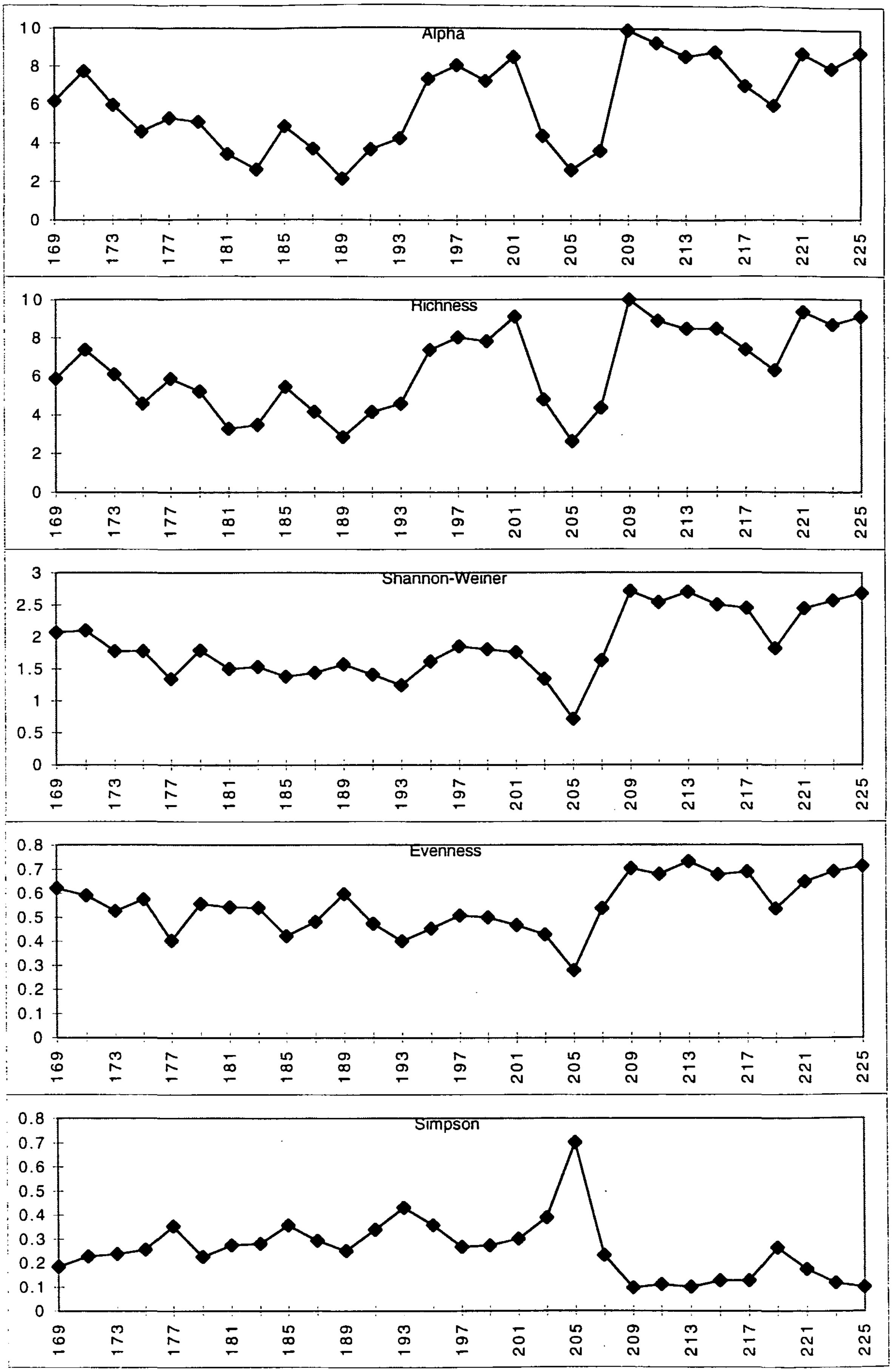


Figure 6.1. Diversity data from the Hartmoor Hill Borehole. (x-axis = sample no.)

particularly high dominance, the corresponding trough on the graph of Species Richness indicates a relatively low number of species compared with the adjacent samples.

It is evident from the various indices that there is a marked change in the nature of the assemblage at around sample 207. Samples 207 – 203 are similar in composition and the remaining samples from 201 – 169 form a separate group distinct from the first group of samples.

Sample Number	Number of Species	Alpha	Richness	Shannon-Weiner	Evenness	Simpson
169	28	6.169	5.86	2.07	0.621	0.183
171	35	7.719	7.38	2.1	0.589	0.227
173	29	5.950	6.08	1.77	0.526	0.236
175	22	4.576	4.56	1.77	0.573	0.255
177	28	5.285	5.86	1.34	0.402	0.352
179	25	5.084	5.21	1.79	0.555	0.225
181	16	3.376	3.26	1.5	0.541	0.273
183	17	2.587	3.47	1.53	0.539	0.279
185	26	4.855	5.43	1.38	0.423	0.355
187	20	3.656	4.13	1.44	0.481	0.291
189	14	2.092	2.82	1.57	0.595	0.248
191	20	3.638	4.13	1.41	0.472	0.337
193	22	4.206	4.56	1.24	0.401	0.429
195	35	7.317	7.38	1.61	0.453	0.356
197	38	8.057	8.03	1.85	0.508	0.265
199	37	7.243	7.82	1.8	0.499	0.27
201	43	8.509	9.12	1.76	0.467	0.3
203	23	4.377	4.78	1.34	0.428	0.388
205	13	2.586	2.61	0.712	0.278	0.702
207	21	3.594	4.34	1.63	0.537	0.231
209	47	9.929	9.99	2.71	0.703	0.0956
211	42	9.266	8.9	2.54	0.679	0.109
213	40	8.551	8.47	2.7	0.732	0.0987
215	40	8.812	8.47	2.5	0.677	0.126
217	35	7.048	7.38	2.45	0.688	0.125
219	30	6.012	6.3	1.82	0.535	0.262
221	44	8.758	9.34	2.45	0.648	0.173
223	41	7.949	8.69	2.57	0.691	0.118
225	43	8.768	9.12	2.68	0.714	0.099

Table 6.1. Diversity data for Hartmoor Hill Borehole.

6.3.1.2. Multivariate Methods.

Hierarchical Agglomerative Clustering.

This method produces some distinctive clusters, and is illustrated on Fig. 6.2. At around the 45 % similarity level, 3 groups are separated and 1 sample (205) stands alone. As previously noted for the univariate results this sample has a very distinctive diversity. Ignoring sample 205, of the other three groups, two are quite distinctive, and remain separate from the other groups for quite a large drop in similarity. The first consists of samples 225- 209, and the

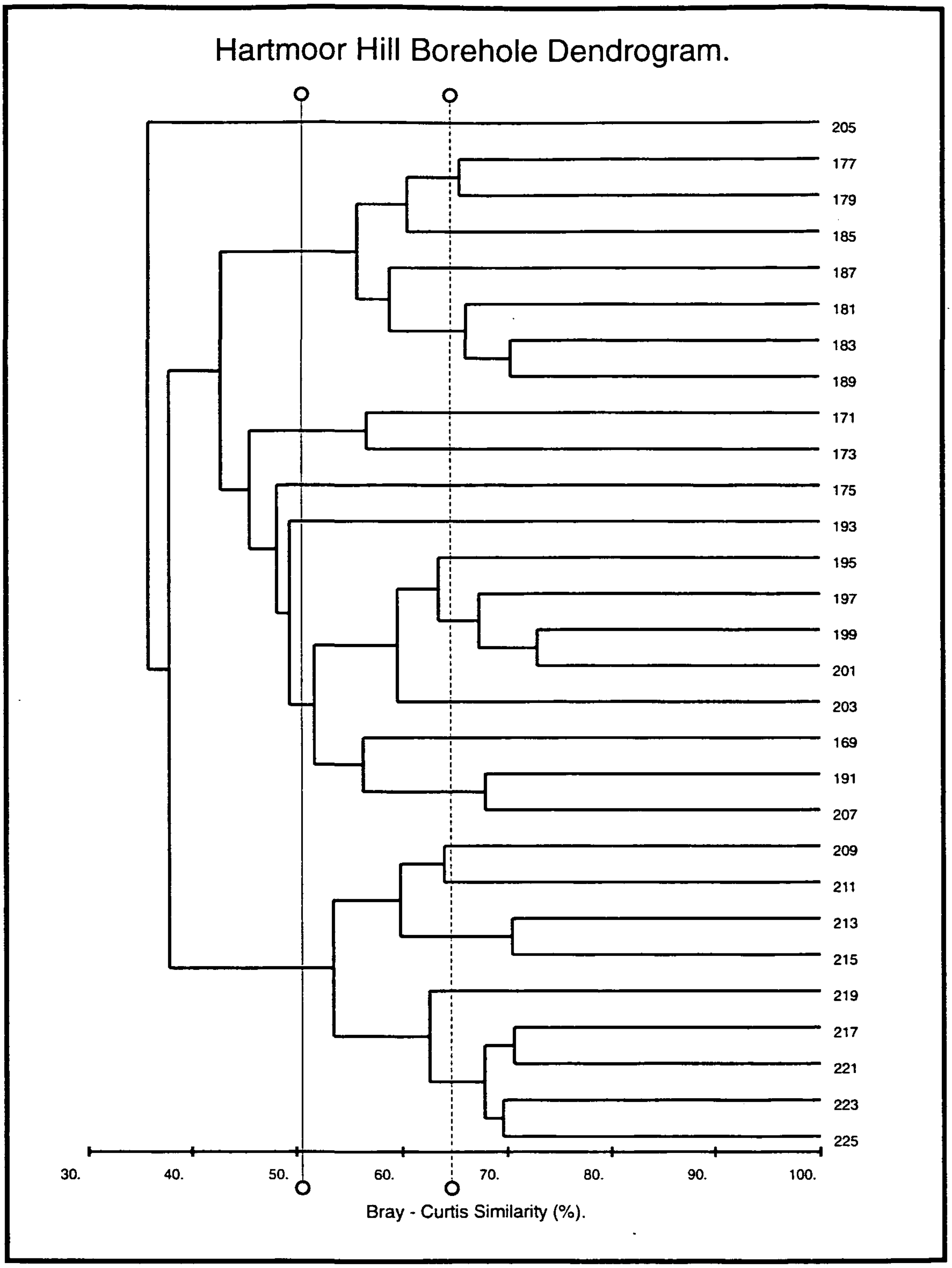


Figure 6.2. Dendrogram for the Hartmoor Hill Borehole, based on Heirarchical Agglomerative Clustering. y-axis - sample numbers, x-axis - similarity co-efficient. Lines of similarity threshold are indicated at around 51% (continuous line) and 65% (dashed).

other consists of samples 177-189. The remaining group is not so distinctive, however at higher degrees of similarity this group can be split into smaller groups of which the one at around 68 % similarity consisting of samples 195 – 203 is the most convincing.

MDS.

The MDS plot for Hartmoor Hill is shown on Fig. 6.3. The stress for the 2-dimensional MDS configuration is moderately high (0.16), which indicates there is some difficulty in displaying the relationships between the samples in two dimensions. However at first inspection it is still possible to discern broad groupings. In Fig. 6.4, the samples have been arranged into "natural groupings", in that samples which are closest together are grouped, and a hierarchical structure is built up. This is done by eye and is obviously subjective, but there appears to be three distinctive broad groups, two pairs of samples and one sample which stands alone. This produces groups consisting of samples: 209 - 225; 195 - 203; 177 - 189. Three pairs of samples: 171, 175; 173, 193 and 191, 207. Sample 205 stands alone well away from the other groups. Sample 169 does not seem to fit particularly well into any group although it lies between a group and a pair.

If the two methods are combined and groups from cluster analysis are superimposed, another grouping will result. If there is a reasonably good consistency between the two methods then one would expect a similar configuration of groups. If two similarity thresholds are arbitrarily chosen at around 51% and 65% from the cluster analysis results and superimposed on the MDS plot, similar groupings are picked out, as illustrated in Fig. 6.5. The difficulty in positioning the sample pair 171 and 173 on the MDS plot seems to be the only inconsistency. The similar clustering of the MDS plots on Figs 6.4 and 6.5 indicate that both the MDS and cluster analysis produce consistent results, and it seems reasonable to assume, given the limitations of both methods, that the groupings are significant.

6.3.2. Bowden Farm Borehole samples - statistical analysis.

6.3.2.1. Univariate methods.

The diversity indices were calculated for samples 72 to 144 from Bowden Farm Borehole.

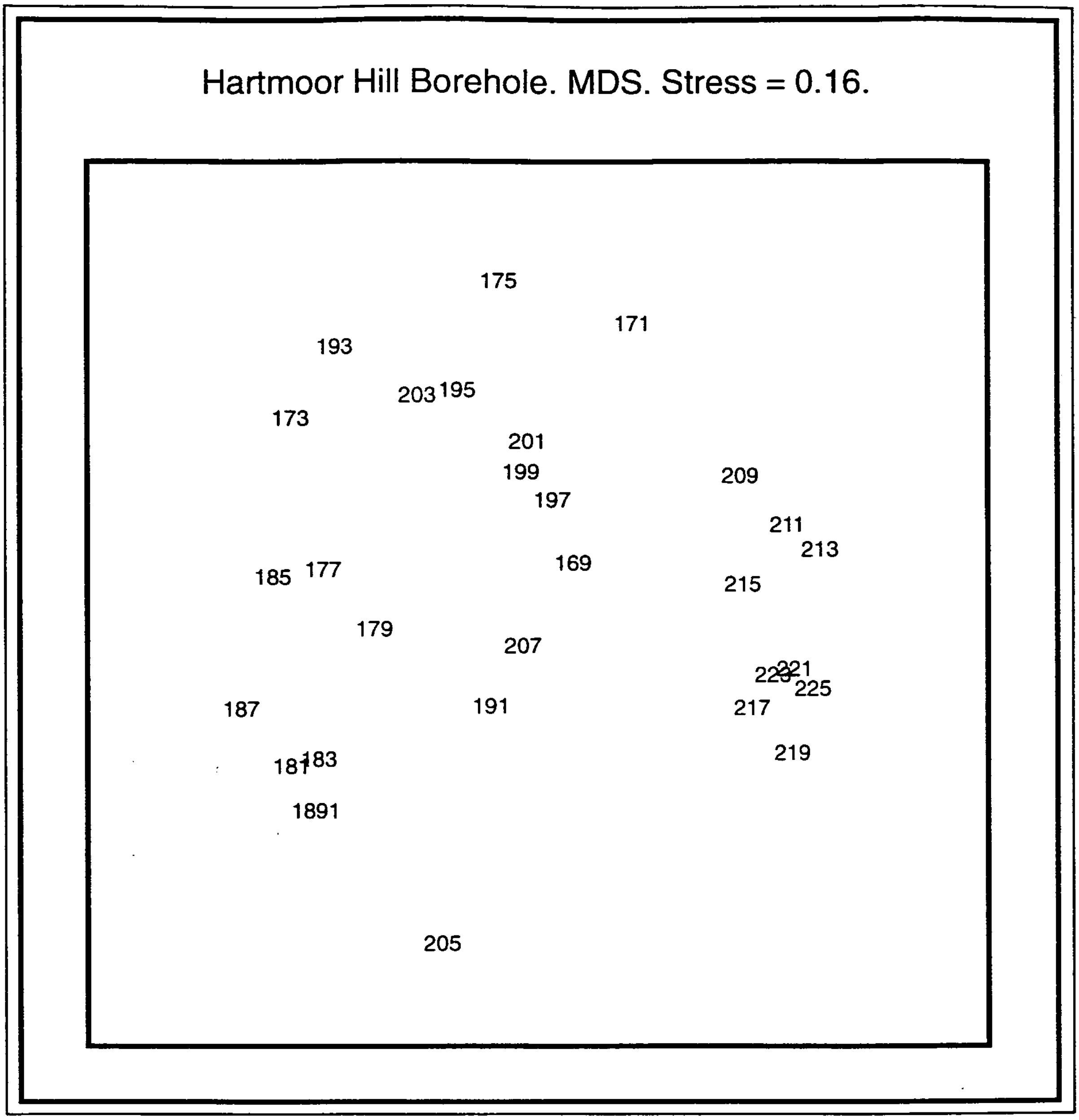


Figure 6.3. MDS plot for the Hartmoor Hill Borehole.

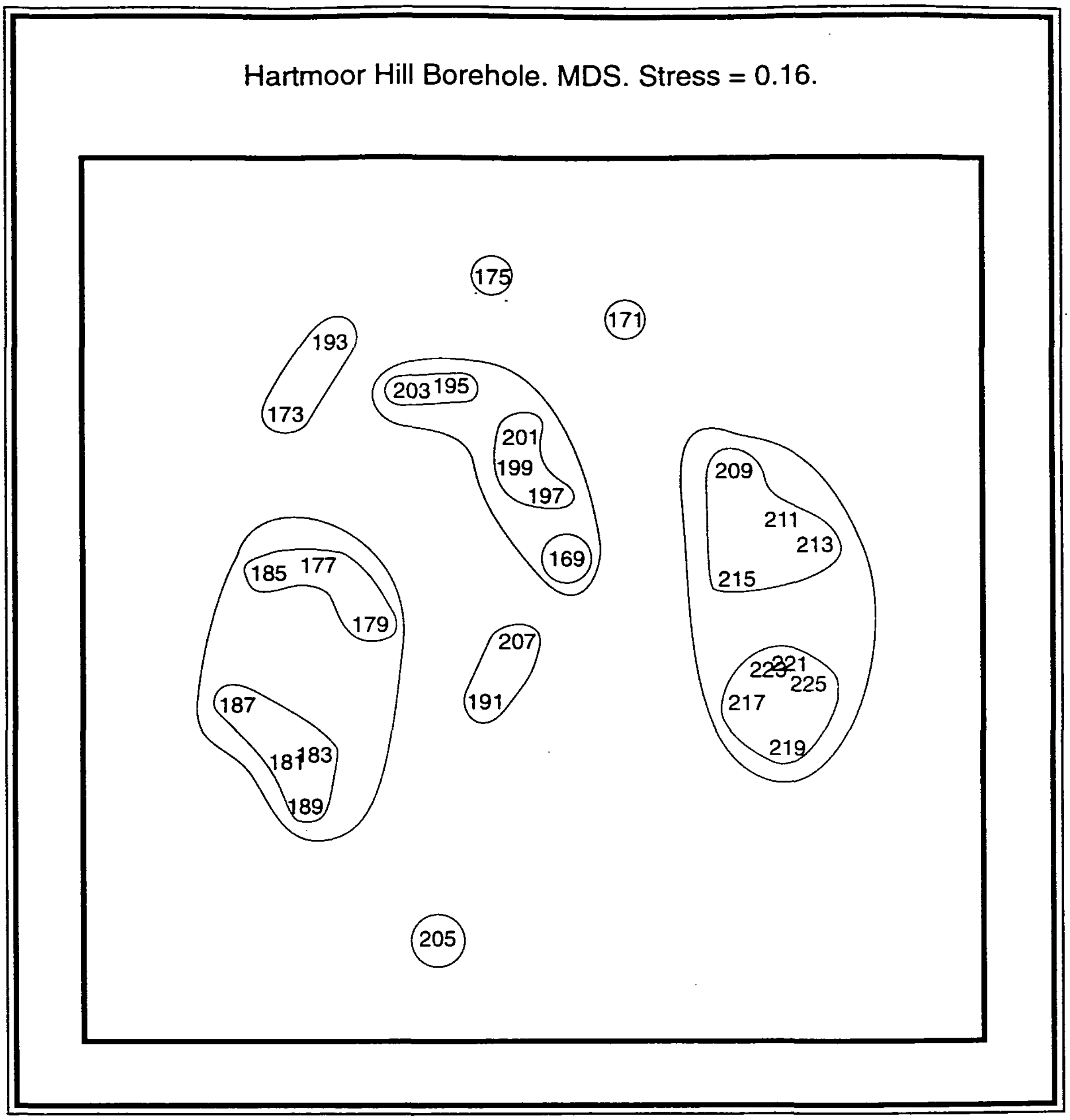


Figure 6.4. MDS plot for the Hartmoor Hill Borehole. Sample groups have been selected by successively combining closest points.

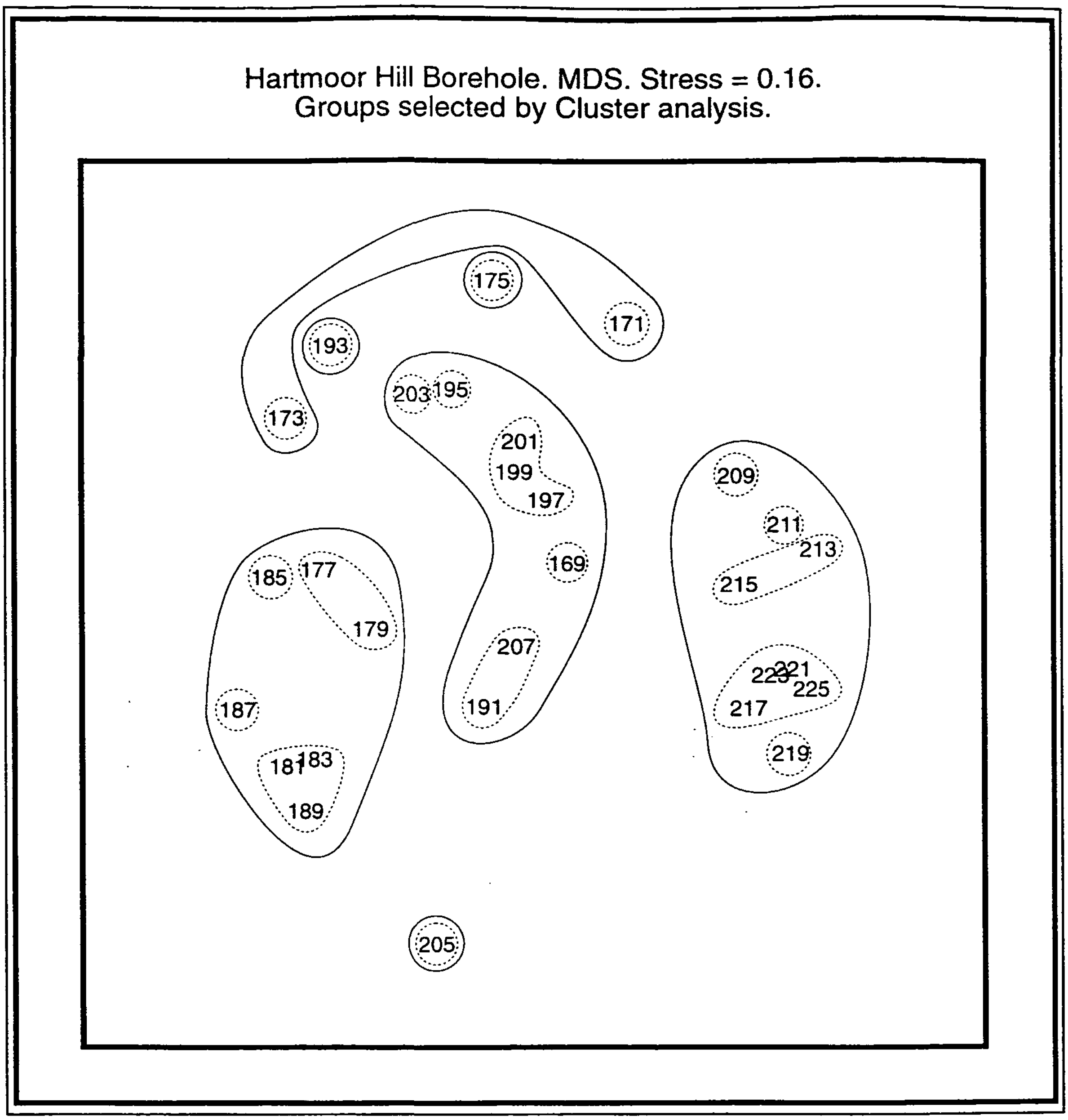


Figure 6.5. MDS plot for the Hartmoor Hill Borehole. Groups selected by the clustering of samples on the dendrogram as indicated by the threshold lines at similarity levels ~50% (solid line) and 65% (dashed), see also Fig. 6.2.

The results are shown in Fig. 6.6 and Table 6.2. The diversity of the species remains fairly constant throughout this borehole and the indices show a uniform pattern. The species number tends to increase from the lowest stratigraphic sample (144) to the middle of the borehole (around sample 104) where the largest number of species are recorded. This is marked by the peak on the Species Richness graph. Apart from sample 112, which has a higher dominance than the adjacent samples, the overall trend is an increase, followed by a sharp decrease in species number to the highest stratigraphical sample (72) where the lowest number of species are recorded (6 in total). The highest dominance is reached at sample 76 whereas the maximum value for *J*, Pielou's Evenness is recorded at sample 72. The only factor of note is the difference of samples 72, 112 and perhaps 104 from their adjacent samples.

Sample Number	Number of Species	Alpha	Richness	Shannon-Weiner	Evenness	Simpson
72	6	0.954	1.09	1.25	0.699	0.331
76	11	2.210	2.17	1	0.418	0.489
80	16	3.413	3.26	1.51	0.544	0.365
84	13	2.911	2.61	1.31	0.51	0.399
88	20	3.490	4.13	1.74	0.581	0.252
92	26	4.558	5.43	1.53	0.471	0.293
96	24	4.526	4.99	1.58	0.496	0.302
104	36	8.001	7.6	2.02	0.564	0.22
108	33	6.811	6.95	2.22	0.635	0.17
112	28	5.638	5.86	1.56	0.47	0.288
116	32	6.893	6.73	2.15	0.621	0.168
120	28	4.859	5.86	2.13	0.639	0.135
124	17	3.530	3.47	1.68	0.594	0.224
128	22	4.277	4.56	1.74	0.562	0.25
132	15	2.427	3.04	1.23	0.455	0.351
136	14	2.451	2.82	1.28	0.485	0.315
140	14	2.463	2.82	1.4	0.531	0.326
144	19	3.521	3.91	1.36	0.461	0.355

Table 6.2. Diversity data for the Bowden Farm Borehole.

6.3.2.2. Multivariate methods.

Hierarchical Agglomerative Clustering.

The dendrogram for Bowden Farm has a number of distinguishing features, and is illustrated on Fig. 6.7. Sample 72 is separated from the other samples into a group of its own. At approximately the 50% similarity level three groups are distinguished, with sample 112 forming a single sample group. Samples 76 – 88 and 124 – 144 form two distinctive clusters; the sample group 92 – 120 is not so well defined. The overall result is to group the

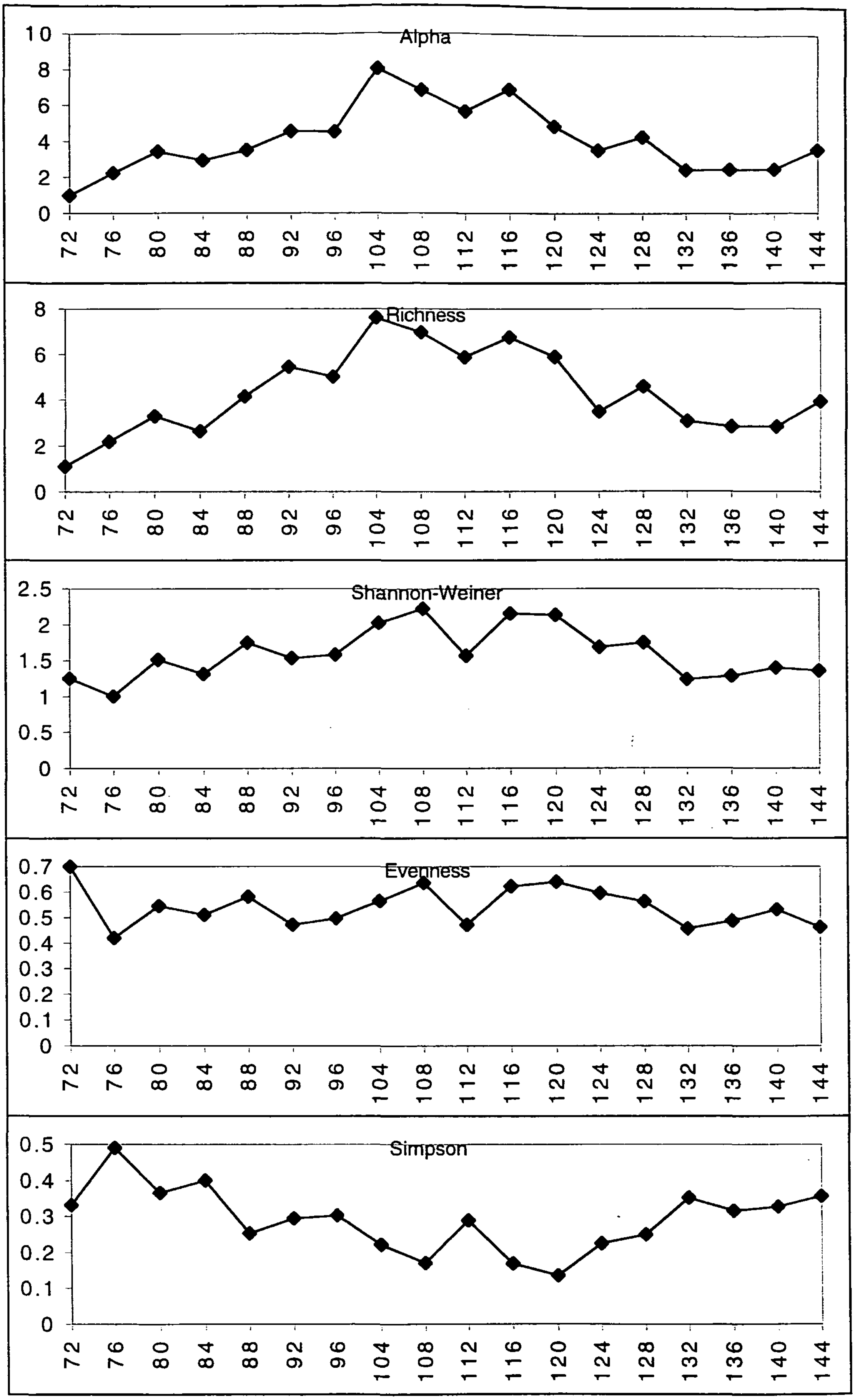


Figure 6.6. Diversity data for the Bowden Farm Borehole.
(x-axis = sample no.)

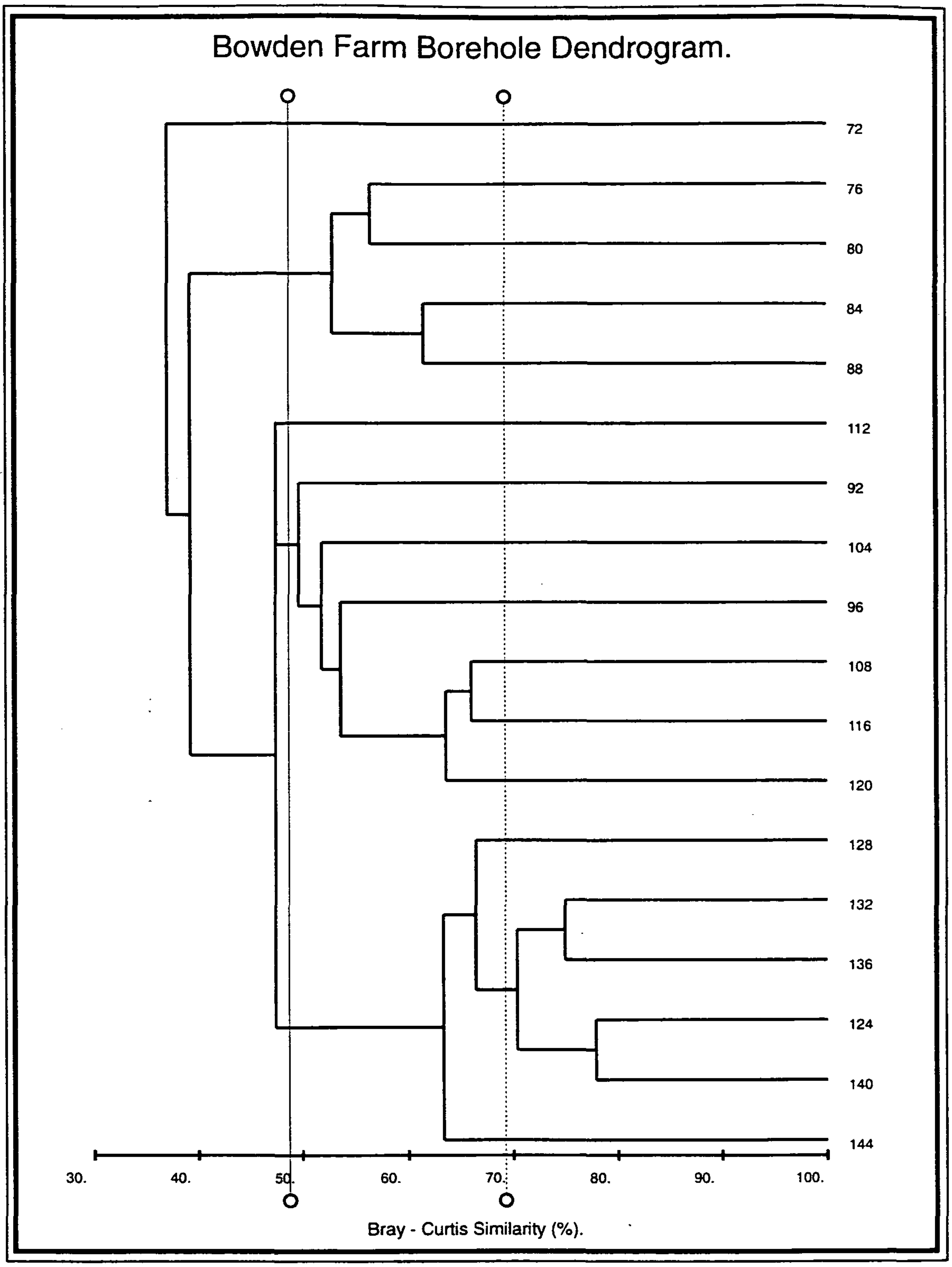


Figure 6.7. Dendrogram for the Bowden Farm Borehole based on Heirarchical Agglomerative Clustering. y-axis - sample numbers, x-axis - similarity co-efficient. Lines of similarity threshold are indicated at around 48% (continuous line) and 68%

samples into three, which effectively divides the borehole into three distinct sections, with sample 72 standing on its own.

MDS.

The stress for the 2-dimensional MDS configuration for the Bowden Farm Boreholes is again moderately high (0.16) which indicates difficulty in displaying the relationships between the samples. The MDS plot is shown in Fig. 6.8. By initially grouping the closest samples a subjective grouping can be built up, this is shown in Fig. 6.9. Three broad groups are distinguished with two samples plotting separately. The groups consist of samples 76 – 92, 96 - 108 + 116 and 120 - 144. Sample 72 plots on its own, as does sample 112, but has a greater affinity to the established groups.

Again, if both clustering and MDS methods are combined with 50% and 60% thresholds for similarity being chosen, the corresponding hierarchy of clusters are defined, as shown on Fig. 6.10. This grouping is consistent with the clustering method; sample 72 is on its own and the three main clusters are distinguished. At the 50% and 60% level of similarity the groupings seem to be natural, although within the group containing samples 76 – 88 the pairing of the samples does appear inconsistent. The combined figure (Fig. 6.10) when compared with the MDS Fig. 6.9 shows a fairly good comparison, the broad groups are roughly similar although the exact grouping of samples are slightly different.

6.3.3. East Stour Borehole samples - statistical analysis..

6.3.3.1. Univariate Methods.

Samples 16 to 54 were analysed from the East Stour Borehole. The plots of the various Diversity indices are shown in Fig.6.11 and Table 6.3. The most striking feature of the plot of the indices is the sharp increase in dominance for sample 16 (and conversely the decrease in Evenness, as would be expected). This is also shown on the Shannon-Weiner plot. The Species Richness indicates a general decrease in species numbers towards the top of the borehole (sample 16) and the samples can roughly be divided into three sections.

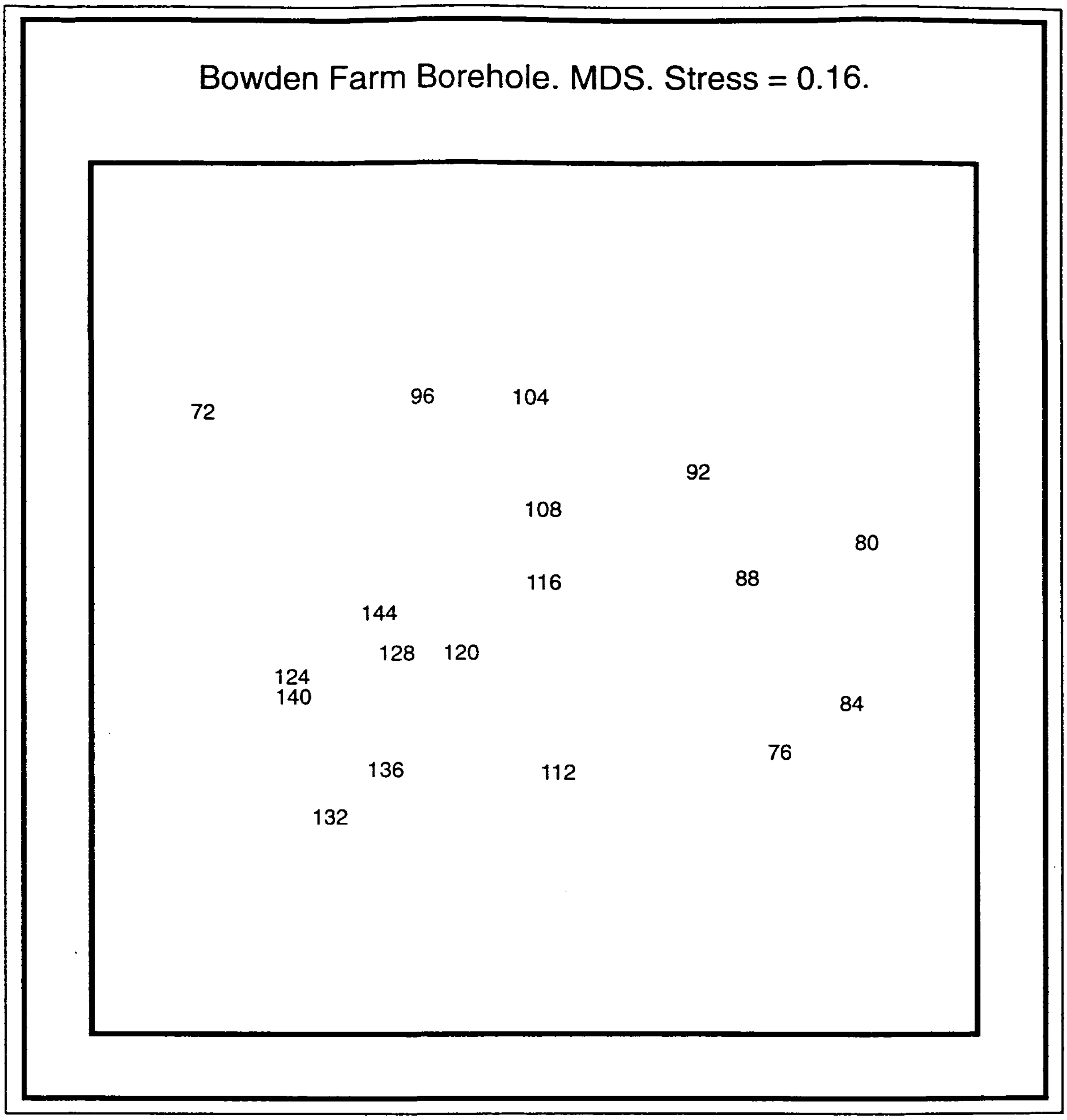


Figure 6.8. MDS plot for the Bowden Farm Borehole.

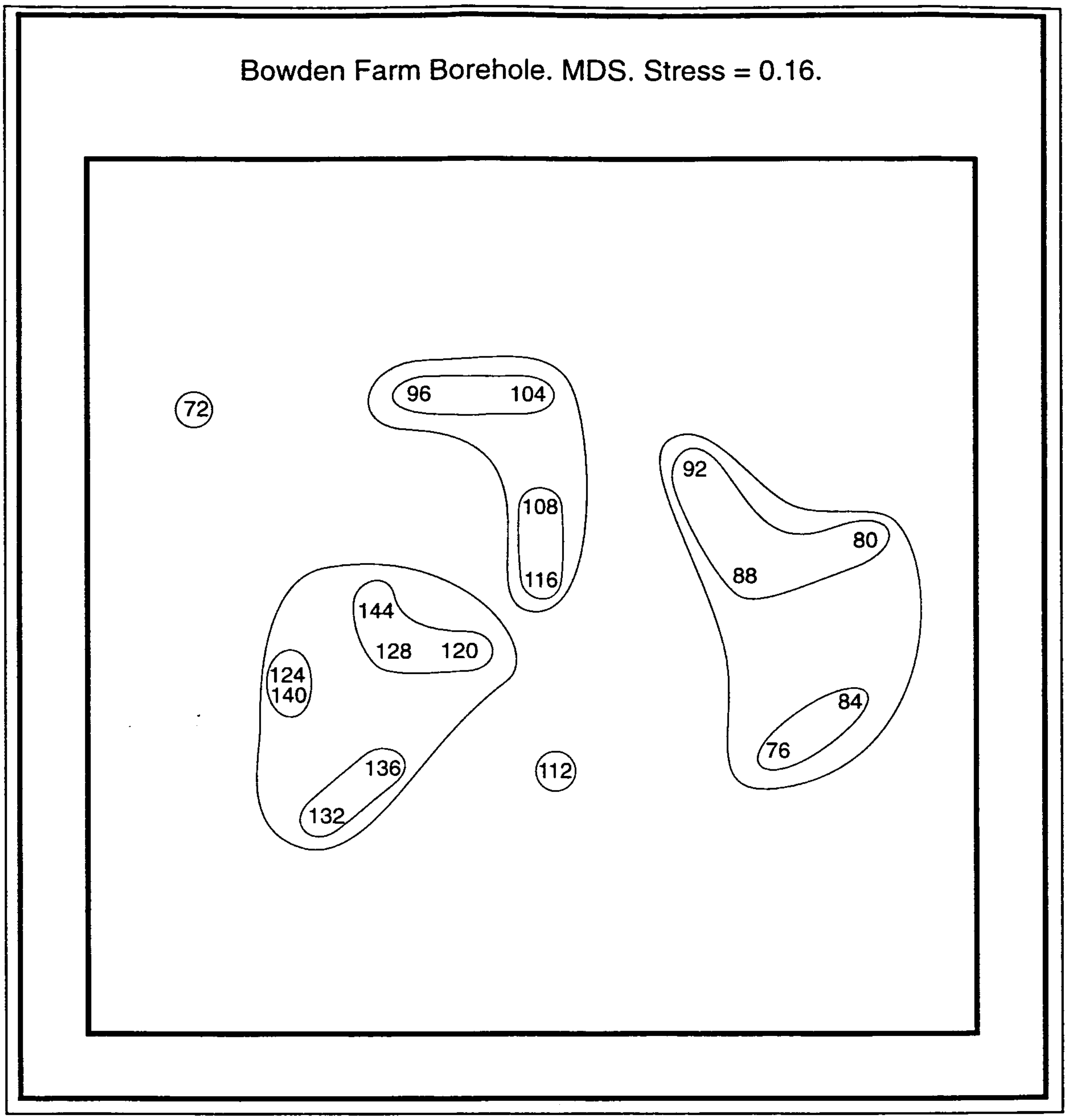


Figure 6.9. MDS plot for the Bowden Farm Borehole. Groups have been selected by successively combining closest samples and groups of samples.

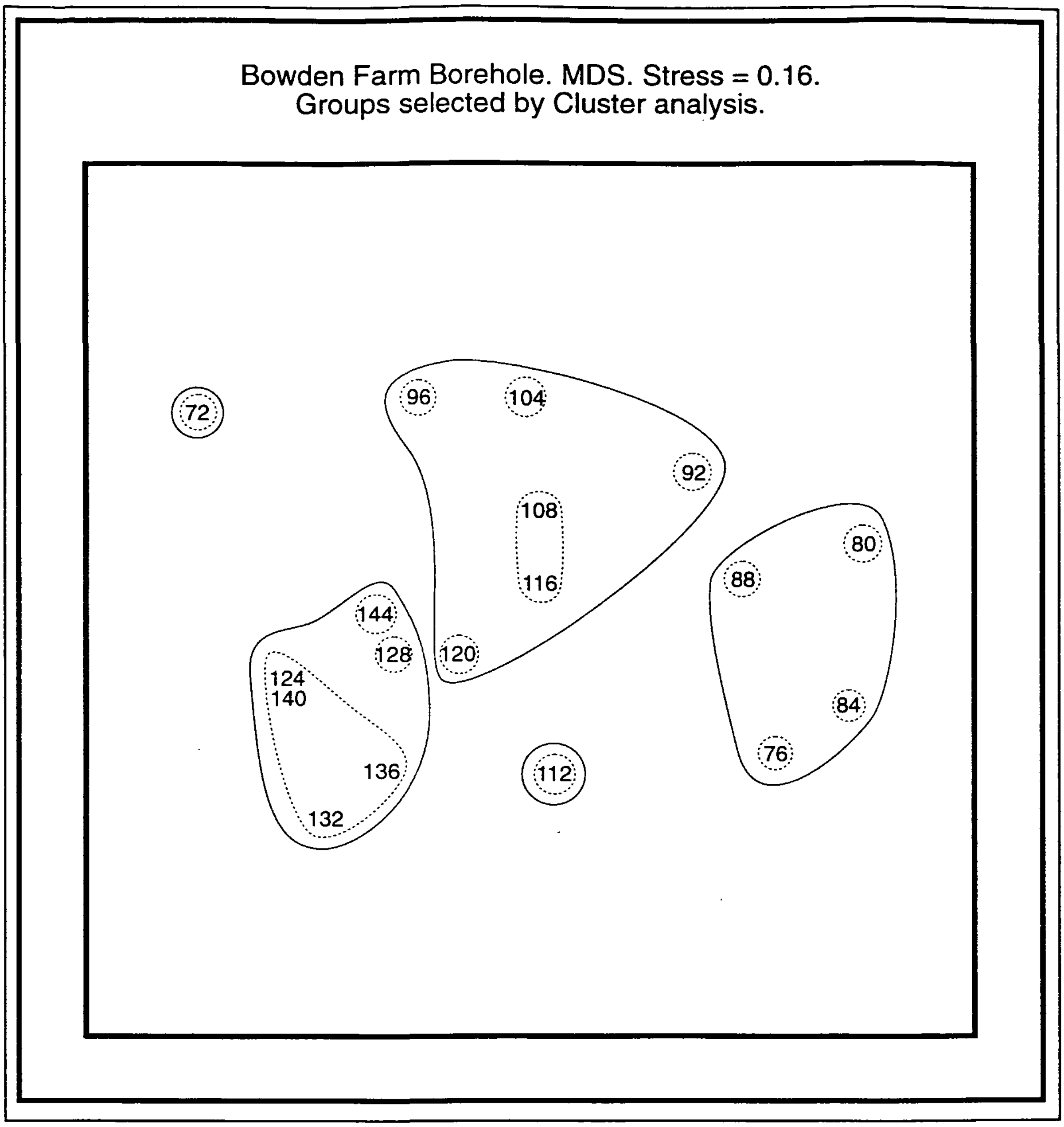


Figure 6.10. MDS plot for the Bowden Farm Borehole. Groups selected by the clustering of samples on the dendrogram as indicated by the threshold lines at similarity levels 50% (solid line) and 70% (dashed), see Fig. 6.7.

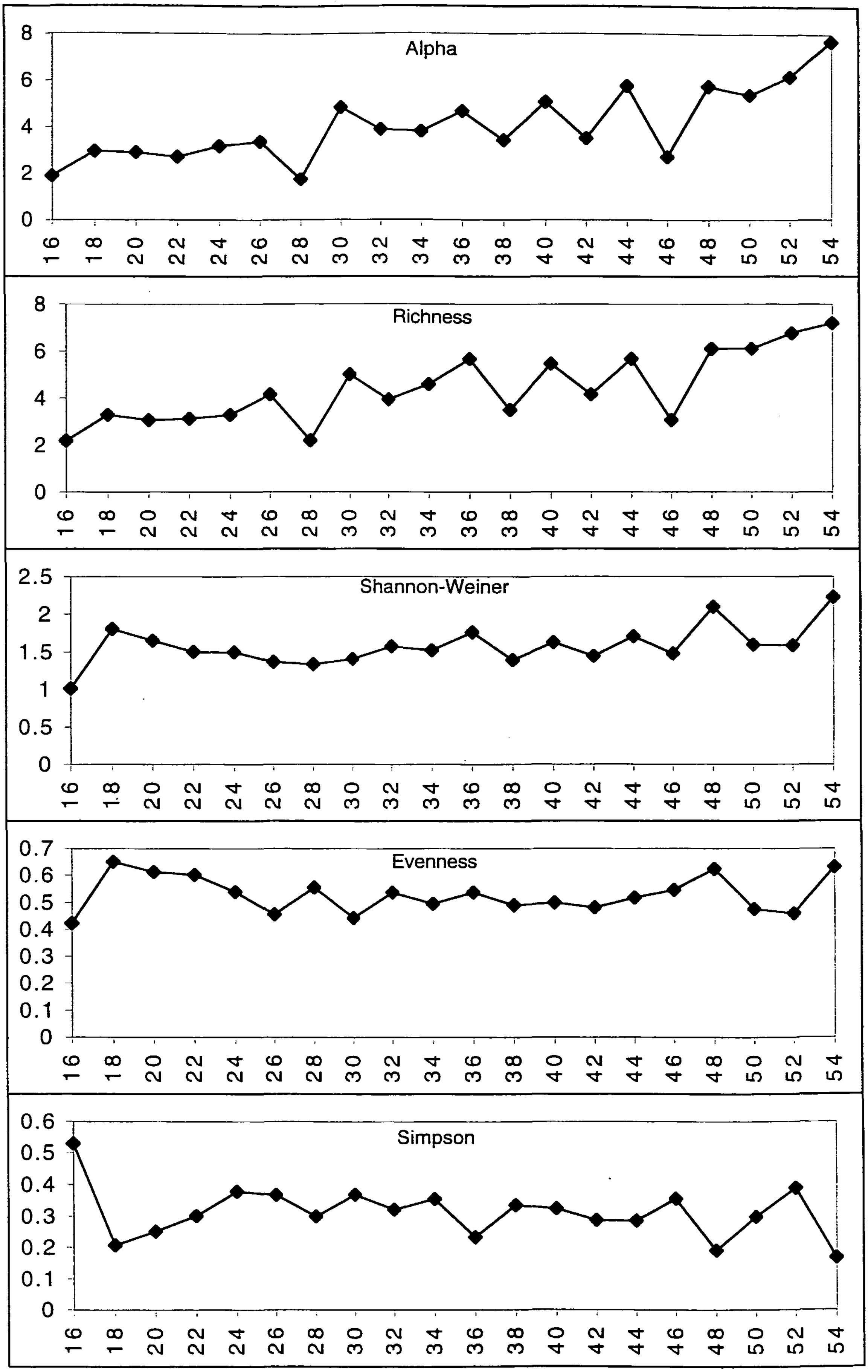


Figure 6.11. Diversity data for the East Stour Borehole.
(x-axis = sample no.).

Sample Number	Number of Species	Alpha	Richness	Shannon-Weiner	Evenness	Simpson
16	11	1.884	2.17	1.01	0.422	0.528
18	16	2.931	3.26	1.8	0.65	0.206
20	15	2.892	3.04	1.65	0.611	0.25
22	0	-	-	-	-	-
24	16	3.162	3.26	1.49	0.538	0.376
26	20	3.352	4.13	1.36	0.454	0.366
28	11	1.741	2.17	1.33	0.554	0.297
30	24	4.809	4.99	1.4	0.441	0.368
32	19	3.864	3.91	1.57	0.535	0.32
34	22	3.779	4.56	1.52	0.493	0.353
36	27	4.655	5.65	1.76	0.536	0.231
38	17	3.418	3.47	1.39	0.489	0.334
40	26	5.045	5.43	1.62	0.497	0.322
42	20	3.484	4.13	1.44	0.48	0.285
44	27	5.750	5.65	1.7	0.516	0.284
46	15	2.711	3.04	1.47	0.544	0.353
48	29	5.738	6.08	2.09	0.622	0.189
50	29	5.382	6.08	1.59	0.473	0.296
52	32	6.161	6.73	1.58	0.457	0.388
54	34	7.677	7.17	2.22	0.629	0.166

Table 6.3. Diversity data for the East Stour Borehole.

Samples 54 – 48 have a high richness, samples 46 – 28 have a fluctuating value for Species Richness, but show a trend which is slightly lower than the previous section, and samples 26 – 16 which all have a have a similar low value. The values of the other indices, although varying to different degrees indicate similar divisions. Sample 36 however, indicates a deviation from the adjacent sample values. In the Shannon-Weiner plot the graph "smoothes out" after sample 36, and there is a trough for this sample in the Simpson Dominance plot.

6.3.3.2. Multivariate Methods.

Hierarchical Agglomerative Clustering.

The dendrogram for the East Stour Borehole does not produce particularly distinctive groups (Fig. 6.12). At the 30% similarity level the samples are divided into two clusters, consisting of samples 16-28 and 30 to 54. At the 40% similarity level sample 30 stands alone and the two initial groups can be divided into two and three respectively. In general there is a low percentage of similarity between the samples.

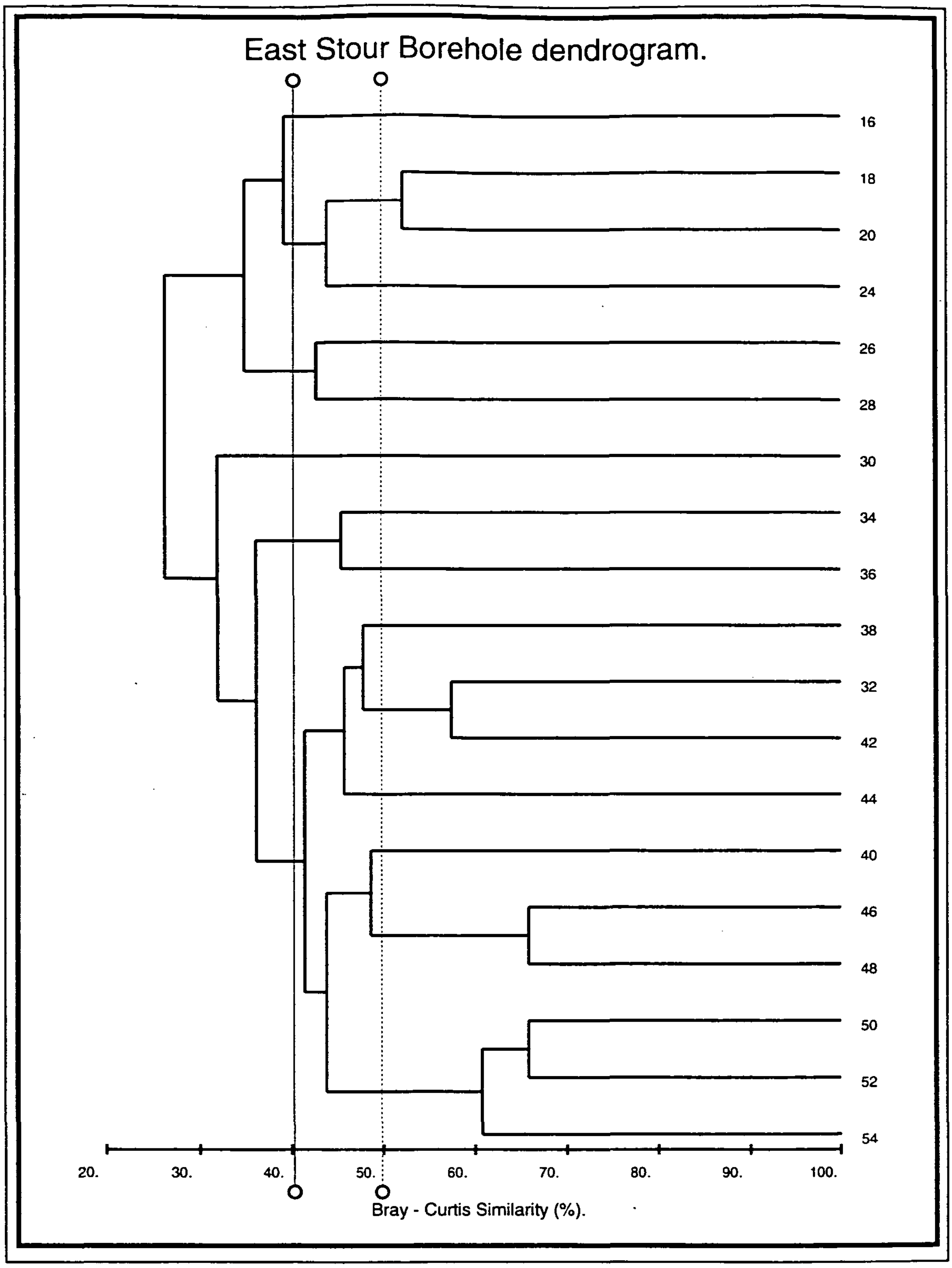


Figure 6.12. Dendrogram for the East Stour Borehole based on Heirarchical Agglomerative Clustering. y-axis - sample numbers (only the last two digits shown, first three digits are 304, i.e. sample 26 = 30426), x-axis - similarity co-efficient. Lines of similarity threshold are indicated at 40% (continuous line) and 50% (dashed)

MDS.

The MDS plot for the East Stour Borehole has the highest value of stress for the 2-dimensional configuration out of the four boreholes (0.18), although broad groupings can still be distinguished (Fig. 6.13). Although possessing a moderately high stress value, according to Clarke and Warwick (1994), 0.18 still gives a potentially useful 2-dimensional picture. In this situation it is probably essential to cross – reference this method with the Clustering analysis before any interpretations are carried out.

The initial interpretation of the MDS plot produces the groups shown in Fig. 6.14. One large group is distinguished, one smaller group, one a pair of samples and three samples which do not seem to fit with the other groups. The groups consist of samples 16 – 24 and 36 - 54. Samples 28 and 32 are paired and 30, 34 and 26 plot separately from any other sample.

Combining the clustering with the MDS methods with arbitrarily chosen similarity thresholds of 40 and 50% produces groupings, which, although not totally random in their appearance, do not appear particularly natural as illustrated on Fig. 6.15. This becomes more evident when other values of similarity are superimposed on the ordination, e.g. 48%, and in the case of sample 44 being grouped with 32, 38 and 42, at around 45 % similarity.

When the initial interpretation (Fig. 6.14) and the combined plot (Fig. 6.15) are compared it would appear that the initial interpretation is the more natural.

The results for this borehole are not particularly conclusive. The high value of stress for the MDS indicate that the results should not be heavily relied apon, and should be compared with another method, i.e. Cluster Analysis. Neither method may show the full picture, but as Clarke and Warwick (1994) state, both methods should be used and viewed in combination with each other. This may make it clear which points on the MDS are problematic to position and an ordination in a higher dimension may prove consistent with the cluster groupings. Or conversely, the MDS plots may make it clear that some groups in the cluster analysis are fairly arbitrary subdivisions of a natural continuum. Although neither interpretation of the

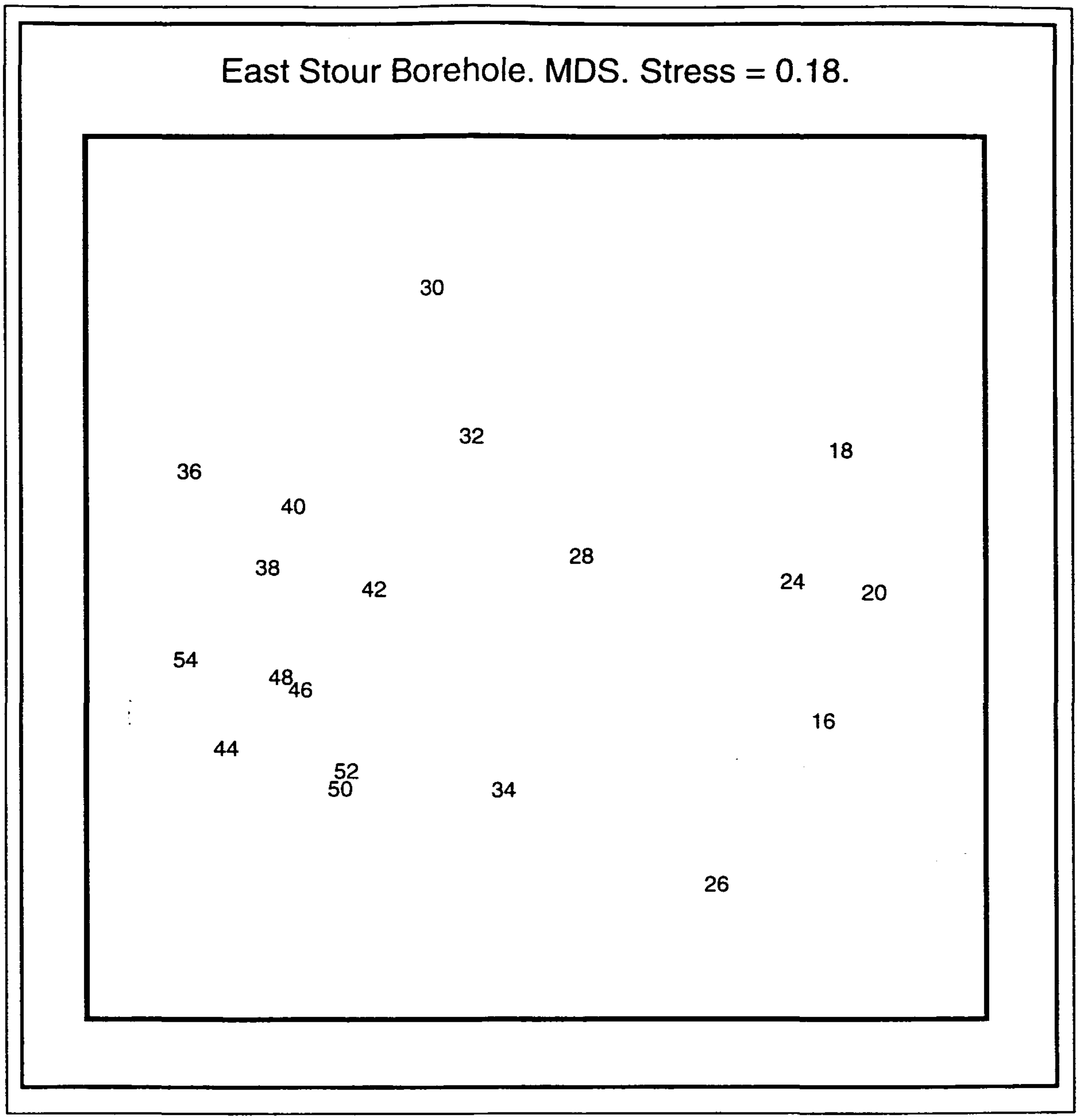


Figure 6.13. MDS plot for the East Stour Borehole. (Only the last two digits of the sample numbers are shown, the first three digits are 304. i.e. sample 26 = 30426)

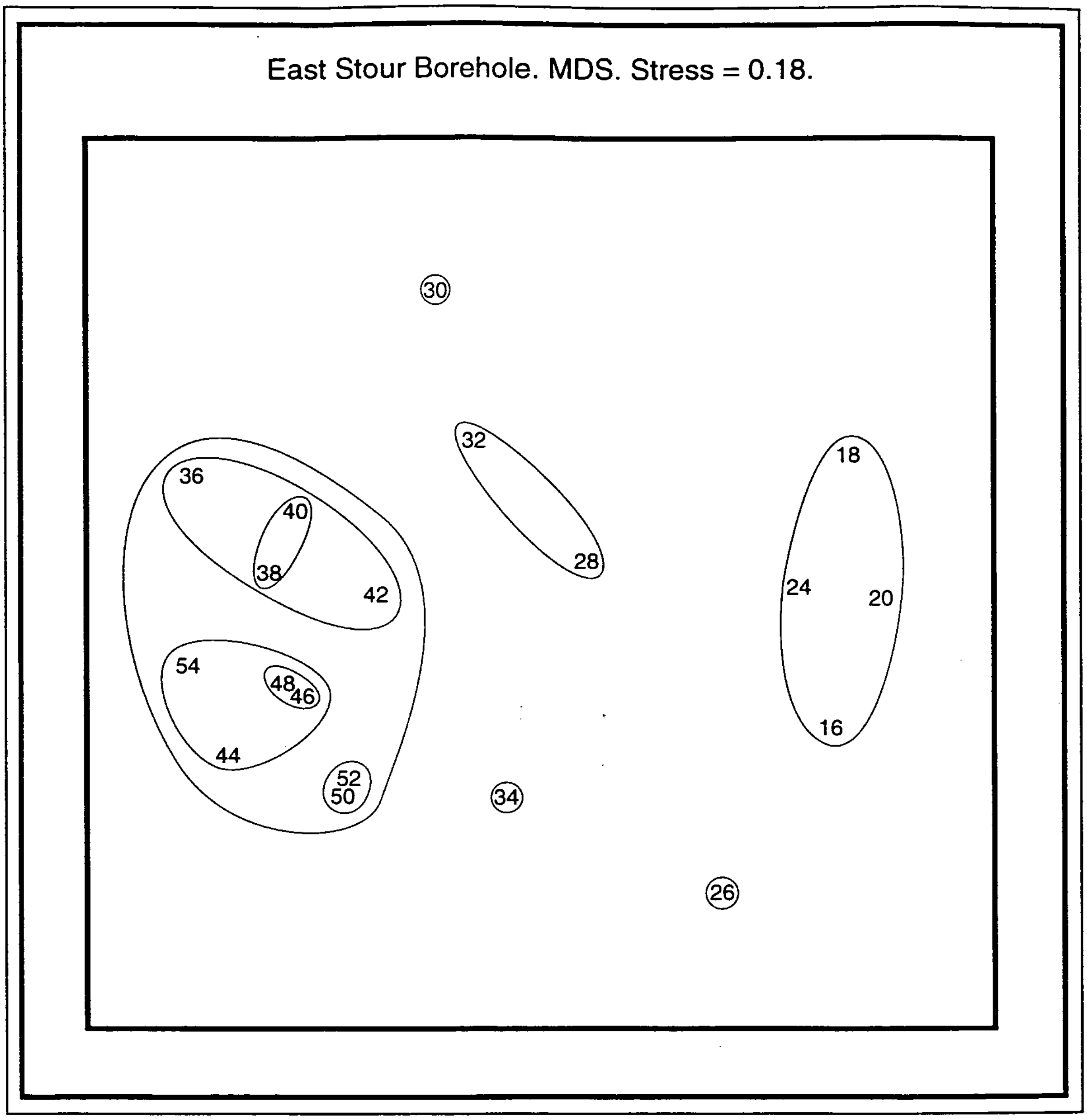


Figure 6.14. MDS plot for the East Stour Borehole. (Only the last two digits of the sample numbers are shown, the first three digits are 304. i.e. sample 26 = 30426). Groups have been selected by successively combining closest samples and their subsequent groups.

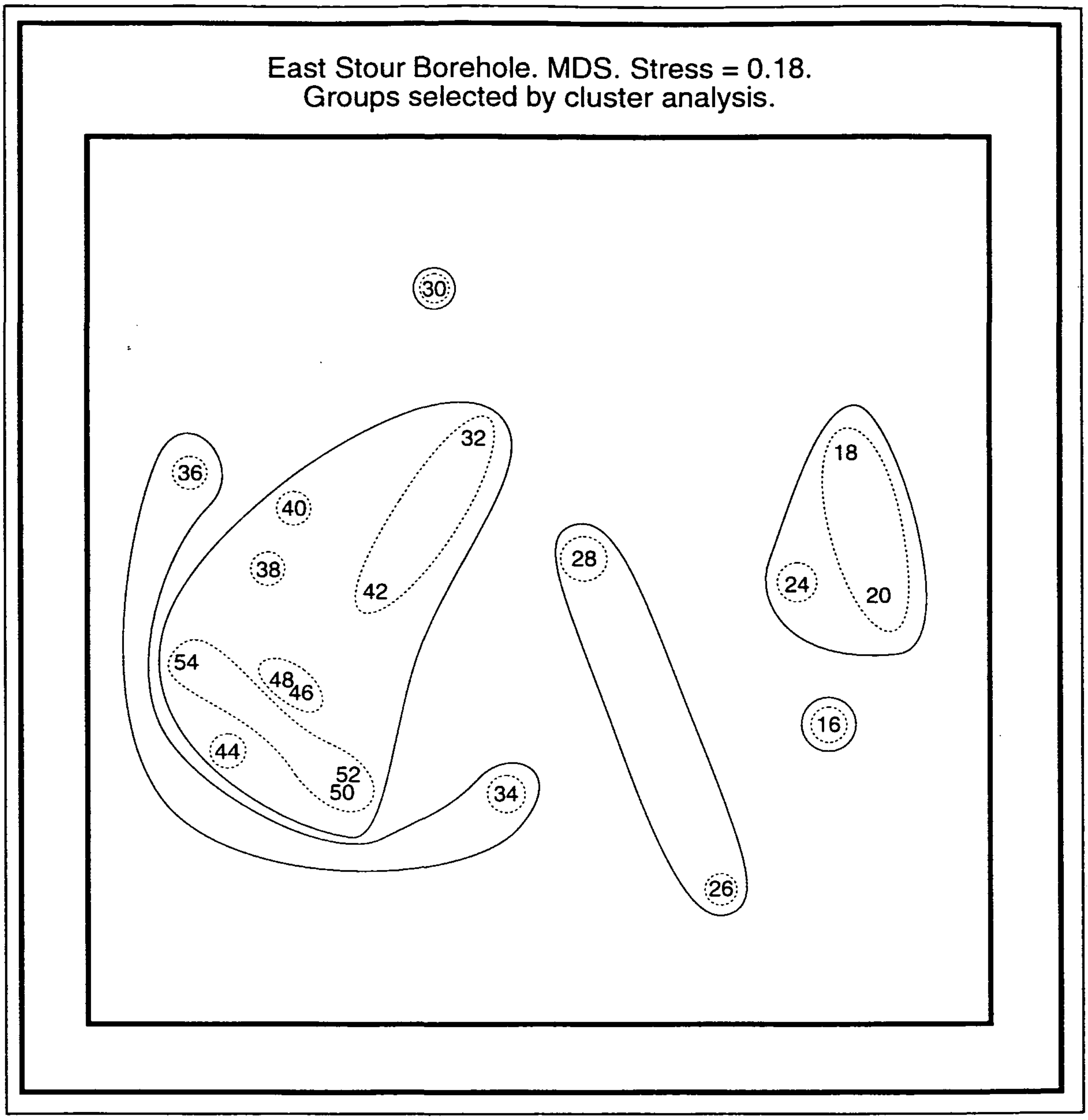


Figure 6.15. MDS plot for the East Stour Borehole. (Only the last two digits of the sample numbers are shown, the first three digits are 304. i.e. sample 26 = 30426). Groups selected by cluster analysis, and the threshold lines of similarity at 40% (solid line) and 50% (dashed).

MDS are particularly conclusive, the results indicate that the clustering analysis may be somewhat arbitrary.

6.3.4. Hallett's Farm Borehole samples - statistical analysis.

6.3.4.1. Univariate methods.

Samples 10 to 58 were analysed form the Hallett's Farm Borehole. The values for the various diversity indices are presented in Fig. 6.16 and Table 6.4. The results for the various diversity indices include a number of interesting features. The Shannon-Weiner values indicate a steady increasing value for the samples 58 to 46. Sample 44 has a distinctive trough, as does sample 38. From sample 36 there is a slow reduction in the value until sample 30. The samples following this, show an overall reduction in the Shannon-Weiner value, but exhibit an erratic trend until sample 20, which reaches a sharp minimum. Sample 18 has a very high value.

Sample 16 again has a low value, which then increases gradually to sample 12 before falling slightly at sample 10. Sample 20 has a very high Dominance and a corresponding low number of species and Species Richness. There are peaks on the Species Richness graph at sample 28, 36, 44 and 52 with associated troughs in between. Although there is a peak in Species Richness at sample 52 which records the largest number of species, there is no difference from adjacent samples in any of the other indices.

6.3.4.2. Multivariate methods.

Hierarchical Agglomerative Clustering.

The Hallett's Farm dendrogram produces some easily distinguishable groups (Fig. 6.17). At around the 50% similarity level the clustering can select 3 main groups, two sets of paired samples and two samples which stand alone. The three main groups consist of samples 58 – 46, 36 – 22 and 18 –10, the stand alone samples are 44, and sample 20, which is completely separated from the rest of the groups. The paired samples are 40 & 41 and 16 & 38. The dendrogram has a more ordered appearance to the previous borehole dendrograms.

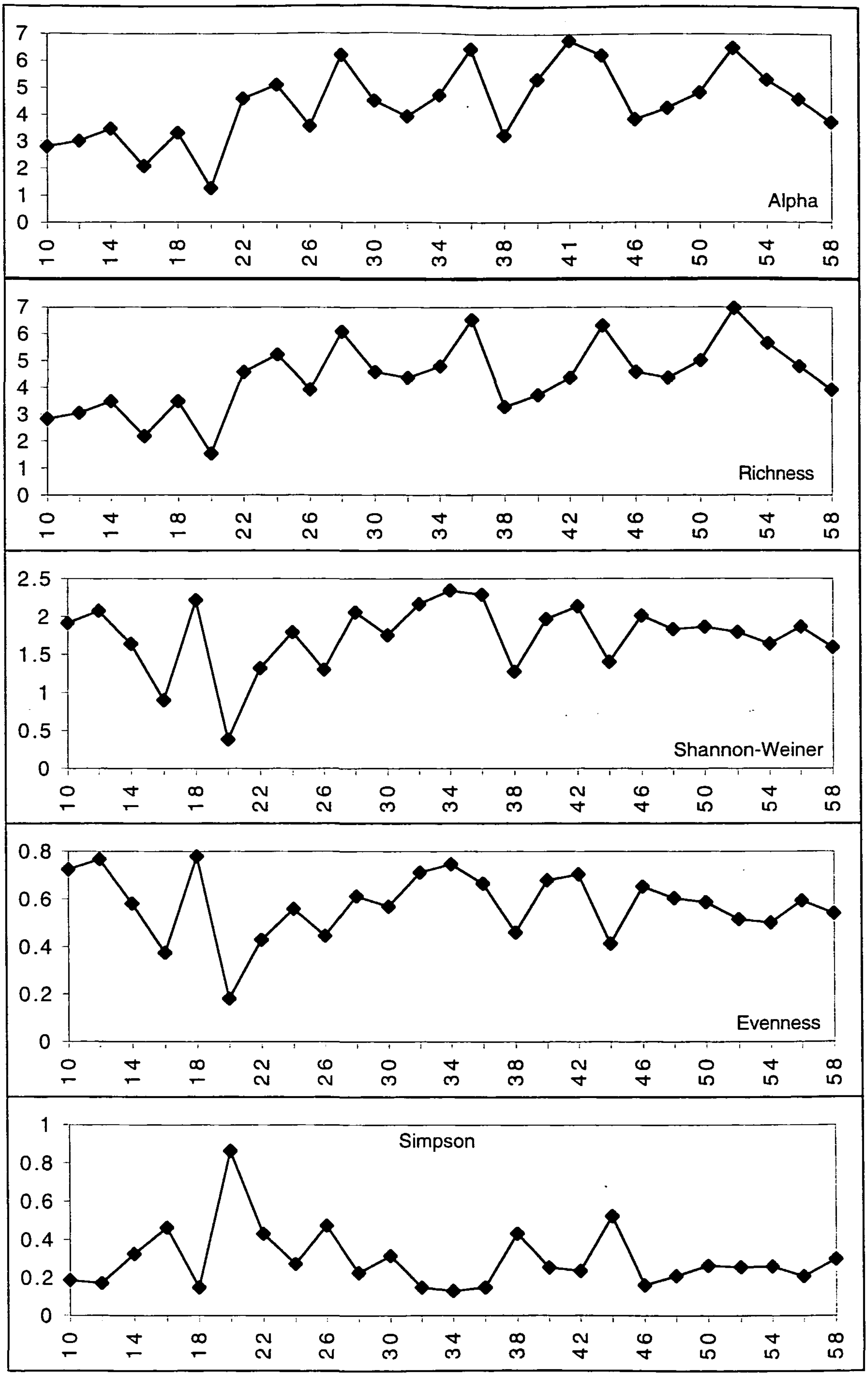


Figure 6.16. Diversity data for the Hallett's Farm Borehole. (x-axis = sample numbers).

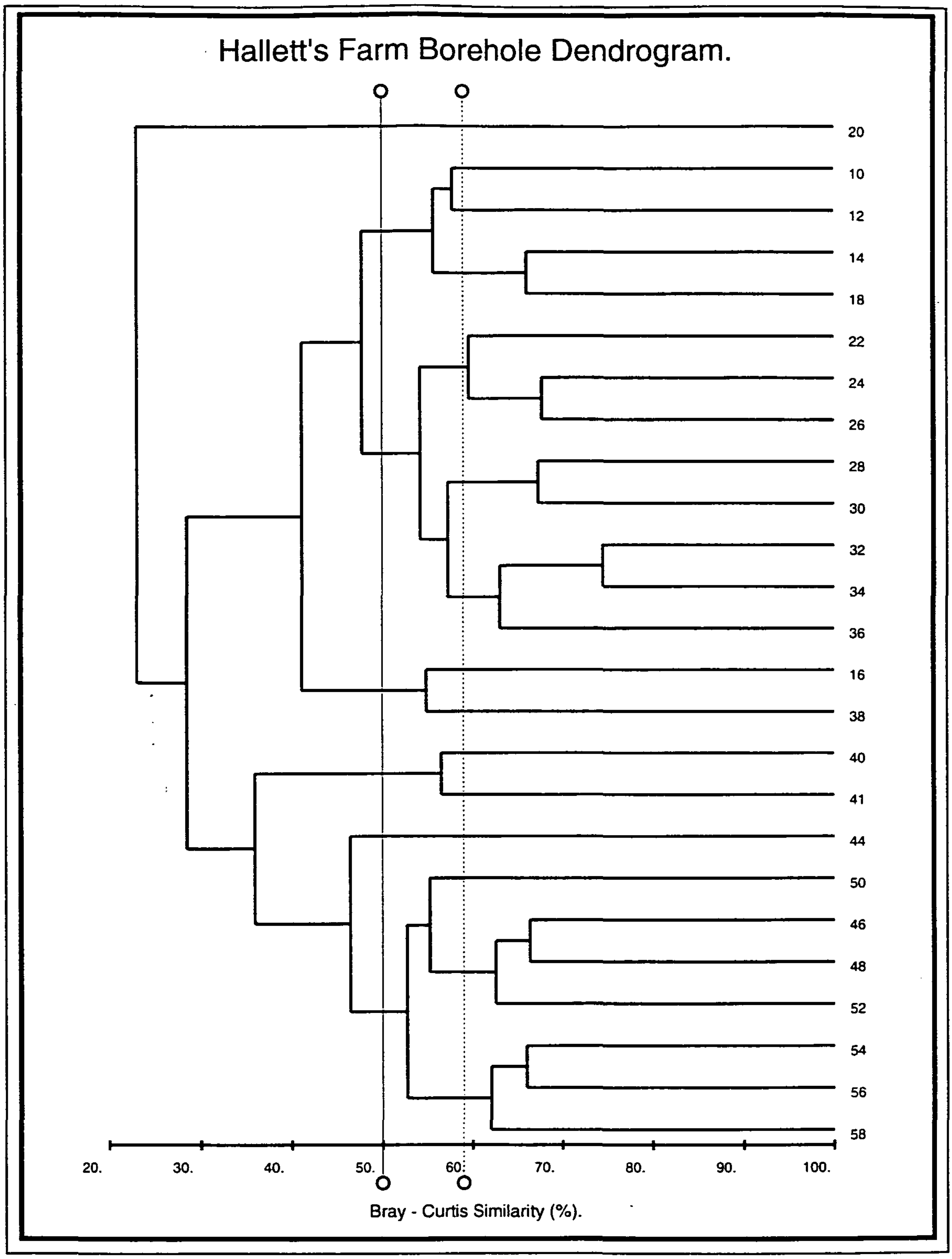


Figure 6.17. Dendrogram for the Hallett's Farm Borehole based on Heirarchical Agglomerative Clustering. y-axis - sample numbers, x-axis - smilarity co-efficient. Lines of similarity threshold are indicated at 50% (continuous line) and ~60%

Sample Number	Number of Species	Alpha	Richness	Shannon-Weiner	Evenness	Simpson
10	14	2.798	2.82	1.91	0.723	0.184
12	15	3.015	3.04	2.07	0.765	0.168
14	17	3.460	3.47	1.64	0.58	0.322
16	11	2.056	2.17	0.893	0.372	0.461
18	17	3.291	3.47	2.21	0.778	0.145
20	8	1.228	1.52	0.375	0.18	0.861
22	22	4.557	4.56	1.32	0.428	0.428
24	25	5.070	5.21	1.79	0.557	0.269
26	19	3.537	3.91	1.3	0.443	0.471
28	29	6.185	6.08	2.05	0.609	0.223
30	22	4.483	4.56	1.75	0.567	0.312
32	21	3.899	4.34	2.16	0.71	0.147
34	23	4.688	4.78	2.34	0.745	0.128
36	31	6.435	6.51	2.28	0.663	0.145
38	16	3.223	3.26	1.27	0.458	0.429
40	18	5.303	3.69	1.96	0.677	0.25
41	21	6.757	4.34	2.13	0.701	0.234
44	30	6.194	6.3	1.4	0.412	0.521
46	22	3.811	4.56	2.01	0.65	0.159
48	21	4.231	4.34	1.83	0.601	0.208
50	24	4.806	4.99	1.86	0.586	0.261
52	33	6.462	6.95	1.79	0.513	0.253
54	27	5.273	5.65	1.64	0.499	0.257
56	23	4.539	4.78	1.86	0.592	0.205
58	19	3.707	3.91	1.59	0.539	0.295

Table 6.4. Diversity data for the Hallett's Farm Borehole.

MDS.

The stress for the 2-dimensional MDS configuration for the Hallett's Farm borehole samples is 0.14 which is the lowest of the samples analysed. This value is closer to what Clarke and Warwick (1994) describe as "a good ordination with no real prospect of a misleading interpretation"; see above. The MDS plot for Hallett's Farm is shown on Fig. 6.18. The initial interpretation produces some well defined groupings (Fig. 6.19). Two distinctive groups, 3 pairs and one single sample are recognised. The groups consist of samples 14, 18, 22 - 36 for the first group; 44- 58 for the second group; pairs 10 and 12, 16 and 38, and 40 and 41, sample 20 plots separate from the other groups, at distance

Combining both the cluster analysis and MDS methods and choosing arbitrary similarity levels of 50% and 60% produce groups of samples shown on Fig. 6.20. The superimposed cluster groupings appear natural, and agree with the groupings on the MDS plot. This indicates that both methods are adequately representing the division of the assemblage. The

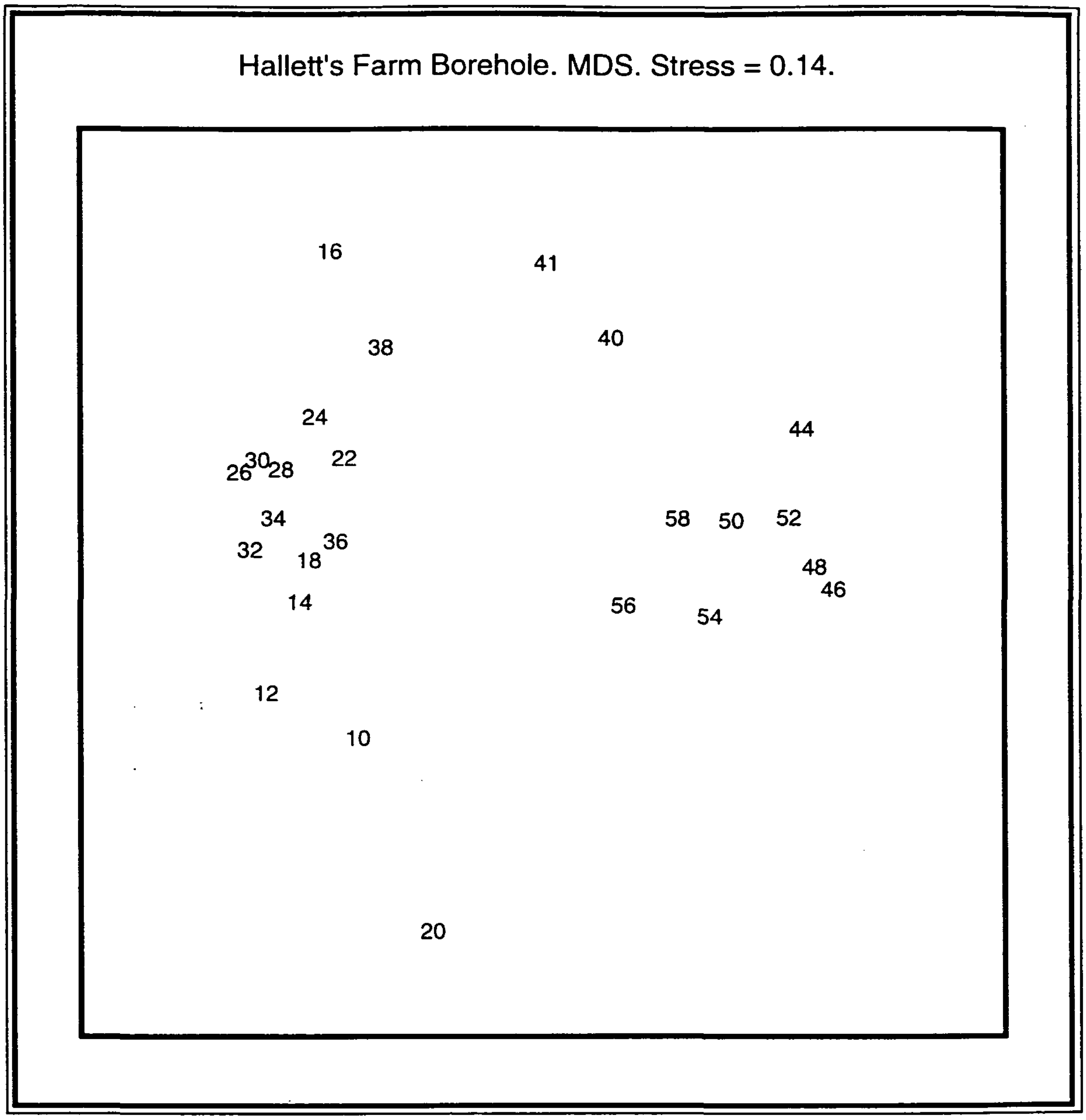


Figure 6.18. MDS plot for Hallett's Farm Borehole.

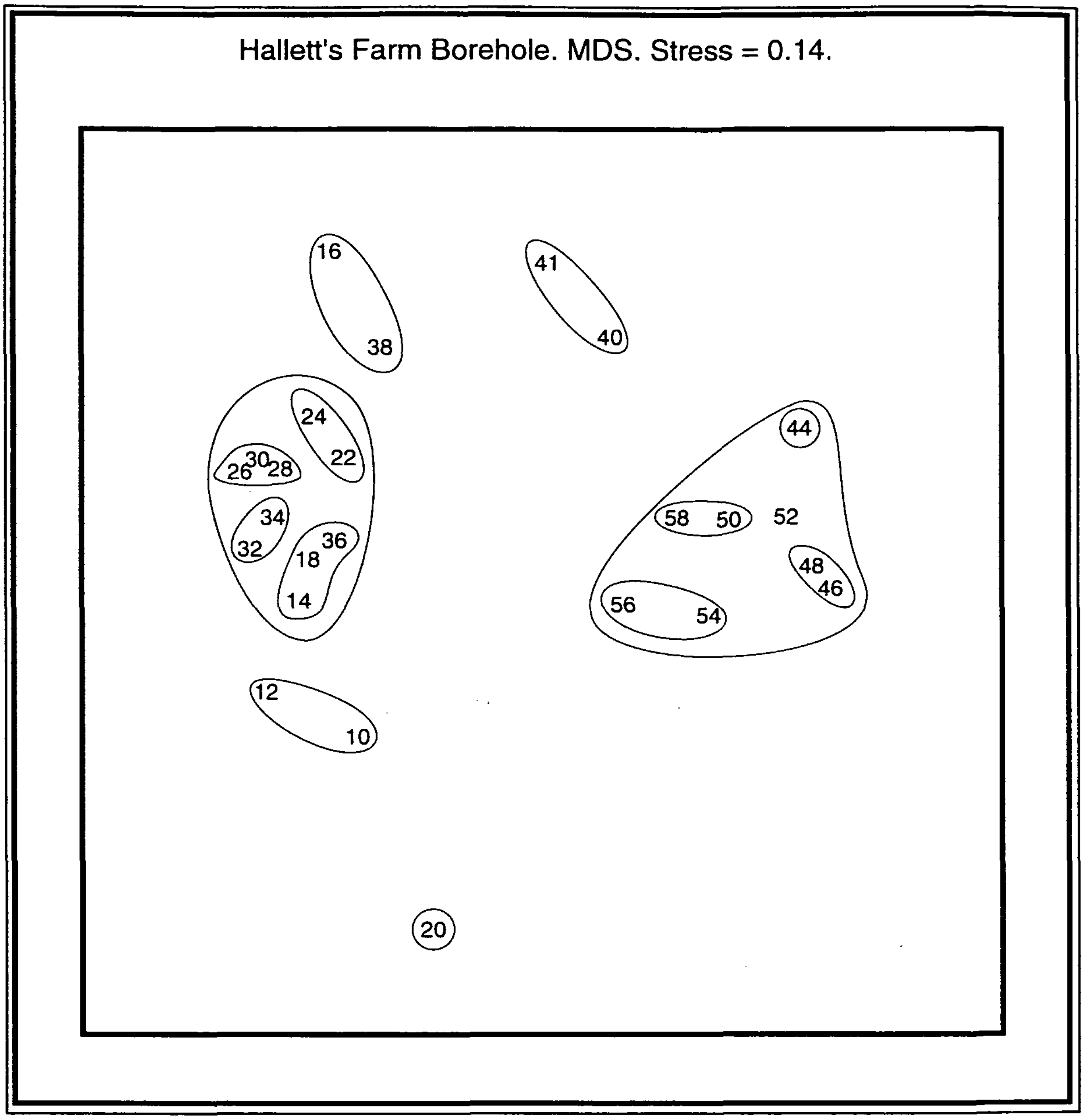


Figure 6.19. MDS plot for Hallett's Farm Borehole. Groups selected by successivley combining closest samples and their subsequent groups.

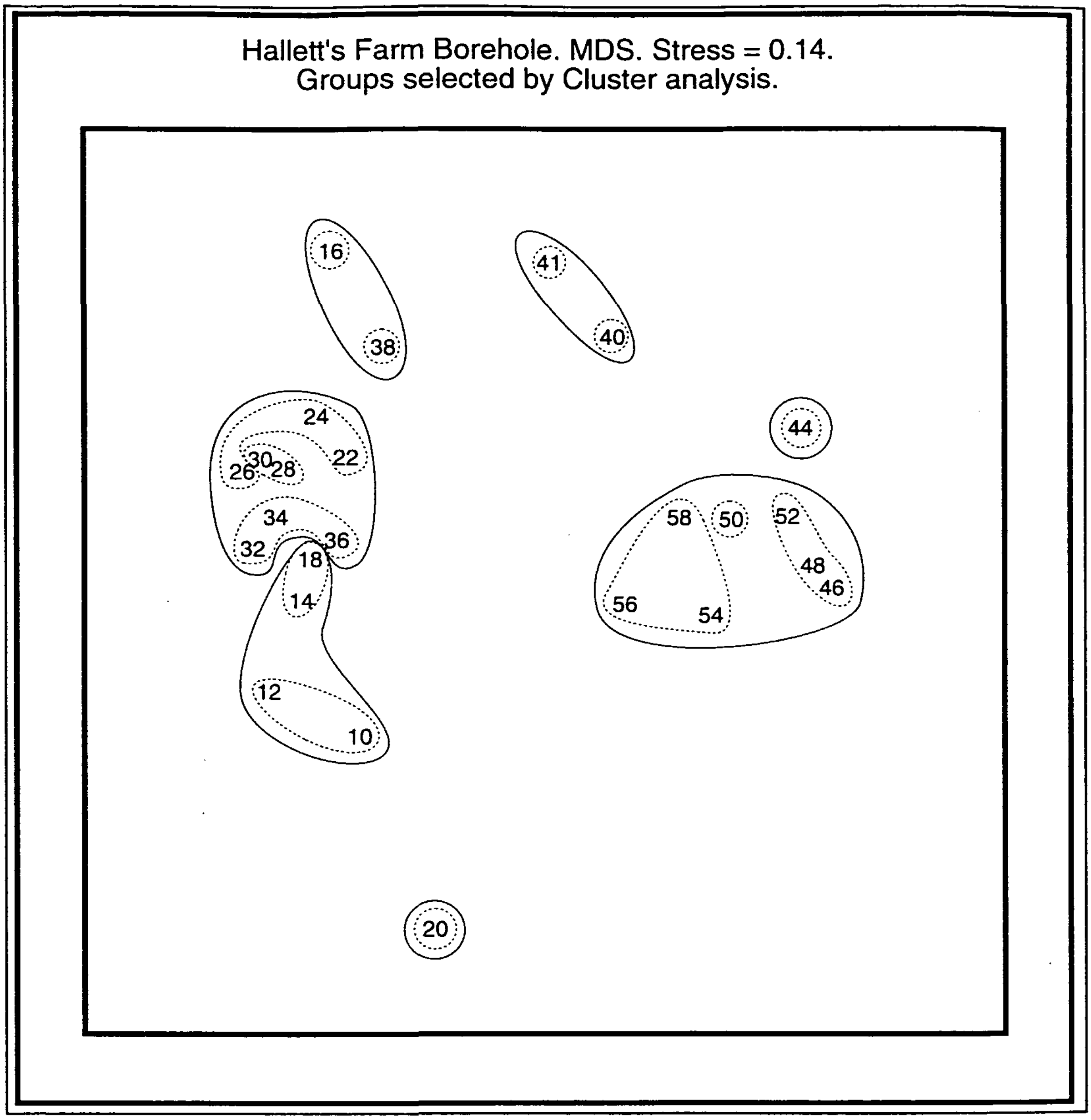


Figure 6.20. MDS plot for Hallett's Farm Borehole. Groups selected by cluster analysis, indicated on the dendrogram by similarity threshold lines at 50% (solid line) and ~60% (dashed line), see also Fig. 17.

initial interpretation of the MDS plot (Fig. 6.19), when compared to the combined cluster analysis plot (Fig. 6.20), show marked similarities, the minor difference is that samples 14 and 18 are grouped with 10 and 12, on the combined plot.

6.3.5. Conclusions.

In the previous section three different methods are used to group together the samples from each of the four boreholes. The results for the different methods are analysed and the groupings of the samples indicated are summarised and compared on Figs. 6.21 - 6.24. In the case of the univariate diversity indices, results are in the forms of trends, peaks and troughs on the graphs, and single samples which seem to represent a different assemblage from the adjacent samples. The cluster analysis and the MDS analysis are more straight forward, in that the results are in the form of discrete groups.

By combining the results of all three methods for each borehole, trends of sample groupings become highlighted. When the samples are arranged in their stratigraphic order, the groupings will record the change of the assemblage throughout the borehole. This, in turn, will aid palaeo-environmental and biostratigraphic interpretation of the assemblage. At this stage all lithological, sedimentological, biostratigraphical and other palaeontological data will be kept separate, and will be integrated in Chapter 7.

6.3.5.1. Hartmoor Hill Borehole.

The three sets of results are plotted next to the samples for Hartmoor Hill Borehole in Fig. 6.21.

There is a general agreement between the three methods and the samples are divided into two broad groups. The most striking feature is the boundary defined above sample 209, sample 205 being totally separated from the adjacent samples. The samples from 225 to 209 are similar, although sample 219 appears distinct as highlighted by the diversity indices, and to a lesser extent on the dendrogram and MDS plots. Both the latter methods appear to form groups separated between samples 217 and 215.

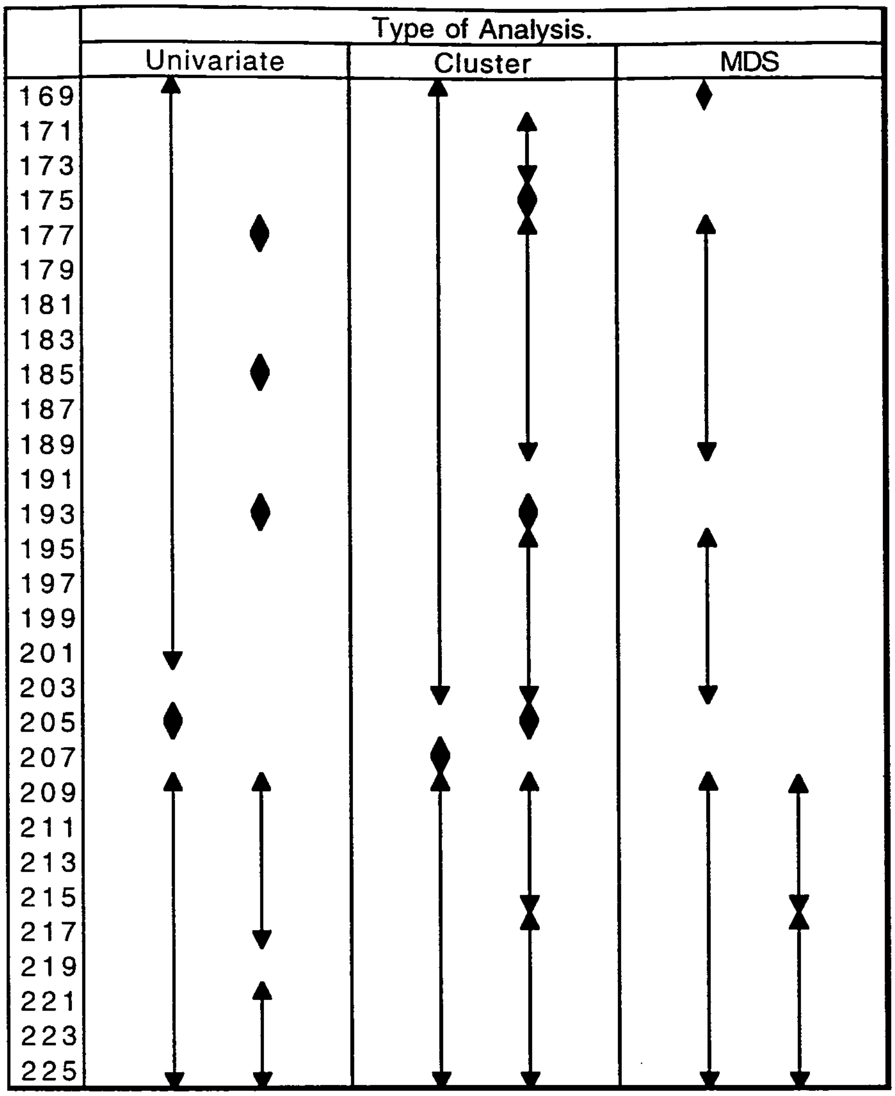


Figure 6.21. Combined statistical results for the Hartmoor Hill Borehole.

For the remainder of the samples 203 to 169, other groups are highlighted. Samples 203 to 195 form a fairly coherent group, but are separated from the remaining samples by 191 and 193. The composition of these two samples are very distinct from one another. This is illustrated on Fig. 6.21 and on the dendrogram and MDS plots (Figs 6.2, 6.4 and 6.5) The diversity indices show distinct changes for sample 193. The next distinct group consists of samples 189 to 177.

6.3.5.2. Bowden Farm Borehole.

The combined results are plotted next to the samples for Bowden Farm Borehole in Fig. 6.22.

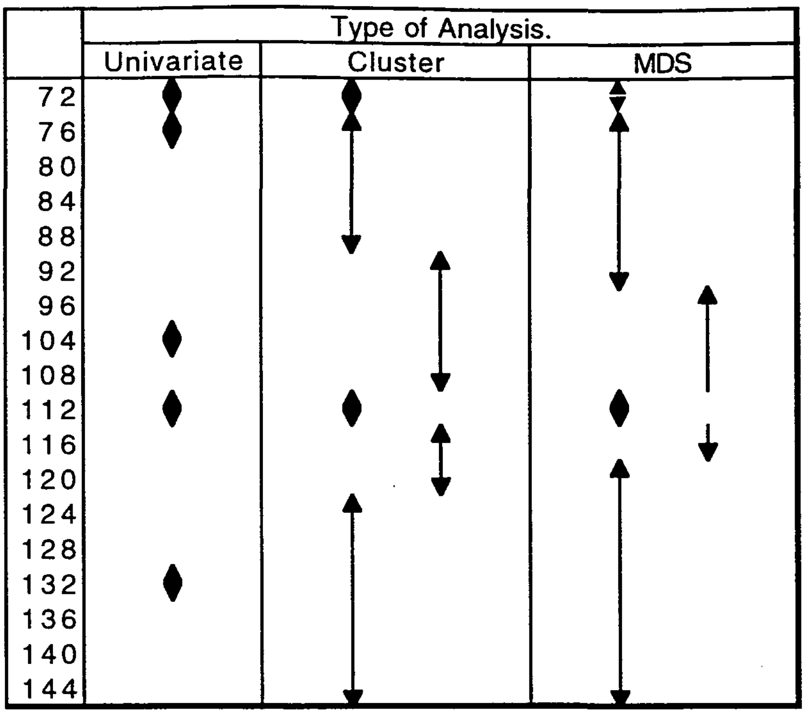


Figure 6.22. Combined results of statistical analysis for the Bowden Farm Borehole

The results for Bowden Farm Borehole are not as striking as for the other boreholes and the trends are less distinctive. The most noticable feature is that sample 72 is picked out by all three methods as being different from all other samples. This is also the case for sample 112, but to a lesser extent. In general the borehole is divided into three groups of samples. The first group consists of samples 144 to 124 (or 120), although this boundary is not very distinct, which is emphasised by the difference in the dendrogram and MDS plots (Figs 6.7, 6.9 and 6.10). The next group (excepting 112) consists of samples 120 to 92 or 116 to 96 depending on the method employed. The final group contains samples 76 to 88 or 92 (again there is a discrepancy in the dendrogram and MDS plots). The results tend to indicate an overall general similarity between all the samples, with only sample 72 being distinct.

6.3.5.3. East Stour Borehole.

The results for the East Stour Borehole are combined on Fig. 6.23.

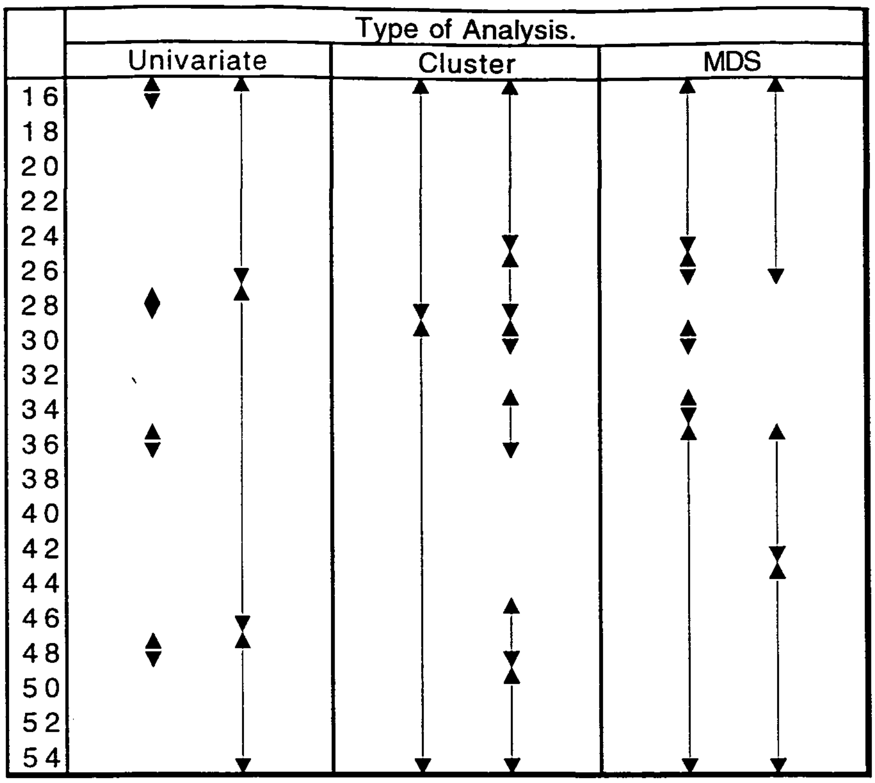


Figure 6.23. Combined results of statistical analysis for the East Stour Borehole. (Only last two digits of the sample numbers shown).

The positioning of the sample groups are not exactly the same for each method, but broad groups are discernible. The two broad groupings consisting of samples 54 to 36 and a smaller group of samples 26 to 16 are picked out on the MDS plot. The remaining samples 34 to 28 are quite distinctive from one another and tend not to form any natural groups. The dendrogram is not particularly clear (Fig. 6.12), but divides the borehole into two broad groups. One group consisting of samples 54 to 30, and the other consisting of the remaining samples 28 to 16.

6.3.5.3. Hallett's Farm Borehole.

The results for the samples analysed from Hallett's Farm borehole are combined and illustrated on Fig. 6.24 and distinctive trends are discernable.

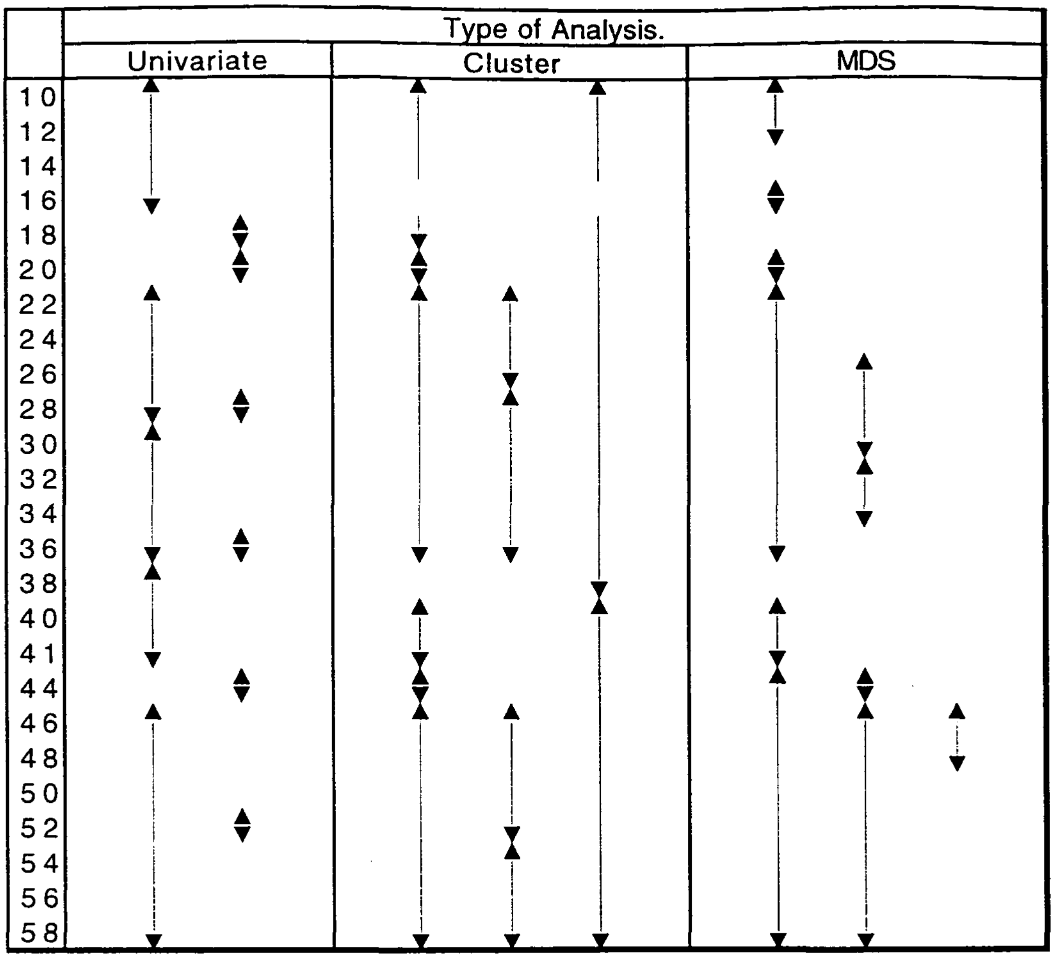


Figure 6.24. Combined results of statistical analysis for the Halletts Farm Borehole.

The most striking is the separation of sample 20 and to a lesser extent samples 18 and 16 from the rest of the samples. Two broad groups are indicated. The first is defined as consisting of samples 58 to sample 46 or 44. The second group consists of samples 36 to 22. Samples 40 and 41 are picked out as a separate pair, as are samples 10 and 12.

6.4. Interpretation of sample groupings.

Each distinct group of samples, selected by the various methods described previously, indicate the similar composition of each sample within a group. Every sample within a group should generally have a similar faunal distribution. Every distinct environment will have a distinctive assemblage associated with it, and in turn, each depositional environment will be reflected in the lithology. This is especially true for benthonic organisms. Most of the foraminiferal assemblages recorded form the Upper Jurassic of Britain have been reported as being facies-dependant (e.g. Shipp, 1989), which is basically true for most benthonic foraminifera. This factor must be taken into consideration when considering any wider palaeo-ecological interpretations from the various groups of samples. Each group may indicate a particular community that remains consistent and stable throughout a certain period of time and be indicative of a particular environment or of certain ecological controls. It is probable that the changes from one group to another may not represent an evolutionary change in the assemblage but more likely to be related to lithofacies or environmental change. Whatever the groups indicate, they become useful when a particular stratigraphic boundary is difficult to observe. This may be caused by the lateral degeneration of a previously distinctive lithological boundary, or through the physical difficulty of little or no exposure, access only to borehole material or ditch-cuttings, where detailed sampling and sedimentary evidence is difficult to obtain. In these cases a distinctive grouping of samples based on the methods described above, may provide evidence of faunal change, which can in turn provide evidence for stratigraphic correlation and palaeo-ecological and palaeo-environmental interpretation.

6.4.1. Hartmoor Hill Borehole sample groups.

The distinctive division between the groups of samples above and below 205 is not coincident with an observed lithological boundary. The lithology at this level within the borehole is a very fine clay with the occasional silty horizon. The results of the statistical analysis however indicate a very distinctive faunal break. This boundary is envisaged as being coincedent with the boundary between the Upper Oxford Clay Formation and the base of the Hazelbury Bryan Formation. In north Dorset the boundary is recognised lithologically at the base of the Hazelbury Bryan Formation which is defined as the last occurrence of silty/sandy clay (Bristow *et al.*, 1995). In the Hartmoor Hill borehole this has proved difficult to observe, so the only evidence of a stratigraphic boundary is provided by the faunal break. The assemblage of the Oxford Clay Formation is generally more diverse than that of the Corallian which is also illustrated in the diversity plots (Fig. 6.1), as the Species Richness is generally at a higher level below sample 205 than above. The number of species is also significantly higher (this would be expected as Species Richness is a function of the number of species); see Table. 6.1. The other boundary indicated between sample 193 and 191 by the sample groups represents a lithological change from the more silty lithologies of samples 201 to 193 to the more clayey lithology above. The other boundary highlighted by the grouping of samples is between samples 177 and 175. Lithologically there is no distinctive difference between the two groups of samples (189-177) and (175 - 169) above. The grouping of samples above sample 175 may be a factor of contamination due to the poor recovery of material at this position in the borehole.

6.4.2. Bowden Farm Borehole sample groups.

The divisions of the sample groups in the Bowden Farm Borehole seem to reflect purely lithological changes. The majority of the borehole consists of the Hazelbury Bryan Formation with the initial members of the Stour Formation at the very top. Up until sample 124 the lithology is predominantly silty clay. Sample 116 is the first pure clay sample. This is reflected in the distinct grouping of samples 144 to 120. The group that includes samples 116 to 96 are all from clay lithologies, apart from sample 112. This sample is from a distinctive silt horizon and the composition of the assemblage appears to change accordingly. The slow rise of the Richness index to sample 104 is indicative of the clayey nature of the lithology. From sample 104 upwards the lithology becomes progressively siltier and sandy as regressive cycles become more dominant. From sample 92 upwards the lithology becomes very sandy and all samples up to 80 are from lithologies with a high silt content or with sand present. Sample 76 and 72 are from similar clay horizons, but are very different from each other in the analysis. Sample 72 is from the first member of the overlying Stour Formation, the Woodrow Clay Member. This sample is the only distinctive element of the analysis. The difference probably represents the change in depositional environment of the Woodrow Clay. The environment envisaged here is a tidal flat which differs from the generally offshore shelf clays to subtidal clayey sands and extremely sandy clays of the Hazelbury Bryan Formation (Bristow *et al.*, 1995).

6.4.3. East Stour Borehole sample groups.

The lithologies covered by the East Stour Borehole include the Hazelbury Bryan Formation and the Woodrow Clay, Cucklington Oolite, Sturminster Pisolite and Newton Clay Members of the Stour Formation. Although the borehole penetrated the Clavellata Beds Formation no samples were taken from this lithology. The first broad group recognised contains samples 54 to 36, although in the cluster analysis 34 and 36 are paired and separate for the rest of the samples below. All these samples are from the Hazelbury Bryan Formation. Samples 36 and 34 are from the Woodrow Clay, and although sample 36 is not too dissimilar from the samples below, 34 is distinct. Samples 28 to 16 are all taken from the Newton Clay Member and are represented in a sample grouping, although not so well defined. Sample 28 is from a very sandy horizon from within the Newton Clay and therefore appears separate from the other samples. The deposition of the Newton Clay Member was under deeper water, following the transgression over the limestones of the Cucklington Oolite and Sturminster Pisolite. The samples taken from the muddier lithologies within these limestones do not group with any other samples to provide any useful information. Although due to their widely varying composition, which distinguishes them from the rest of the samples, they are effectively grouped together.

6.4.4. Hallett's Farm Borehole sample groups.

The lithologies covered by the Hallett's Farm borehole start at the top of the Cucklington Oolite and overlying Sturminster Pisolite Members, although these lithologies are not sampled. The Newton Clay Member, the Todber Freestone Member, the Clavellata Beds Formation, the Sandsfoot Formation and the Ringstead Waxy Clay Formation are all sampled. The first boundary indicated by the sample grouping is between samples 44 and 46. Sample 44 is within the Clavellata Beds Formation and sample 46 lies within the Todber Freestone Member. There is a sharply defined transgression at the base of the Clavellata Beds Formation with the deposit representing a basal lag (Bristow *et al.*, 1995). The Todber Freestone represents a high energy shallow water environment. A faunal gap, as indicated by the ammonite zonation, occurs between these lithologies. This is represented on the diversity diagrams by the distinct difference between samples 44 and 46. Samples 41-38 form a distinct group and are taken from the lower part of the Sandsfoot Formation. The Sandsfoot Formation lies unconformably above the Clavellata Beds. These samples could represent the locally developed Sandsfoot Clay, as above 38 the samples are grouped into a large cluster. Samples 41 and 40 are from distinctive siltier horizons, however, and this may reflect in the grouping. The next distinctive boundary is at sample 20 which is a completely separate from the samples above and below. This sample could define the transgression and subsequent deposition of the Ringstead Waxy Clay Formation. The lower part of this Formation is interpreted as being deposited under reduced salinity conditions. The samples above 18 are grouped together but are only loosely similar. The lithologies of the Sandsfoot Formation and Ringstead Waxy Clay Formation are not easily separated in the borehole by sedimentololgical difference. The distinct faunal break, however, suggests that the boundary occurs between samples 22 and 20.

6.5. Summary.

In general the groupings of the samples throughout the boreholes tend to reflect changes in lithologies and it would be a mistake to interpret each cluster of samples as an evolutionary change in the assemblage. One would expect a distinctive change in the benthos with a change in the environment of deposition. Where the clustering method has its advantages is in highlighting stratigraphic boundaries where there are no distinct lithological changes. The analysis of the borehole samples has distinguished the boundary between the Upper Oxford Clay Formation and the Hazelbury Bryan Formation at around sample 205 in the Hartmoor Hill Borehole and the boundary between the Sandsfoot Formation and the Ringstead Waxy Clay Formation at around sample 20 in the Hallett's Farm borehole.

The disadvantages with these technique, as applied to the boreholes, is that in some cases the samples are not sufficiently close to pick out trends, and in some cases only one sample represents an entire lithology. With a closer sample spacing a better resolution of grouping would be obtained. These results are combined with the biostratigraphic and palaeo-ecological data in Chapter. 7.

Chapter 7. Palaeo-ecological Interpretation.

7.1. Introduction

Palaeo-ecological interpretation of Jurassic assemblages has inherent difficulties. The use of quantitative palaeo-ecological analysis, such as faunal distribution patterns, has not been applied to the interpretation of palaeo-environments during the Upper Jurassic as frequently as to assemblages from younger periods. These methods have, however, been applied to assemblages from the Cenozoic, and to a lesser extent to the Cretaceous, with good results. The problem with the interpretation of Jurassic assemblages is their lack of similarity with modern faunas as they represent a relatively early stage in the evolution of the foraminifera. The position of the land-masses in Late Jurassic times presented a very different environment; the vastly different climate and oceanic circulation all combine to produce a benthonic foraminiferal assemblage very different to those studied today. Perhaps the most important feature is the gross composition of foraminiferal assemblages during the Jurassic. Subsequently, the process of evolution has altered the distribution pattern of foraminifera as many new families and species have evolved. The Jurassic period represents the acme of the evolution of the Nodosariacea Superfamily where they are extremely dominant. Although the Nodosariacea range through to the present day, in the late Mesozoic and Cenozoic their dominance declined. Prior to the Cretaceous their ecological range was more widespread and they occupied much shallower environments (Haynes, 1981) while after the Cretaceous the Nodosariacea migrated to occupy deeper environments. Importantly, the presence of the Rotaliina, very dominant in Recent faunas, was not a conspicuous component of Jurassic assemblages, reaching their maximum abundance later. The subsequent evolution of the Rotaliina provided a rapid expansion in the number of foraminiferal taxa and an invasion into environments and ecological niches previously dominated by Jurassic assemblages. Their ability to form symbiotic relationships with algae helped secure their dominance over the Nodosariacea which were outcompeted in their previously preferred ecological niches. The migration of the Nodosariacea into deeper waters through time has been interpreted as a retreat from the more readily adaptable Rotaliina (Haynes, 1981).

The intense study that Recent faunas have received (e.g. Boltovskoy and Wright, 1976; Murray, 1973, 1991) has greatly increased our knowledge of the ecology of foraminiferal faunas and the composition and distribution of taxa in the various environmental positions throughout the benthonic habitat. The feeding strategies and preferred living position of foraminifera in relationship with the substrate has also received study (e.g. Charnock and Jones, 1985; Corliss, 1985; Corliss and Chen, 1988 and Severin, 1983) and our knowledge of the ecology of modern faunas has been greatly augmented. In Cenozoic foraminiferal studies the method of applying Recent analogues to help elucidate palaeo-environments has proved to be useful in evaluating these assemblages (eg. Murray and Wright, 1974 for the Cenozoic of the Isle of Wight). However, palaeo-environmental interpretations for pre-Upper Cretaceous assemblages based on Modern analogues must be used with caution; their ecology can not be simply implied from comparisons with the Recent. Groups of foraminifera in the Jurassic were dominant in particular environments because they were the most successful groups at the time. After the explosive evolution of the rotaliinids there was more competition and Jurassic assemblages lost out to the more adaptive rotaliinids. The Globigerinina were in their infancy and have not been reported from the Upper Jurassic successions of Britain.

7.2. Techniques employed.

The following sections will deal with the palaeo-ecological interpretation of the Upper Jurassic foraminiferal assemblages recorded in the studied succession from north Dorset. An initial overview of the fauna is presented, then the assemblages (samples) from each of the boreholes will be discussed. Within each borehole the main lithological sections (which represent discrete palaeo-environments) will be discussed in relation to the assemblage. In the following sections a number of statistical techniques are applied, and analysis of the assemblage will help interpret the palaeo-ecology. The methodology differs from that in Chapter 6 as the interpretation of the results provides separate conclusions. In Chapter 6, the samples are analysed *a priori*, in that the samples were treated purely as numbers once the analysis had been performed and were divided into discrete groups. These groups contain samples with similar faunal assemblages. Each separate grouping may represent a stable assemblage which occupied a particular palaeo-environment. The analysis in this chapter will interpret the palaeo-environment of each sample group, the emphasis being placed on quantitative analysis were possible (e.g. application of suggested α-index environments). The techniques are described below.

7.2.1. Simple faunal distribution.

7.2.1.1. Distribution of suborders.

The original treatise on Foraminiferida by Loeblich and Tappan (1964) used a classification system consisting of three Suborders (Textulariina, Miliolina and Rotaliina) which is fundamentally a division based on the wall structure. The use of these ratios in ternary diagrams has been employed successfully by Murray (1973, 1991) to elucidate environments from the Recent and the Cenozoic of the Anglo-Paris Basin (Murray and Wright, 1974). In the subsequent classification (Loeblich and Tappan, 1988) new suborders were introduced. The six suborders present in the Jurassic can be combined in the same way (Textulariina, Involutinina, Spirillinina, Lagenina, Robertinina and Miliolina).

A more general ratio of calcareous benthonics:agglutinated foraminifera can also be utilised. Scott (1974) remarks that this ratio is greater in deeper water than for shallow water. Johnson (1975, 1976) also applied these ratios successfully to foraminiferal assemblages from the Domerian and Toarcian of the Mochras Borehole.

The percentage frequency of the suborders can also be utilised for delineating major faunal trends. The Textulariina have been used as a crude measure of depth (or more correctly as a measure of restricted marine conditions, which effectively equates to depth), when they are the sole component of an assemblage. However there is debate as to whether assemblages composed entirely of agglutinated taxa are actually original assemblages or merely the surviving component after diagenetic removal of the $CaCO_3$ taxa.

7.2.1.2 Generic distribution.

The distribution of genera is useful for the comparison of assemblages of differing ages. It is more appropriate to use data for modern genera in ascertaining palaeo-environments than for species. Given the above mentioned difference in species and genera composition between the Recent and the Jurassic only broad interpretations can be made. The ecological data presented for certain genera by Murray (1973, 1991) and Charnock and Jones (1985) for the Recent can be useful for the broad interpretation of Jurassic genera. Generic distribution has been employed by Nagy *et al.* (1990) as a palaeo-ecological tool for the Jurassic of the North Sea Basin. Generic distribution is particularly useful as individuals of many Jurassic assemblages are subjected to compression and dissolution, which can make identification to the specific level uncertain.

7.2.1.3. Specific distribution.

This technique is more useful for comparison of similar-aged assemblages where similar ecological parameters will be applied to each assemblage and the problems of homeomorphy and differences in gross faunal composition can be avoided.

7.2.2. Diversity.

Diversity indices, equitability indices, dominance indices and the information indices have been successfully employed in modern ecology and have more recently (since the 1960's) been applied to palaeo-ecology. For a description of each equation see Chapter 6. The indices will be discussed below in relationship to their uses in palaeo-ecology, with examples from previous studies. The quantitative interpretation will also be discussed.

7.2.2.1. The Fisher α index.

See Section 6.2.1 for details. Although this index has ceased to be used by biologists in modern ecology it has proved useful for palaeo-ecological studies. It relies on the premise that the distribution of the number of individuals of each species follows a mathematical logarithmic series. Although Buzas *et al.* (1977) have shown that the distribution of foraminiferal populations in *Thalassia* habitats fit the logarithmic series, the distribution of many species abundances clearly do not fit. It is because of this that the use of this index by ecologists has declined (Gibson and Buzas, 1973). One advantage of the α index is that it is easy to use and can be read off a base graph by plotting number of species against number of individuals. Murray (1968) carried out tests to evaluate the dependency of the α index on sample size and discovered that although the variation was not great there was a tendency for α to increase with sample size. In his study of Recent environments, Murray (1973, 1991) has made extensive use of the α index despite the aforementioned problems and has effectively characterised the foraminiferal population for different marine environments. In a general sense, $\alpha = 5$ is a boundary separating normal marine environments ($\alpha > 5$) from abnormal marine environments ($\alpha < 5$). Murray (1973) states that hyposaline and hypersaline marshes, lagoons and hyposaline shelf seas all have low diversity. Normal shelf seas and normal marine lagoons have diversity of $\alpha>5$.

Due to the extensive applications of this index to modern foraminiferal faunas and more recently to palaeontological assemblages (Wright and Murray, 1972), the α index has been favoured by most micropalaeontologists (e.g. Nagy *et al.*, 1990; Buzas *et al.*, 1977; Nagy, 1992; Nagy *et al.*, 1995) as an index of diversity.

The α index is used in this study to help emphasise assemblages from restricted marginal marine environments and to distinguish between shallow and deeper water assemblages.

7.2.2.2. Information Function.

Gibson and Buzas (1973) state that due to the complexities of nature (especially when considering within-habitat diversity) no single model seems to adequately account for species diversity. They remark that it would be desirable to have a measure of diversity that takes into account the number of species and their proportions but does not depend upon any particular mathematical model.

The most frequently used such measure is the Shannon-Weiner information function *H(S)* (Gibson and Buzas, 1973). This is an index of heterogeneity, first introduced by MacArthur and MacArthur (1961) for bird species diversity. For a description of the equation see Section 6.2.1. Buzas and Gibson (1969) apply the information function to calculate foraminiferal diversity and state that it measures the number of species and their proportions without making any assumptions as to an underlying distribution. The Shannon-Weiner information index has been used by a number of authors for the distribution of foraminifera: Beerbower and Jordan (1969) discuss the application of information indices to palaeo-ecological problems and were the first to utilise the index in palaeontology. Gibson and Buzas (1973) also use the information index and report on the distribution of Miocene foraminifera from the Eastern margin of North America, Sen Gupta and Kilbourne (1974) discuss the benthic foraminifera on the Georgia Continental Shelf and Johnson (1976) applied this function to the Toarcian and Domerian (Jurassic) foraminifera from the Mochras Borehole. Nagy *et al.* (1988) used the information function with generic abundance for the Middle Jurassic to Early Cretaceous foraminifera from eastern Spitsbergen.

Murray (1991) however points out some of the difficulties inherent in the use of the information function. Firstly, it is highly dependant upon sample size, and invariably produces an underestimated value for any given sample. This is a factor of inadequate sample size and the need to recognise every single species present in an assemblage. However, Gibson and Buzas (1973) state that one of the information function's attractive attributes is that it minimises the problem of comparing diversity in different sized samples. The increase of species number with increasing sample size is a product of recording more of the rare species, and as the information function is based on the common species, the addition of rarer species tends not to affect *H(S)* greatly.

7.2.2.3. Equitability.

Another index associated with the concept of heterogeneity is equitability. This is the measure of the evenness with which importance is divided among species (Peet, 1974). The equitability index used in this study is Pielou's Evenness (*J*); see Section 6.2.1 for discussion of the equation. Equitability has been used in the palaeo-ecological study of foraminifera by Gibson and Buzas (1973), Sen Gupta and Kilbourne (1974) and Johnson (1976).

In general the diversity *H(S)* and *J* record higher values for assemblages from deeper water and lower values for shallower water assemblages.

7.2.2.4. Other indices

Other indices used are Simpson Dominance Index and Margalef's Richness Index. See Section 6.2.1. for details.

7.2.2.5. Simple generic and specific predominance.

A simple measure of dominance is also used. The most dominant two species from each sample are plotted. This method is useful in recognising prevalent favourable conditions and a measure of competition within the assemblage. Abrupt changes in environment are also highlighted if this includes a change (or alteration) of the dominant species. The generic dominance is also used. The concept of generic dominance was introduced into a study of the gulf of Mexico by Walton (1964). Murray (1991) mentions that fossil generic dominance patterns can often be matched with those of modern genera so can be potentially useful palaeo-ecological techniques (e.g. Sliter and Baker, 1972).

7.2.3. Complex statistical methods.

7.2.3.1. Multivariate statistical methods.

These are reviewed and applied to the samples in Chapter 6. The results pertaining to palaeo-environmental interpretation will be applied in the discussion during the following sections.

7.2.3.2. Similarity index.

A similarity matrix is constructed from the species/distribution data sets and is the starting point for most multivariate analyses (see Chapter 6 for description). At its basic level the plot of the similarity index is a measure of how similar a sample is compared to the sample immediately above it. It is calculated in the following way. The similarity (S) is 100 if the two samples are identical and S = 0 if the samples have no species in common. The similarity co-efficient used in this study is the Bray-Curtis co-efficient. It has become particularly common in ecological work (Clark and Warwick, 1994). This graphic representation is useful in the recognition of faunal change.

7.2.4. Other microfaunal components.

These are purely qualitative methods. Certain fragmentary microfossils may provide important information for palaeo-ecological interpretation. Echinoderm debris in the form of echinoid spines, plates etc., ophiuroid debris, crinoid debris, holothurian sclerites, otoliths, scolecodonts and micro-gastropods all indicate normal marine conditions and, in the case of echinoid debris, stenohaline conditions. For a detailed discussion of holothurian sclerites see Chapter 5.

7.2.5. Preservation.

The general preservation of the assemblage is also considered. Dissolution, abrasion, broken or compressed forms may help indicate aspects of the environment or may be products of diagenesis, or post-mortem transport.

7.3 Jurassic faunal associations.

The palaeo-ecological interpretation of Jurassic assemblages by previous workers is important to mention as there is relatively little information available.

The environmental significance of the foraminiferal groups is summarised in Table 7.1 and has been inferred by the following authors: Barnard *et al.* (1981), Gordon (1970), Nagy *et al.* 1990.

Foraminifera	Suggested environment.
Ophthalminiidae	Shallow water
Adherent foraminifera e.g. *Nubeculinella bigoti*	Slow deposition rate, or presence of bottom currents.
Adherent foraminifera + Ophthalminiidae.	Shallow conditions with ?tidal currents.
Small agglutinated specimens. - *Trochammina, Gaudryina,* small *Ammobaculites.*	Shallow water. Reduced salinity/less oxygenated bottom conditions, especially when occurring alone.
Large agglutinated specimens - *Ammobaculites coprolithiformis, Triplasia.*	Generally deeper conditions.
Epistomina	Shallow water (deeper than for *Ophthalmidium*) normal marine.
Adherent species	Breaks in deposition. Slow rates of deposition or bottom currents.
Nodosariacea (except Polymorphinidae)	Commonly deeper water (although not restricted to this environment)
Polymorphinidae - *Eoguttulina* especially.	??
Solely Textulariina assemblage	Indicative of a restricted marine environment with low salinity

Table 7.1. Palaeo-environmental significance of certain Jurassic taxa as recorded by previous authors.

The data in Table 7.1 is taken mostly from interpretations for the Oxford Clay, but as Shipp (1989) mentions, it is considered that these groups are likely to have a similar environmental significance in other sediments of late Jurassic age.

The Oxfordian in general is charcterised by three types of assemblage corresponding to those described by Gordon (1967) from the Callovian of Brora. These are summarised below after Shipp (1989).

a. Textulariina dominated assemblages, especially *Lagenammina difflugiformis*, *Reophax horridus*, *Ammobaculites suprajurassicus* (= *A. agglutinans*), *Reophax sterkii* and *Ammobaculites coprolithiformis*. This assemblage is also characterised by low diversity. Shipp (1989) notes that this assemblage may have calcareous forms removed by solution during diagenesis.

b. Calcareous benthonics dominant, especially nodosariaceans (60%) with some textulariinids (40%). Moderate diversity. Dominant species is *Lenticulina münsteri*.

Other common taxa are *Citharina flabellata*, *Dentalina gümbeli*, *Lenticulina quenstedti*, *Marginulina scapha*, *Ammobaculites coprolithiformis*, *Eoguttulina liassica* and *Epistomina parastelligera*.

c. An assemblage consisting of an even mix of calcareous benthonics and textulariinids, characterised by the dominance of *Epistomina parastelligera*.

7.4. Overview of the fauna.

7.4.1. Introduction.

The assemblage recorded from the north Dorset Upper Jurassic succession is fairly typical of Upper Jurassic assemblages found north of Tethys.

The general composition of the assemblage will be discussed below, firstly in terms of the total assemblage from all four boreholes, and secondly the assemblage from each borehole will be discussed in detail.

7.4.2. Composition of the total fauna.

The general composition of the assemblage is shown below in terms of wall structure. The six suborders are combined to form the usual three-way division.

Agglutinated (Textulariina):	42%
Calcareous (Involutinina, Spirillinina, Lagenina, Robertinina):	56%
Porcellaneous (Miliolina):	2%

Overall the calcareous benthonic component is the most abundant with the agglutinated forms second.

A more detailed division of the assemblage can be examined if the number of genera and species are listed for each of the Families present. The results are shown in Table 7.2. Due to the fragmental nature of the Nubeculariidae the number of specimens were not counted. It is difficult to achieve a realistic total number of specimens as whole individuals are recorded rarely, many individuals also can be overlooked when picking the assemblage. A simple record of presence/absence is indicated for species of this family and a qualitative abundance is recorded. In general the species *Nubeculinella bigoti* and *Nubeculinella bacularis* var. *tibia* occur infrequently. When they become conspicuous in an assemblage, attention is drawn to this fact.

In this study the assemblage comprises a total of 26 families consisting of 43 genera and 148 species. The nodosariids and the vaginulinids are the most diverse families represented within the north Dorset sections and also include the most abundant species. The agglutinated families Trochamminidae and Lituolidae are the most diverse agglutinated families and in the case of the lituolids contain the most abundant agglutinated species.

Family	**Number of Genera**	**Number of Species**	**Abundance of Taxa (%)**
Saccamminidae	1	1	1
Ammodiscidae	2	2	<0.1
Hormosinidae	1	5	0.7
Haplophragmoididae	1	9	3.2
Lituolidae	2	13	30.4
Placopsilinidae	2	2	<0.1
Spiroplectamminidae	1	3	<0.1
Trochamminidae	1	12	5
Verneuilinidae	2	3	0.4
Eggerellidae	1	1	<0.1
Textulariidae	2	6	0.9
Involutinidae	1	2	0.5
Spirillinidae	1	3	5.3
Cornuspiridae	1	2	0.1
Nubeculariidae	1	2	*
Ophthalmidiidae	1	2	0.8
Spiroloculinidae	1	1	<0.1
Hauerinidae	2	3	0.8
Robuloididae	1	2	<0.1
Nodosariidae	6	25	0.9
Vaginulinidae	6	31	22.3
Lagenidae	1	3	<0.1
Polymorphinidae	2	6	0.4
Ceratobuliminidae	1	2	0.2
Epistominidae	1	6	26.9
Placentulinidae	1	1	<0.1

Table 7.2. The generic and specific composition of all Families. Family % is based on number of individuals recorded. * Not included in abundance counts, see text for explanation.

The most striking aspect of the assemblage as a whole is that in many samples two species are predominant. These are the vaginulinid *Lenticulina münsteri* (Roemer) and the lituolid species *Ammobaculites coprolithiformis* (Schwager). *L. münsteri* comprises up to 70% of the assemblage in many samples and is usually greater than 40%. Likewise, the large variable species *A. coprolithiformis* can dominate samples in the same way and can comprise up to 60% of the assemblage. Other species and families are very abundant at certain horizons and tend to appear in floods. This is particularly true for some species of the epistominids. They tend to have an inverse relationship with the abundance of the lenticulinids and are most common when *L. münsteri* is least abundant. The Textulariina have a negative correlation with the Robertinina. In many samples, species of *Epistomina* are the dominant forms and in some samples *Epistomina parastelligera* (Hofker) can comprise 80% of the total assemblage.

Other species often occur in floods and at some horizons also become the dominant taxa within the assemblage. *Ammobaculites godmani* (Barnard), *Trochammina globigeriniformis* (Parker and Jones), *Trochammina squamata* Parker and Jones, *Spirillina tenuissima* Gümbel and *Ophthalmidium strumosum* (Gümbel) are examples. Each of these species can be the dominant taxon in a particular sample assemblage, and can comprise as much as 70% of the assemblage. In one sample 93% of the total assemblage consists of *T. squamata*.

The most abundant taxon found within the studied sections is *Ammobaculites coprolithiformis* which comprises 22% of the total recorded taxa. *Lenticulina münsteri* is the next abundant and comprises 19% of the total assemblage. The next most abundant species are recorded below:

Epistomina parastelligera (Hofker) - 13%
Epistomina tenuicostata Bartenstein and Brand - 7.5%
Spirillina tenuissima Gümbel - 4.4%
Epistomina stellicostata Bielecka and Pozaryski - 4.2%
Trochammina squamata Parker and Jones - 2.9%
Ammobaculites agglutinans (d'Orbigny) - 2.6%

Ammobaculites godmani (Barnard) - 2.2%

Ammobaculites canui (Cushman) - 2.1%

The remaining species each comprise less than 2% of the assemblage.

7.5 Palaeo-ecological interpretation of the borehole samples.

7.5.1. Introduction.

The distribution of samples from the 4 boreholes is illustrated in Figs 7.1 to 7.4. The samples are shown diagrammatically with respect to the major lithostratigraphic units on Fig. 7.5. In the following sections the palaeo-ecology of the assemblage will be interpreted using the previously mentioned techniques and methods. The sample groupings identified in Chapter 6 will be used to divide the samples and each grouping, where possible, will be interpreted as a palaeo-environmental unit.

7.5.2. Hartmoor Hill borehole.

The top the Hartmoor Hill Borehole starts within the Hazelbury Bryan Formation and this borehole covers most of the formation. It spans the junction with the underlying Upper Oxford Clay Formation, and includes part of the Weymouth Member. A total of 29 samples have been analysed from this borehole and are numbered form 225 to 169. Samples 169 to 205 are from the Hazelbury Bryan Formation the remainder are from the Oxford Clay Formation (Fig. 7.1).

7.5.2.1. Faunal Distribution.

The following sections refer to Figs 7.6 to 7.12.

Sample Group 225 to 209.

This group is stratigraphically the lowest and represents the oldest sediments recorded in the study. The 9 samples consist of clays and silty clays from the Upper Oxford Clay Formation; samples 219, 213, 211 are from pure clay lithologies. This group can be further subdivided either side of sample 219, which is slightly different in its faunal composition.

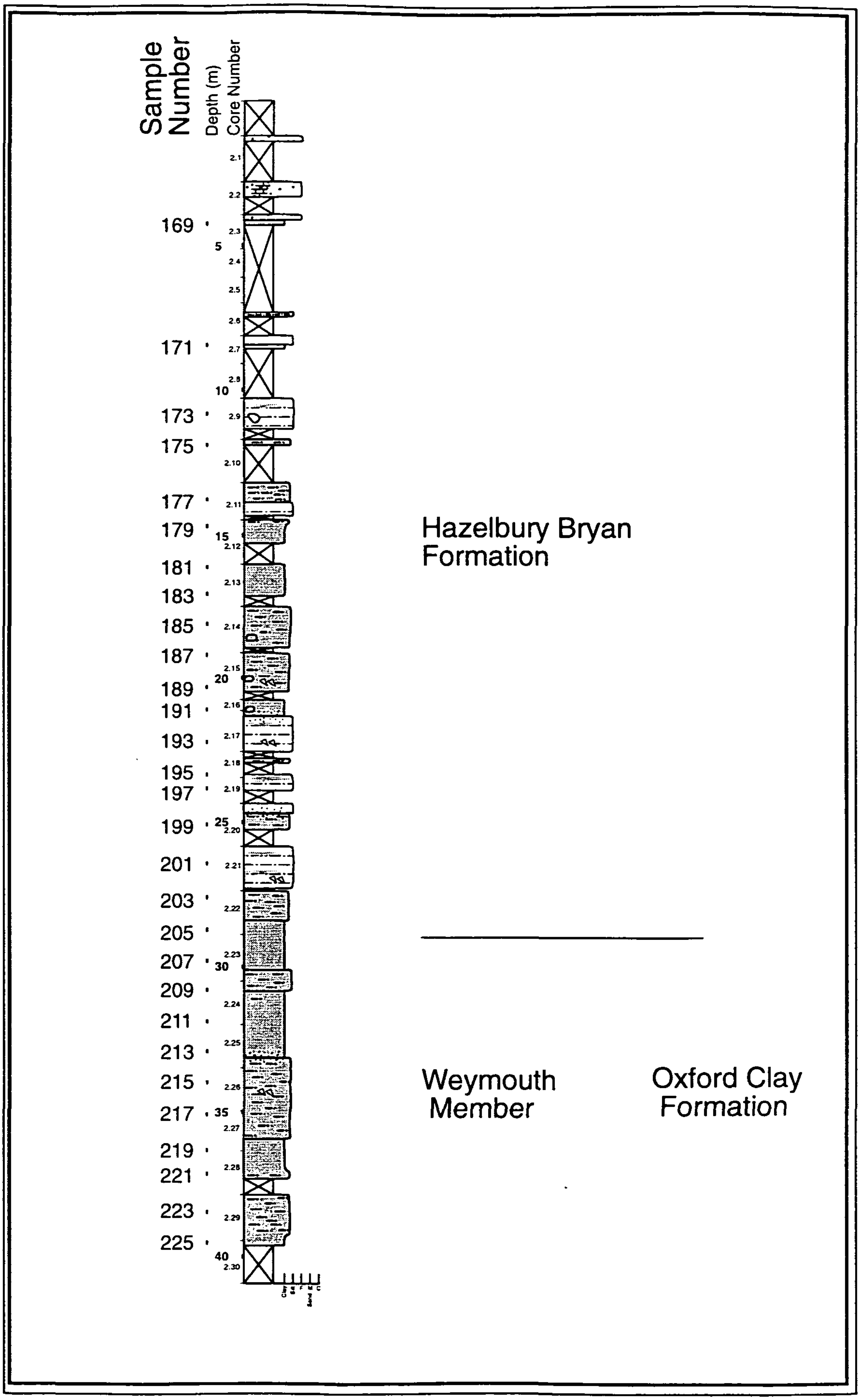


Figure 7.1. Simplified Sedimentary Log of the Hartmoor Hill Borehole showing sample numbers and location.

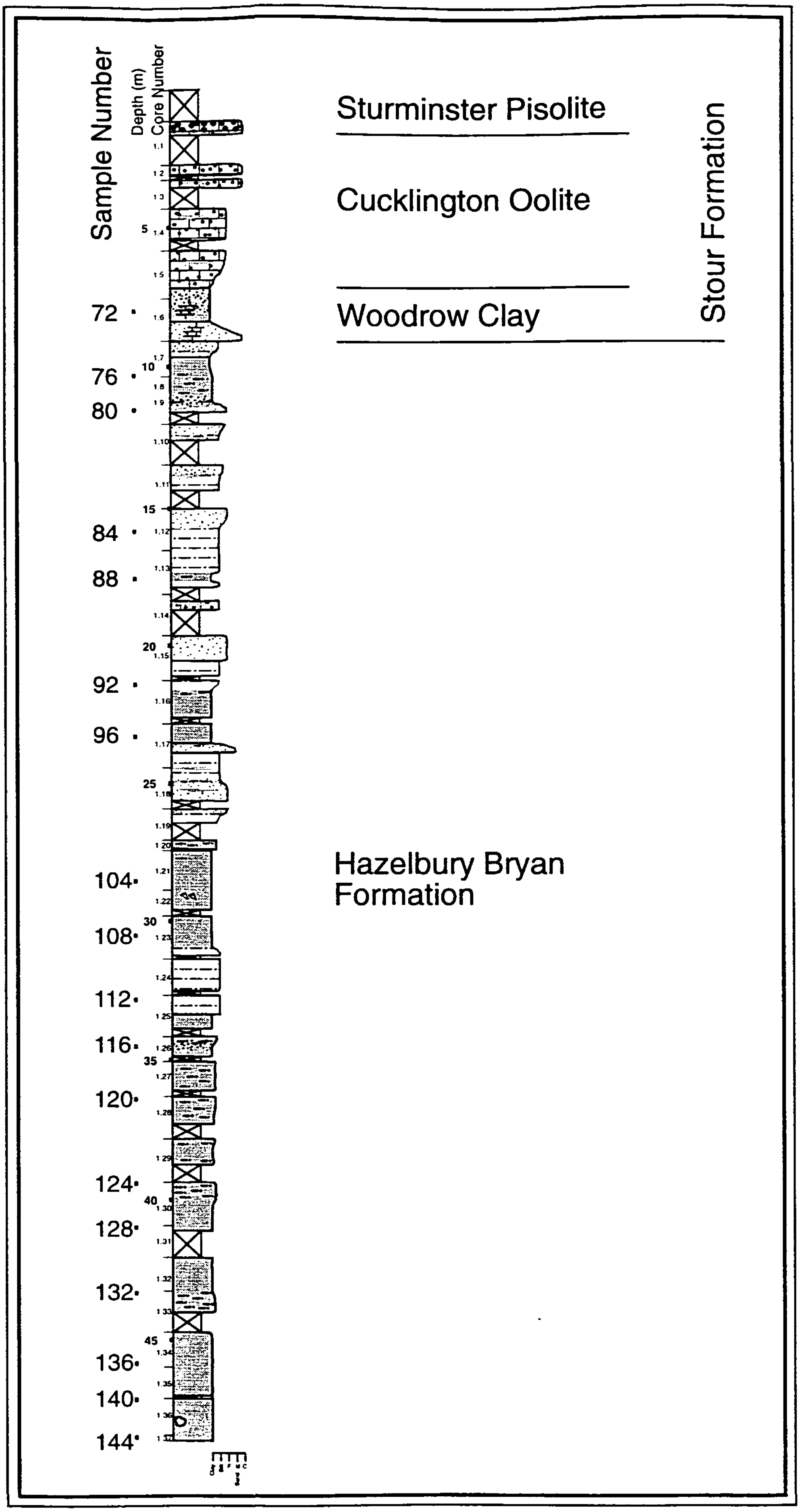


Figure 7. 2. Simplified Sedimentary Log of the Bowden Farm Borehole showing sample numbers and location.

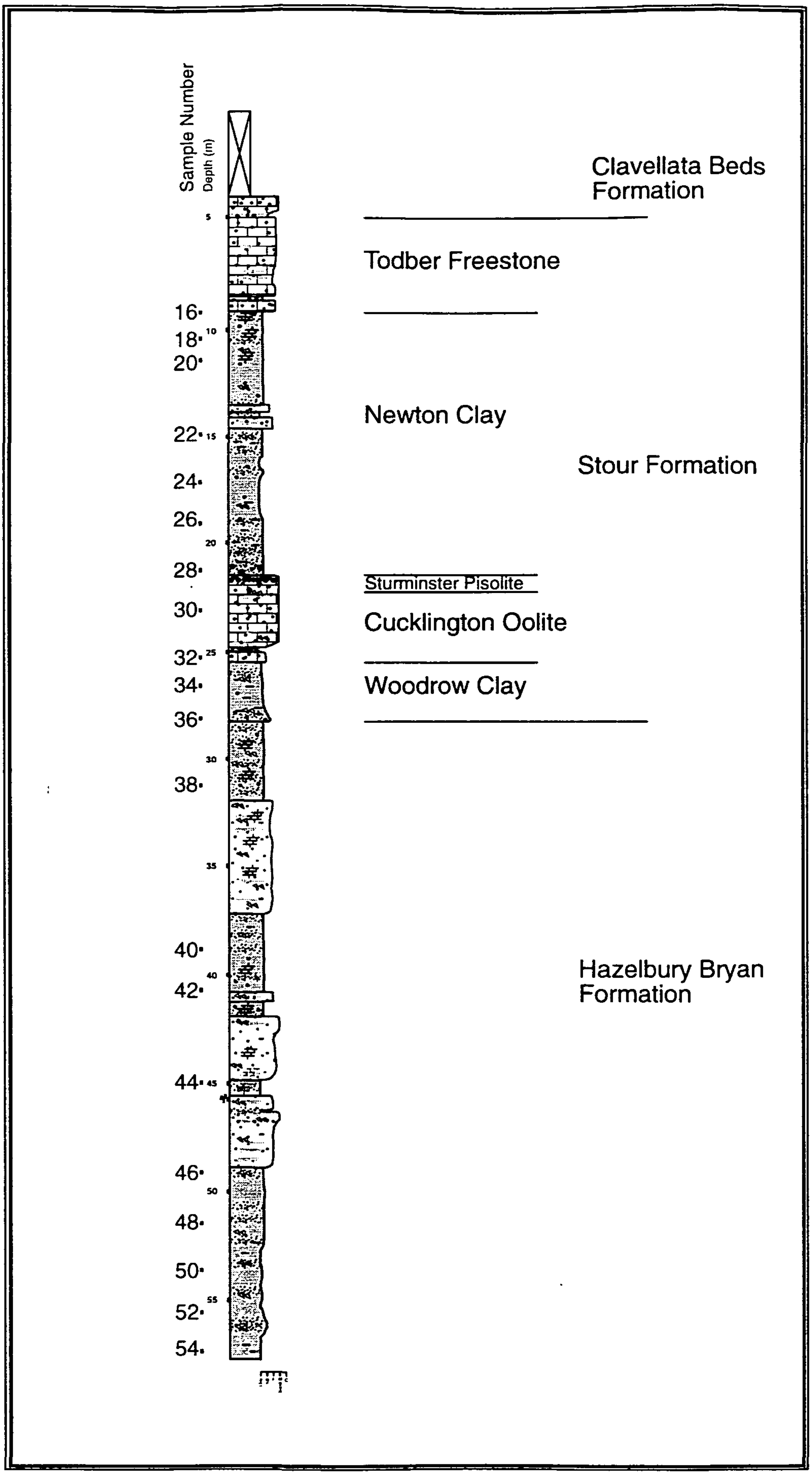


Figure. 7.3. Simplified Sedimentary log of the East Stour Borehole showing sample numbers and location.(For simplicity only the last 2 digits of the sample numbers are shown, i.e. 54 = 30454)

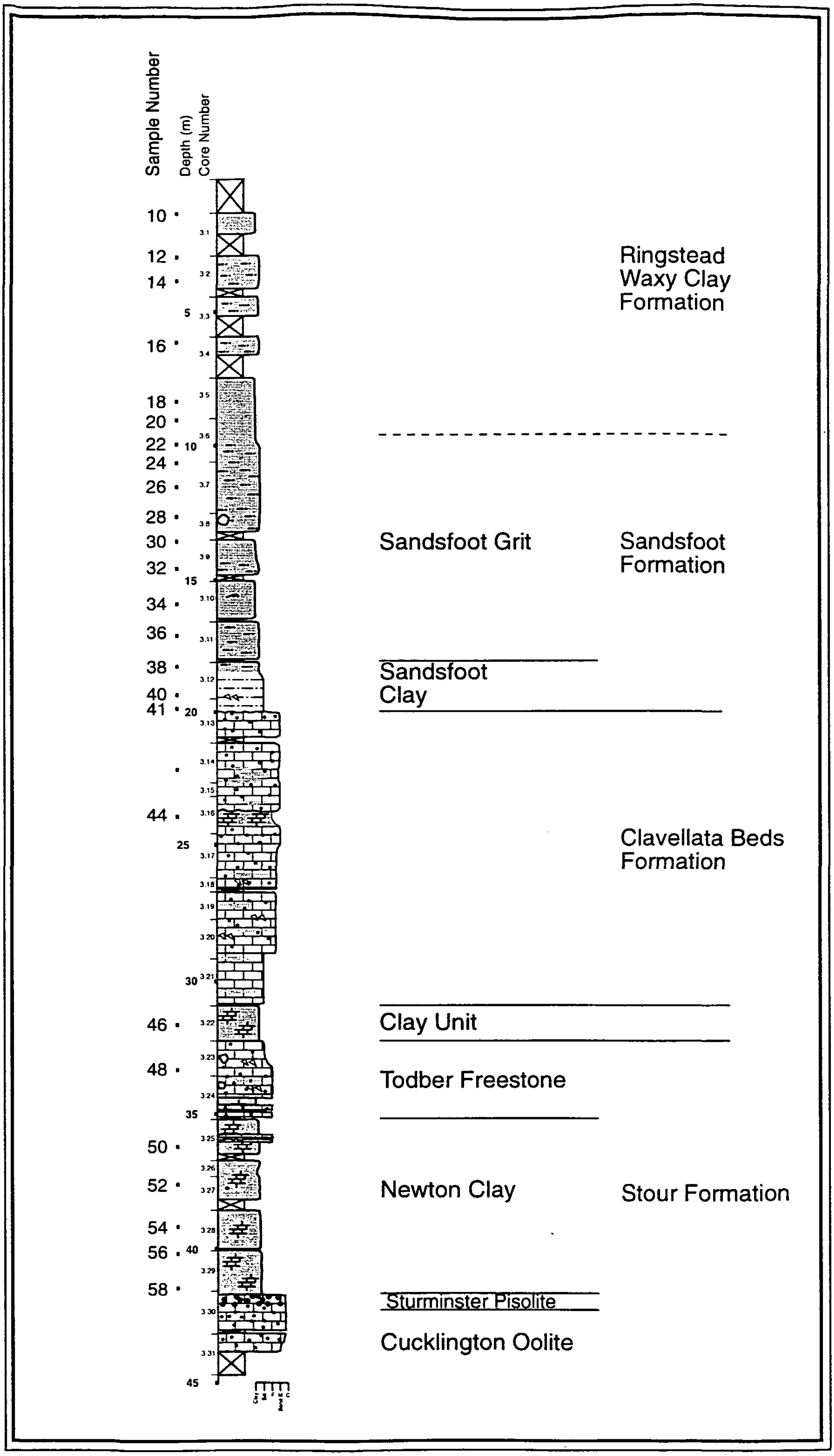


Figure 7.4. Simplified Sedimentary Log of the Hallett's Farm Borehole showing sample numbers and location.

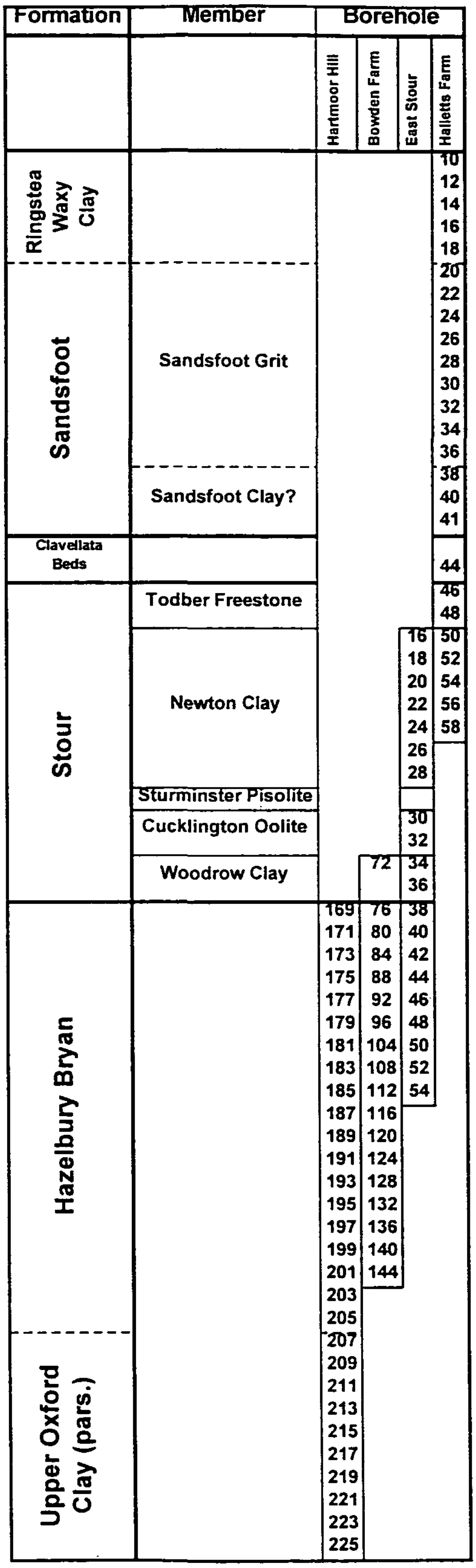


Figure 7.5. Diagrammatic distribution of samples in the Harmoor Hill, Bowden Farm, East Stour and Hallett's Farm Boreholes. (Not to scale).

The Suborders have a distinctive distribution as shown in Fig. 7.6. The Textulariina peak in percentage abundance at sample 213 at just less than 90%; their lowest occurrence is at 219. This distribution is inversely proportional to the Robertinina with their highest occurrence of approximately 70% at sample 219. The Lagenina slowly decline in abundance from approximately 30% at sample 223 to approximately 10% at sample 209. The other Suborders each comprise less than 2% of the total assemblage.

The distribution of the Families in this borehole is shown in Figs 7.7 and 7.8. The Lituolidae contribute most to the Textulariina abundance, although the Trochamminidae are also an important constituent of the assemblage, especially in sample 211, where they comprise 30% of the assemblage (Fig. 7.7). The majority of this family is represented by the species *Trochammina squamata*. The major species contribution (Fig. 7.9) to the Lituolidae is from *Ammobaculites coprolithiformis*, *Ammobaculites agglutinans*, and *Triplasia* sp. 1. The latter species occurs only in samples 213 and 211 throughout the entire study and comprises 14% and 8% of the total assemblage respectively.

Robertinina are dominated by the species *Epistomina mosquensis* and *Epistomina parastelligera* up to sample 211, after which *E. mosquensis* does not occur again, and is replaced by *Epistomina tenuicostata* as one of the major contributors (Fig. 7.9). Sample 219 has a markedly high percentage of the genus *Epistomina* which dominates the assemblage at around 70%; *E. mosquensis* is the dominant species.

Figure 7.10 plots the dominant and sub-dominant genera. There is a marked change in the pattern at sample 219 where, as mentioned above, the assemblage changes from an evenly distributed assemblage with dominant genera at approximately 30%, to an assemblage dominated by the genus *Epistomina* at 70%. The dominant species and subspecies are also plotted in the same way (Fig. 7.10). In a general sense the dominance plots show a trend of *Epistomina* dominant samples up to sample 219, with the remaining samples (217 - 209) dominated by *Ammobaculites*.

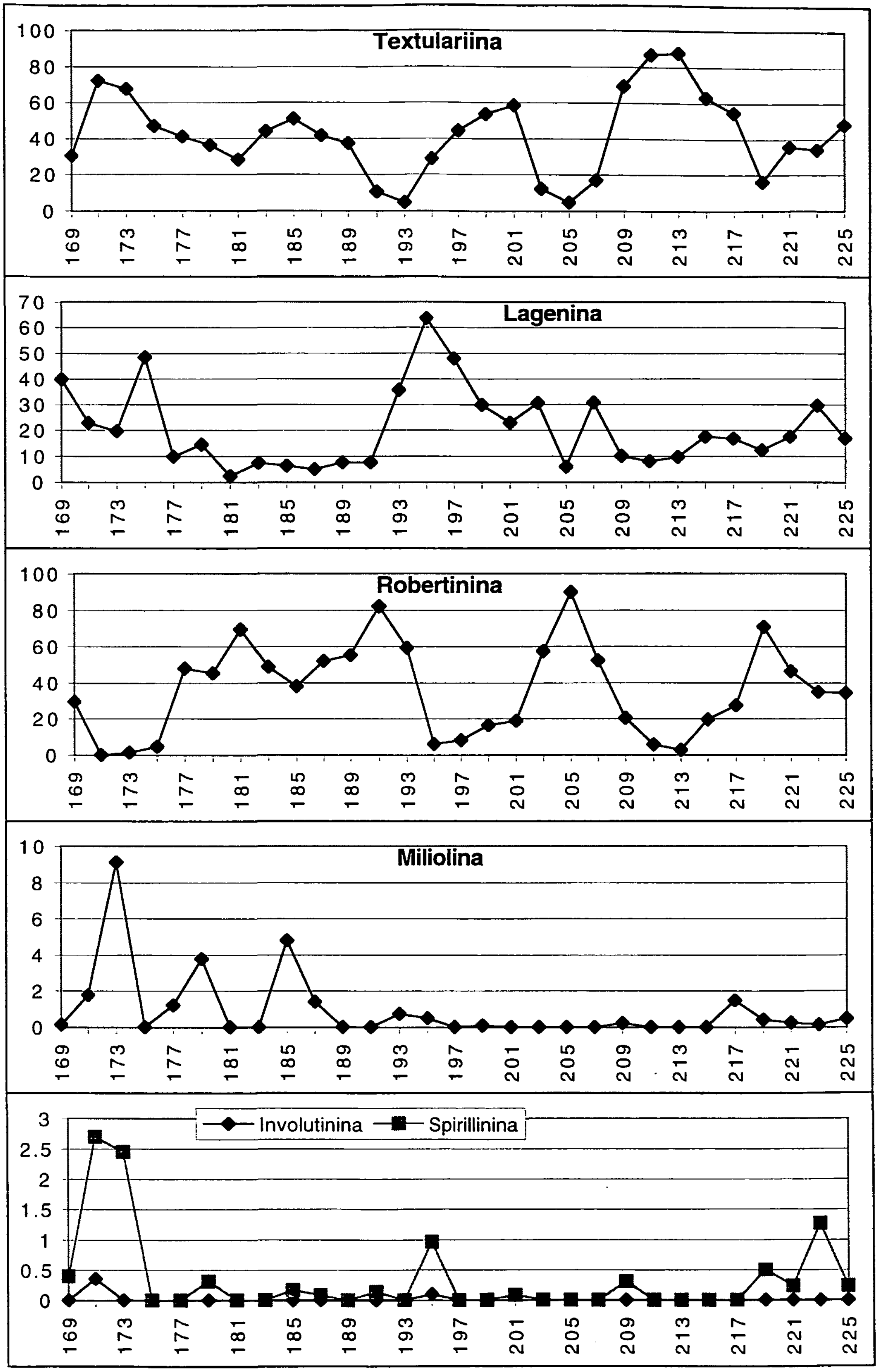


Figure 7.6. Distribution of Suborders for the Hartmoor Hill Borehole.
(x-axis-sample numbers, y-axis-%)

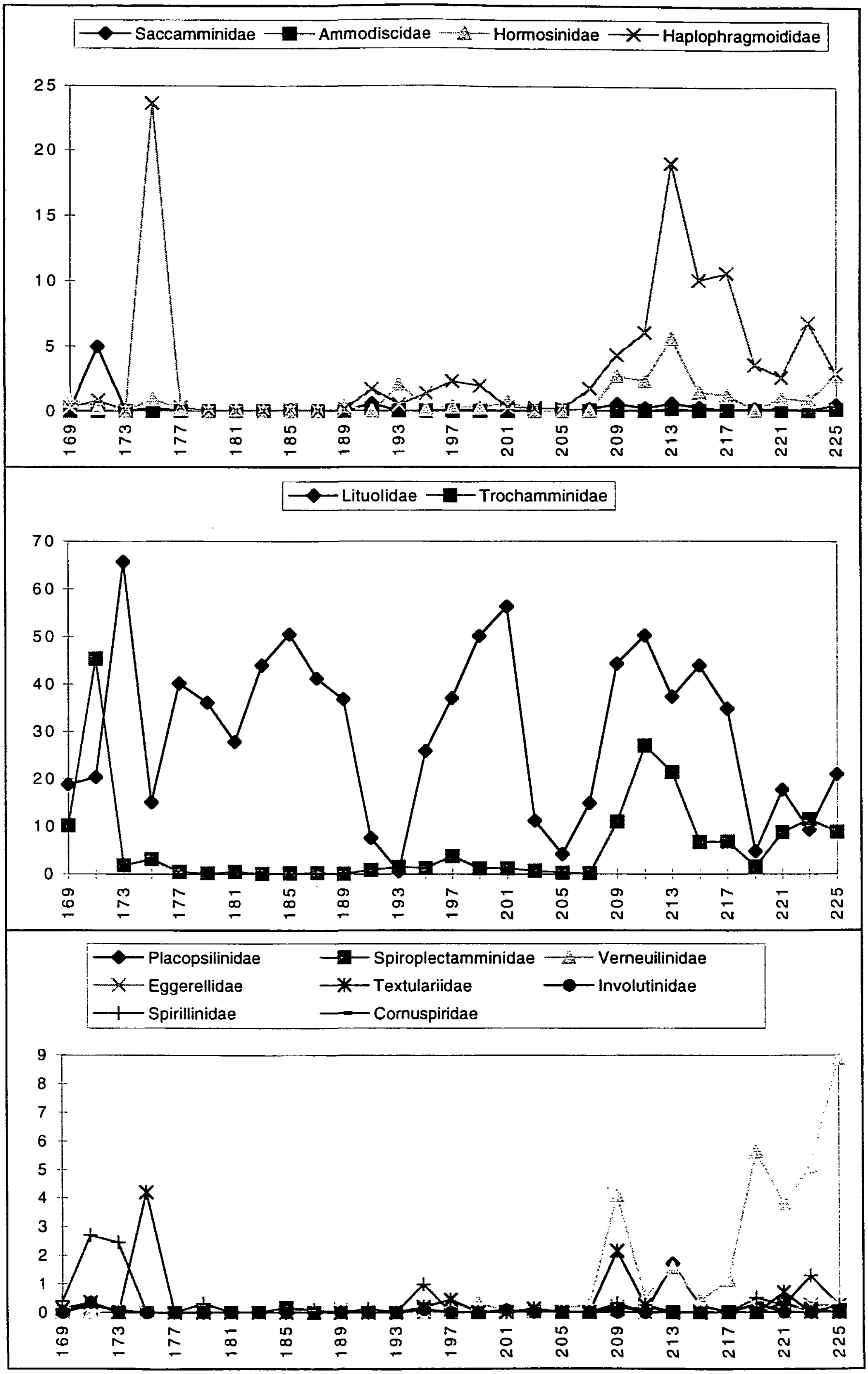


Figure 7.7. Distribution of Families in the Hartmoor Hill Borehole.
(x-axis-sample no., y-axis-%)

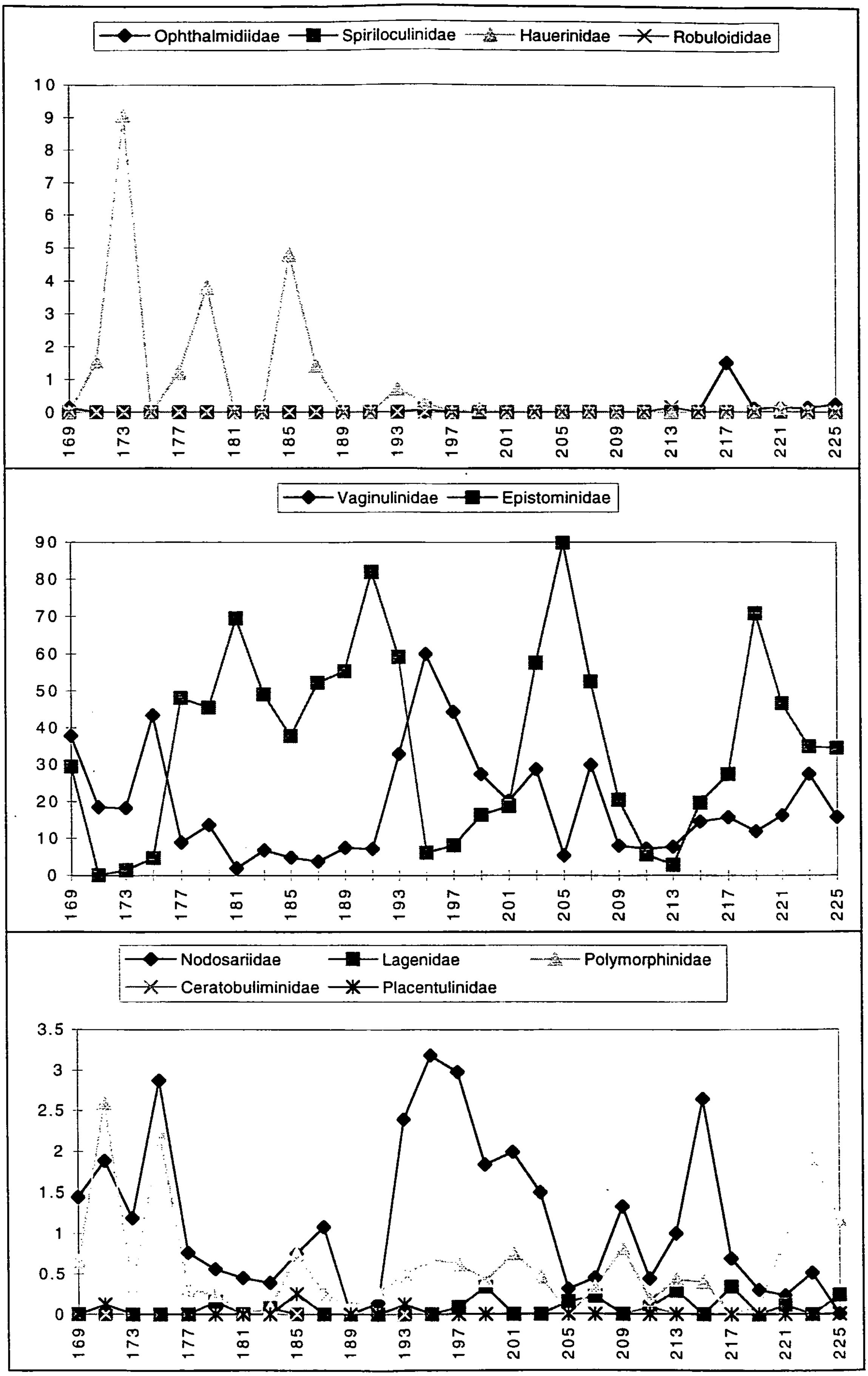


Figure 7.8. Distribution of Families in the Hartmoor Hill Borehole. (x-axis-sample no., y-axis-%)

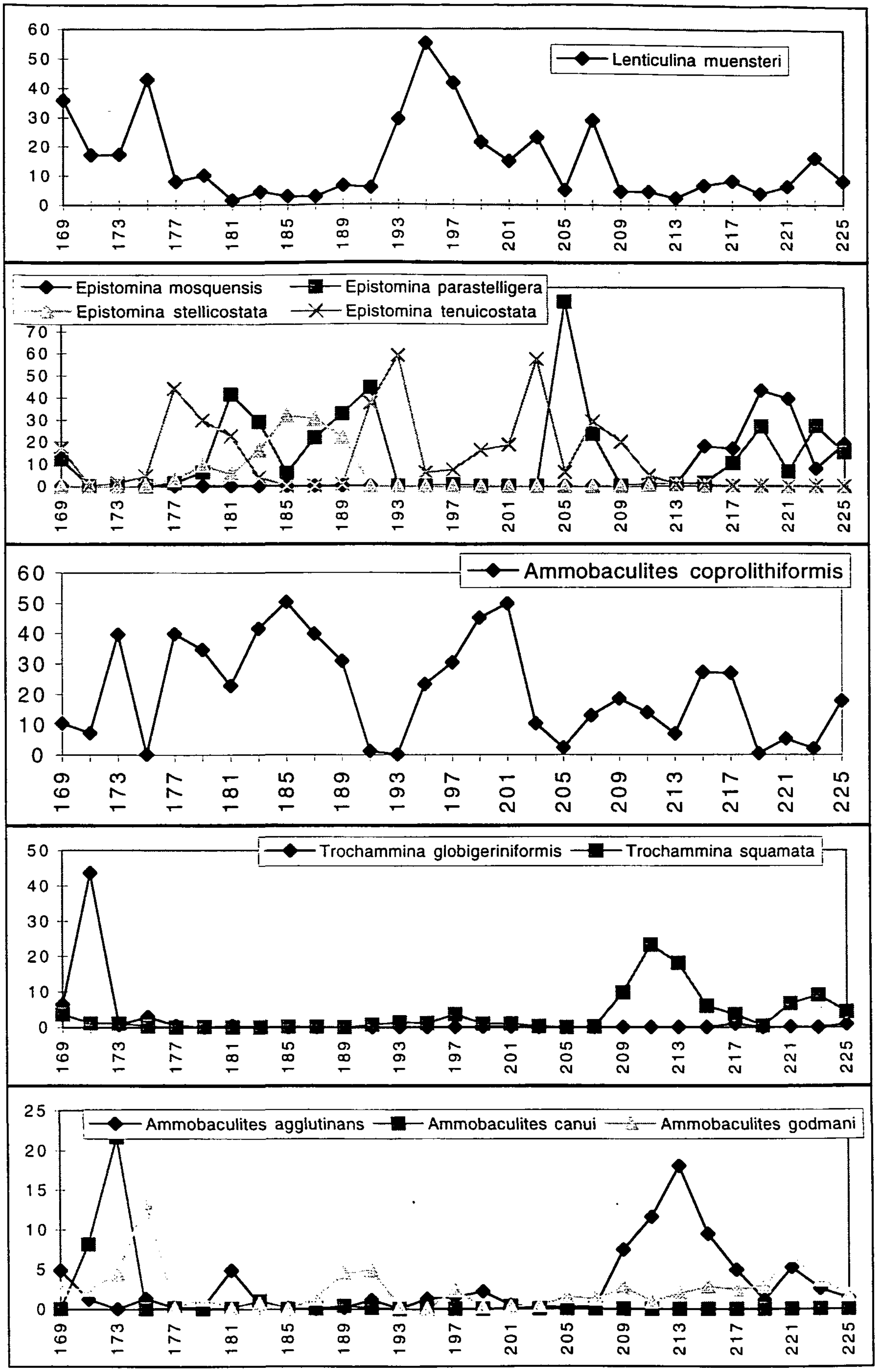


Figure 7.9. Distribution of selected species for the Hartmoor Hill Borehole. (x-axis = sample no., y-axis = %).

Sample	Species	Dominant	Subdominant	Species
169	L. muensteri	36	17	E. tenuicostata
171	T.globigeriniformis	44	17	L. muensteri
173	A. coprolithiformis	40	22	A. canui
175	L. muensteri	43	24	H. sp. 2
177	E. tenuicostata	44	40	A. coprolithiformis
179	A. coprolithiformis	35	30	E. tenuicostata
181	E. parastelligera	42	23	A. coprolithiformis
183	A. coprolithiformis	42	29	E. parastelligera
185	A. coprolithiformis	50	32	E. stellicostata
187	A. coprolithiformis	40	30	E. stellicostata
189	E. parastelligera	33	31	A. coprolithiformis
191	E. parastelligera	44	38	E. tenuicostata
193	E. tenuicostata	59	29	L. muensteri
195	L. muensteri	55	23	A. coprolithiformis
197	L. muensteri	41	30	A. coprolithiformis
199	A. coprolithiformis	45	21	L. muensteri
201	A. coprolithiformis	50	19	E. tenuicostata
203	E. tenuicostata	57	23	L. muensteri
205	E. parastelligera	84	6	E. tenuicostata
207	E. tenuicostata	29	29	L. muensteri
209	E. tenuicostata	20	18	A. coprolithiformis
211	T. squamata	23	14	Triplasia
213	A. agglutinans	18	18	T. squamata
215	A. coprolithiformis	27	18	E. mosquensis
217	A. coprolithiformis	27	17	E. mosquensis
219	E. mosquensis	43	27	E. parastelligera
221	E. mosquensis	39	7	A.godmani
223	E. parastelligera	27	16	L. muensteri
225	E. mosquensis	19	18	A. coprolithiformis

Sample	Genus	Dominant	Subdominant	Genus
169	Lenticulina	37	29	Epistomina
171	Trochammina	45	20	Ammobaculites
173	Ammobaculites	66	18	Lenticulina
175	Lenticulina	43	24	Haplophragmoides
177	Epistomina	48	40	Ammobaculites
179	Epistomina	45	36	Ammobaculites
181	Epistomina	69	28	Ammobaculites
183	Epistomina	49	44	Ammobaculites
185	Ammobaculites	50	38	Epistomina
187	Epistomina	52	41	Ammobaculites
189	Epistomina	55	37	Ammobaculites
191	Epistomina	82	7	Ammobaculites
193	Epistomina	59	32	Lenticulina
195	Lenticulina	58	26	Ammobaculites
197	Lenticulina	43	37	Ammobaculites
199	Ammobaculites	50	16	Epistomina
201	Ammobaculites	56	19	Epistomina
203	Epistomina	57	28	Lenticulina
205	Epistomina	90	5	Lenticulina
207	Epistomina	52	30	Lenticulina
209	Ammobaculites	36	20	Epistomina
211	Ammobaculites	37	27	Trochammina
213	Ammobaculites	37	21	Trochammina
215	Ammobaculites	44	20	Epistomina
217	Ammobaculites	35	27	Epistomina
219	Epistomina	71	11	Lenticulina
221	Epistomina	46	18	Ammobaculites
223	Epistomina	35	26	Lenticulina
225	Epistomina	34	21	Ammobaculites

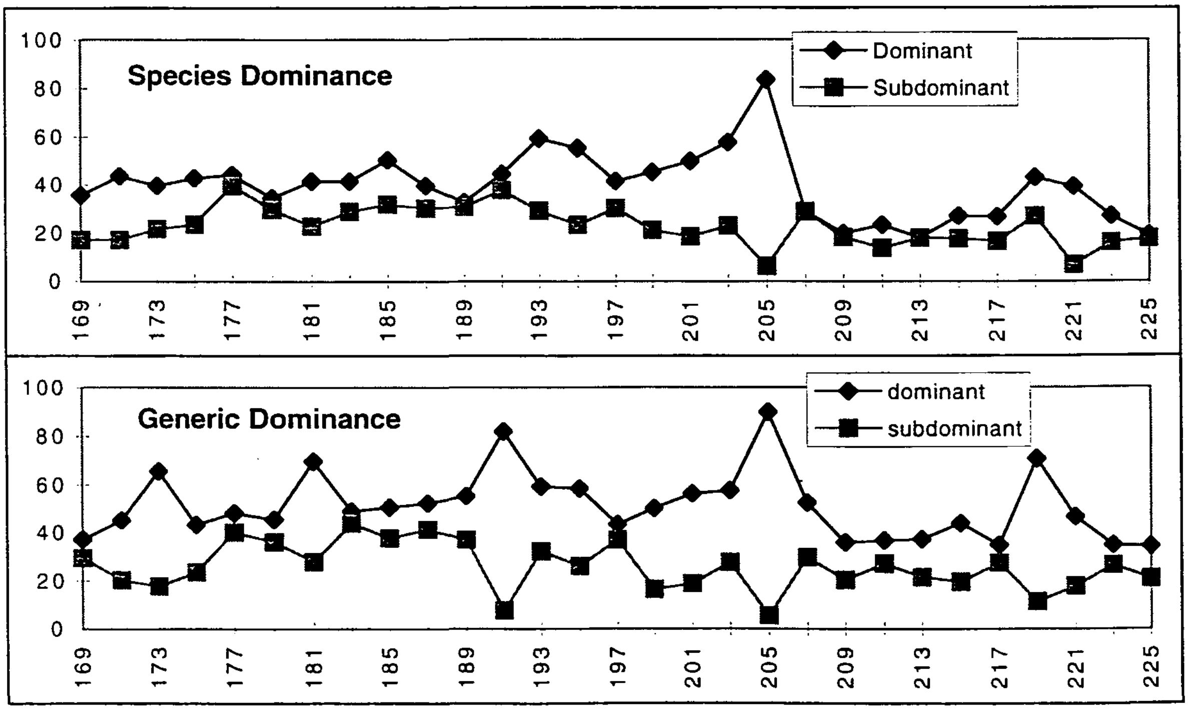


Figure 7.10. Generic and Specific Dominance and Subdominance for the Hartmoor Hill Borehole

Other trends indicated by the distribution of other taxa are less obvious. The Textulariidae have a distinctive peak at sample 209 although, overall, they account for less than 3% of the total assemblage.

The similarity index (Fig. 7.11) shows a good comparison between the samples with surprisingly little difference between 219 and the other samples. A drop in the index at sample 209 illustrates the difference between this sample and the next.

The following indices are all plotted on Figure 7.12. The α index for these samples is in general the highest for the borehole. The mean value is 8.3 with the highest value almost 10 for sample 209 and the lowest at sample 219 of almost 6. The other indices show a fairly regular distribution with a distinctive change for sample 219. The Shannon-Weiner information function shows distinctive high values for these samples which are very different from the rest of the borehole. The dominance index, as would be expected from the analysis above, shows a peak at sample 219. The evenness index shows a regular high value.

Sample Group 207 to 203.

This is a distinctive grouping of samples. Sample 205 has a markedly different assemblage from the other samples in this borehole, although it has an affinity with 203 and 207. Samples 207 and 205 are clay samples, while 203 is from silty clay.

The most distinctive aspect of the assemblage is the dominance of the genus *Epistomina*, especially in sample 205. As shown by the distribution of the Suborders and Families (Figs 7.6 to 7.8) the peak in abundance of the robertininids (epistominids) which, is the highest in the borehole, coincides with the lowest occurrence of the textulariinids (lituolids etc.). Both the generic and specific dominance charts (Fig. 7.10) indicate an almost monotaxic dominance of 90% for sample 205. *Epistomina parastelligera* accounts for 83% of this peak (Fig. 7.9). *Lenticulina* is the second most dominant genera.

The similarity index shows the lowest value for sample 205 (Fig. 7.11). This indicates a marked difference in the faunal composition from the sample above. There is a very distinct drop in the α index to around 2.5 at sample 205 as shown in Fig. 7.12. The same distinctive difference at sample 205 is shown by the other indices, especially illustrated by the Simpson Dominance index showing its highest peak at 0.7. Sample 205 also has the lowest number of species recorded in the Hartmoor Hill Borehole.

Sample Group 201 to 191.

This sample group includes the samples 193 and 191 which tend to plot separate from other samples on the MDS plot and Cluster Analysis dendrogram (Chapter 6, Figs 6.2, 6.3). These samples are from th predominantly silty lithologies of the Hazelbury Bryan Formation (Fig. 7.1).

Trends in the distribution of the foraminifera are again distinctive (Fig. 7.6). The Textulariina show a distinct peak in abundance at sample 210 from their low abundance in the sample group immediately below. From 60% they decrease steadily to sample 193 where they reach their lowest abundance in the entire borehole. The Robertinina are reduced in abundance from the previous sample group and decrease from around 205 to their local minimum at sample 195. There is then a sharp rise in abundance and samples 193 and 191 show abundances of around 60 and 80% respectively. The lageninids increase steadily in abundance from sample 201 and reach a maximum abundance at sample 195 of around 65%, their maximum occurrence in the borehole. There is then a sharp decline in abundance to sample 191 (a complete opposite to the trend shown by the Robertinina) where there is a low abundance of the lageninids at around 8%.

As is common with most of the samples from the Hartmoor Hill Borehole, and in particular the Hazelbury Bryan Formation, the lituolids are by far the most dominant family of agglutinated foraminifera, with *Ammobaculites* the dominant genus (Figs 7.7 and 7.9). The specific dominance graph (Fig. 7.10) shows *A. coprolithiformis* as the dominant species in samples 201 and 199, *Lenticulina münsteri* in samples 197 and 195, and species of *Epistomina* in samples 193 and 191. This alteration of the dominant species is also indicated in the distribution of the Families, as the lituoilids, the vaginulinids and the epistominids alternate as the dominant family (Figs 7.7 and 7.8). In this group of samples there is an inverse relationship between the Lagenina and the Robertinina.

Sample 191 stands out from the rest of the samples in this group in being dominated almost to the exclusion of the other taxa by the genus *Epistomina* which has an abundance of over 80%.

The similarity index for this group of samples (Fig. 7.11) shows a gradual trend; the only distinguishing feature is the lack of similarity between 191 and the sample above. The α index is generally high for the first 4 samples (around 8), as shown in Fig. 7.12. Samples 193 and 191 are different with a drop to around 4. The other indices show a generally similar trend. Sample 193 is picked out as having a higher Simpson Dominance index (and correspondingly low Evenness). This is a product of the single dominance of the species *E. tenuicostata* in this sample at around 60%.

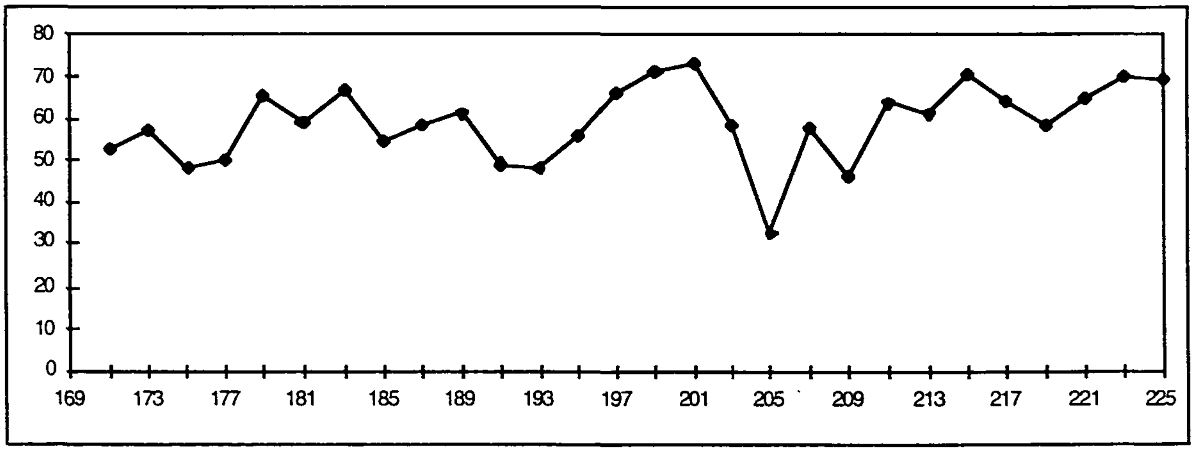


Figure 7.11. Similarity index (Bray-Curtis) for the Hartmoor Hill Borehole. (x-axis=sample number, y-axis = %).

Sample Group 189 to 169.

This sample group represents the stratigraphically youngest samples within the Hartmoor

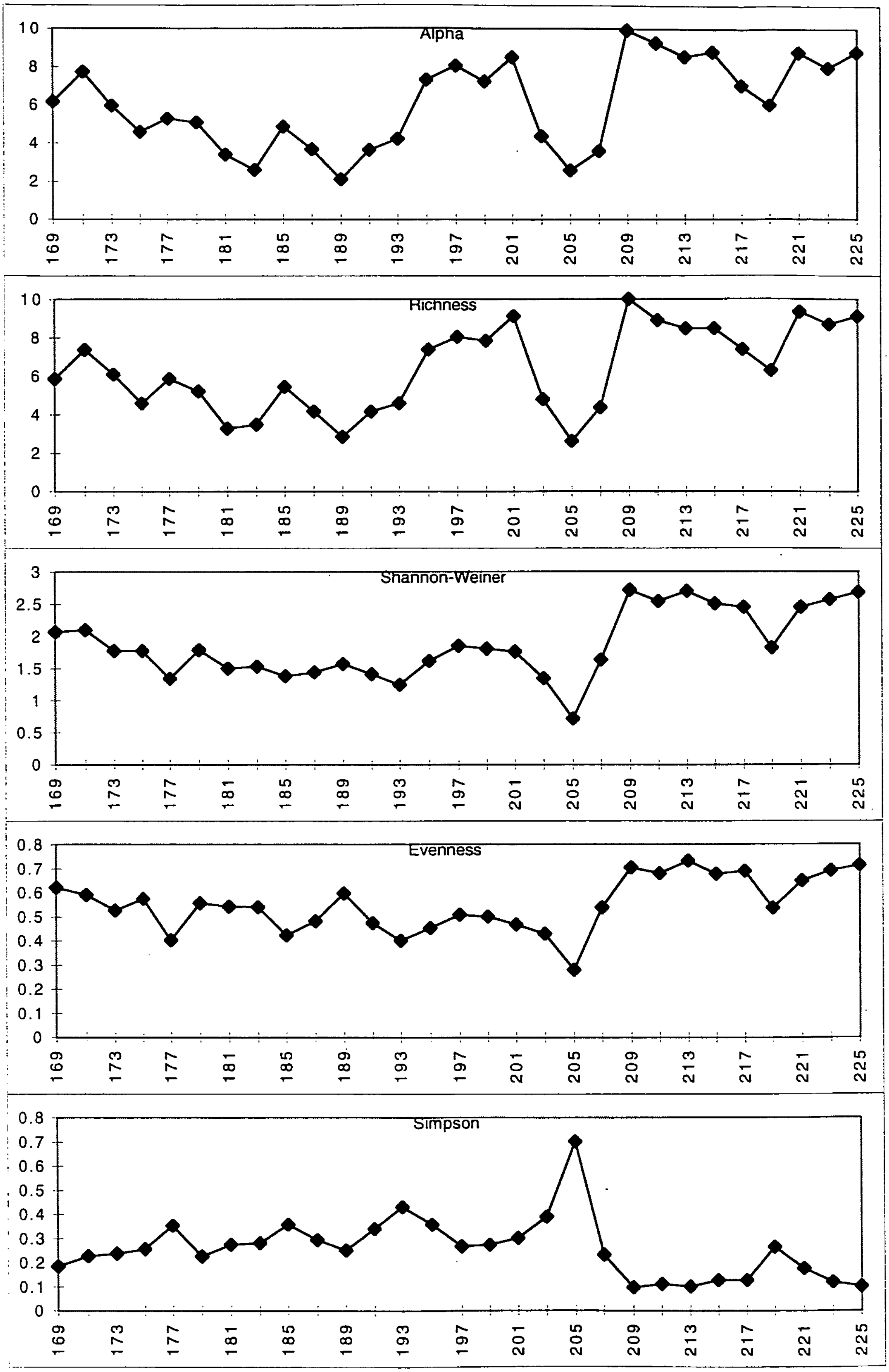


Figure 7.12. Diversity data from the Hartmoor Hill Borehole.
(x-axis = sample no.)

Hill Borehole. There is a marked change in faunal composition in sample 189 which distinguishes this group from the previously described group (201 to 191). However the clustering of samples above 177 on the MDS plot and Cluster Analysis dendrogram are less well defined and these samples seem to be separate from the other groups (Chapter 6, Figs 6.2, 6.3). For ease of description, samples 175 to 169 are described with this group. The lithologies of these samples represent the clays and silty clays of the Hazelbury Bryan Formation and are stratigraphically close to the major sand deposit (Sand C of the Hazelbury Bryan Formation). For details see Fig. 7.1.

Major trends indicated by the Suborders show an inverse relationship between the Robertinina, Textulariina and the Lagenina (Fig. 7.6). The Textulariina show two peaks in abundance, one at sample 185 and the other at 171, with a small dip in abundance at sample 181. Although, once again, the lituolids (in particular *A. coprolithiformis*) are dominant, the most abundant species in sample 171 is *Trochammina globigeriniformis* at 43% which accounts for the overall peak in abundance of the agglutinated assemblage in this sample (Fig. 7.7). This is distinct as the Trochamminidae constitute an insignificant part of the assemblage in the previous two groupings. Another interesting peak in the lituolid abundance is at sample 173 where the common abundance of *A. coprolithiformis* is augmented by the sub-dominance of the species *A. canui* at 21% (Figs. 7.7 and 7.9). Prior to this peak this species is present only in minor abundances and accounts for less than 1% of the assemblage per sample. The sub-dominant species at sample 175 is *Haplophragmoides* sp. 2 which accounts for 23% of the assemblage (Fig. 7.10). This sample also contains abundant *Textularia jurassica* compared to the rest of the samples although only comprising around 4% of the total assemblage.

The Lagenina show a low abundance for samples 189 to 177 but peak at samples 175 and 169 with *L. münsteri* comprising 43% and 35% respectively (Figs 7.6 and 7.9).

The Robertinina show a dominance of the assemblage in samples 189 and 181 where *E. parastelligera* and *E. tenuiscostata* make up around 33% and 42% of the assemblage respectively. Between these peaks the Robertinina decrease in abundance at sample 185 where their minimum coincides with the maximum of the Textulariina. Samples 175, 173 and 171 have little or no epistominid content which again corresponds with the peak in the agglutinated assemblages (Figs 7.6 and 7.9). The paucity of an epistominid assemblage may be attributed to the sandier facies, or possibly, because of the close proximity of these samples with the surface, to weathering and dissolution.

This group of samples contains the first major input from the miliolinid assemblages with peaks at samples 185, 179 and 173 (Fig. 7.6). Although less than 10% of the total assemblage at these samples this group of foraminifera is present in only very minor quantities prior to this. The species *Quinqueloculina horelli* is the dominant form.

Spirillina infima is present in samples 173 and 175 and accounts for the peak in the Spirillinina (Fig. 7.6).

The similarity index for this group of samples shows an uneven trend (Fig. 7.11) with generally moderate similarity (50-60%). The α index shows a general increase from sample 189 with a value of 2 (the lowest in the borehole) to sample 171 where the value has increased to around 8. Sample 185 shows a localised peak at $\alpha = 5$, as shown in Figure 7.12. The other indices show a regular pattern with no marked deviation. Sample 177 shows a minor deviation and shows a peak in the Simpson Dominance Index which indicates that other than the dominant and subdominant species *(E. tenuicostata* 44% and *A. coprolithiformis* 40%) most of the other species are present in only minor abundance. Sample 185 shows a similar peak with species *A. coprolithiformis* and *E. stellicostata* contributing to 50% and 31% of the total assemblage respectively.

7.5.2.2 General Trends.

Refer to the previous Figures 7.6 to 7.12 for details.

The composition of the assemblage from the Hartmoor Hill Borehole appears to follow a distinct cycle. The Textulariina exhibit three major peaks in their abundance, with major declines in abundance in between, where they become an almost non-existent component of the assemblage. The peaks in abundance occur at samples 213, 201 and 171, and the samples with a Textulariina component of almost zero are 193 and 205. When the sedimentary log is consulted (Fig. 7.1) there is no clear relationship with abundance of agglutinated foraminifera and lithology. The samples with the highest proportion of agglutinated foraminifera are from clay and silty lithologies. The major component of the agglutinated foraminiferal assemblage is from the lituolids, which dominate in most of the samples. The pattern of distribution is, in general, followed by the other agglutinated families. One exception is, however, an inverse relationship with the haplophragmoidids. Both peaks in abundance of the Haplophragmoididae coincide with drops in abundance of the lituolids. The trochamminids are generally a small component of the assemblage but are extremely abundant in sample 171 and to a lesser extent in the samples surrounding the peak at sample 211.

The robertininids have an inverse relationship with the textulariinids in that their major abundance peaks coincide with presence of an impoverished agglutinated assemblage.

The Lagenina also seem to have an inverse relationship with the Robertinina especially between samples 205 and 195, although this relationship is not as well defined as between the Textulariina and the Robertinina. The family Vaginulinidae has an even better defined inverse relationship with the epistominids.

The Miliolina are a minor component of the assemblage and prior to sample 185 are virtually absent. Sample 185, 179 and 173 show peaks in their abundance with the maximum abundance of around 9% reached in sample 173.

The dominant genera show a distinct pattern. In general the dominant and subdominant genera tend to be relatively close in abundance. However, at samples 219, 205, 191, 181 and 173, the dominant genus increases substantially in abundance (see Fig. 7.10).

The species dominance pattern is more regular (Fig.7.10). Before sample 205 the dominant species is rarely greater than 30%. At sample 205 there is a distinct change with *Epistomina parastelligera* comprising 83% of the assemblage. Above this sample, the dominant and subdominant species become closer in abundance, but generally a higher percentage of the assemblage than the samples below 205.

7.5.2.3. Palaeo-ecological interpretation.

The samples from the base of the borehole (225) to sample 209 show a high evenness value and a correspondingly low value of the Simpson dominance index (Fig. 7.12). This probably indicates a favourable environment where no one species is particularly well adapted and is outcompeting the rest of the assemblage. The species dominance graph also indicates this and shows that the dominant and subdominant species have a similar abundance of around 30% (Fig. 7.10). The α-index has an average value of 8.3 for these 9 samples and includes the highest value for the entire borehole. This high α index value suggests normal marine conditions. The high evenness and richness values and higher diversity values (Shannon Weiner, etc.) possibly indicate a more stable environment. As Margalef (1963) points out, communities left undisturbed will evolve from immature to mature ecosystems where an increase in complexity will produce an increase in diversity. Samples 213, 211 and 209 include a very abundant assemblage of attached foraminifera (e.g. *Nubecullinella bigoti* and *Nubeculinella bacularis* var. *tibia*, *Placopsillina* and *Subboidella*) which are generally taken to indicate stable environments where there is either a break in the succession with little or no sedimentation, or slight bottom currents that serve to remove the sediment and allow the attached forms to survive and avoid rapid burial. The presence of ophthalmidiids and spirillinids in samples 225 to 217 may indicate shallower water. In general spirillinids are found attached to seaweed and firm substrates (Murray 1971, 1973, 1991), which would tend to indicate a shallower environment. The ophthalmidiids have previously been recorded as indicating shallow water in the Jurassic (Gordon, 1970; Barnard *et al.*, 1981). Shipp (1989), however, indicates that species of

Ophthalmidium in the Corallian have been found in the Nothe Clay which is indicative of a deeper, offshore shelf environment (Fürsich, 1976). This may indicate the preference for a quieter environment by the Ophthalmidiidae. Samples 219 and 217 show a drop in the value of the α index, and sample 219 shows a lower value for the diversity indices.

The large lituolid *Triplasia* sp. 1 occurs only in samples 211 and 209, and *Ammobaculites coprolithiformis* peaks in abundance at samples 217 and 215. Together these large lituolids have been taken to indicate deeper water (Barnard, *et al.* 1981). The trochamminids are a major component of the assemblage in sample 211, and the textulariids show a peak at sample 209. The smaller agglutinated species suggest a shallow water environment (Gordon, 1970), although especially when they occur on their own. Species of *Trochammina* have been reported from environments which indicate low oxygen levels, partially anaerobic conditions or reduced salinity, although again this is more appropriate if the assemblage is dominated by this particular taxon.

The robertininids have previously been taken to indicate either shallow or deep water environments (Gordon, 1970), although Shipp (1989) preferred to envisage salinity as the control of epistominid distribution rather than bathymetry, with more normal marine salinity favouring their abundance. Barnard *et al.* (1981) suggest that *Epistomina* (*Brotzenia*) appears to indicate a relatively shallow environment. In another interpretation of the environment indicated by epistominids, Haynes (1981) reports that in general *Epistomina* indicates deeper, often poorly oxygenated environments and that the tendancy to develop complex internal structures may be related to the exploitation of particulate, detrital organic matter (similar to the Buliminida). In these samples the epistominids become dominant in sample 219 before decreasing in number to almost zero by 209. The most dominant component of the Robertinina in sample 219 is *Epistomina mosquensis*. The almost exclusive epistominid assemblage is taken to represent a normal salinity environment. The very fine clay lithology may not be a suitable depositional environment for the morphologically large lituolids, as they are almost absent in this sample.

Thus, the assemblage from these samples indicates an open marine, relatively deeper water perhaps, offshore shelf environment, with quiet conditions becoming shallower towards sample 209. An abundance of attached forms (*Nubeculinella*) is taken as being indicative of either quiet conditions with a break in sedimentation or (usually in the presence of ophthalmidiids or miliolinids) bottom currents. In samples 213, 211, 209, there is a major increase in the attached forms, but the ophthalmidiids are only present in samples 225-217. Sample 209 however, records the presence of the miliolinid *Cornuspira*. The increase in trochamminids to around 30%, and the abundance of the other small agglutinated taxa (textulariids, *Ammobaculites agglutinans*) may indicate a shallower environment, perhaps with a slightly lowered salinity or dysaerobic bottom conditions. The Oxford Clay depositional environment has, however, been indicated as not being anaerobic (Hudson and Palframan, 1968). Duff (1975) mentions that the Lower Oxford Clay bottom conditions were also not anaerobic. Rutten (1956) suggests that the Oxford Clay was deposited under alternating aerobic and anaerobic conditions. The presence of oyster fragments and horizontal burrows in samples 209 and 211 would probably indicate well oxygenated bottom conditions. Vertical burrows in sample 213 may indicate less favourable conditions, or rapid sedimentation.

An abrupt change in the assemblage is marked in samples 207 to 203, but especially in sample 205. The α index records a drop from around 10 to just over 2.5. The other diversity indices show similar abrupt changes, the Simpson dominance index records the highest value of 0.7 for the entire borehole. The change in value for these indices would indicate that the environment has become restrictive by some degree which inhibits the diversity of the assemblage and favours the abundance of a small number of species. Communities characterising "normal" environments have generally higher species diversity than do communities from environments which experience extreme conditions (Odum and Kornicker, 1958; Gibson, 1966). The number of species in sample 205 is 13 which is the lowest in the entire borehole. The sample is dominated by *Epistomina*, in particular *E. parastelligera* which comprises over 83% of the assemblage. The next most abundant species is *E. tenuicostata* which comprises around 6%. The lithology this sample is taken from is particularly fine clay. An environment which favours almost exclusively epistominids is difficult to envisage. Mechanical sorting of the sample or preferential dissolution would more likely effect the aragonitic taxa than agglutinating or calcareous taxa. The lithologies of these samples, although fine clay, are not particularly different from those surrounding. Silt starts to become more abundant in the samples younger than these however, and sample 201 represents the first pure silt lithology. Also, many of the ranges of taxa either stop at sample 209, or the taxon becomes less abundant after these samples. It is clear then that the samples 207 to 203 represent a distinctive feature. Gordon (1967) reported that *E. parastelligera* become particularly important in samples from the Callovian of Brora, although at the time he did not understand the significance of their disribution pattern.

The environment may represent a sudden deepening whereby fine sedimentation increases and there is a substantial amount of particulate matter in the water. As Haynes (1981) mentions, the epistominids may be better adapted to these environments. The only other taxa present (albeit in small numbers) are trochamminids and textulariids which are better suited to restricted environments, and *Lenticulina münsteri*, which is an ubiquitous taxon.

Samples 201 to 169, in general, have a greater content of silt, fine and medium sand and so probably represent a generally shallower environment than the previous samples. This is also indicated by the α index which has an average value for samples 201 to 169 of $\alpha = 5.3$ compared to the average value of $\alpha = 8.3$ for samples 209 to 225. This general trend is also displayed in the Margalef Richness Index and (perhaps clearest defined) by the Shannon Weiner information function which shows higher values before sample 205 and low values after sample 205 (Fig. 7.12). As mentioned previously (Section 7.2.2.2.) lower values of the information function may represent shallower environments.

The distribution of the lageninids from 201 to 193 show a distinct peak which coincides with the silt-rich horizons in this part of the borehole. The morphology of the dominant genus *Lenticulina* is probably better suited to more turbulent environments, the robust nature of the test and the hydrodynamic properties are all indicative of an ability to cope with a shifting siltier environment. The robertininids are an insignificant component of the assemblage in these samples and the large lituolid *A. coprolithiformis* is in decline. The presence of spirillinids and miliolinids also indicates a shallower environment, although the absence of the trochamminids and other small textulariinids probably indicates a more oxygenated, higher energy environment. The absence of the Robertinina in these samples would suggest deposition in a near shore facies, probably in the transition zone between offshore shelf and the lower foreshore or perhaps foreshore.

The reversal of these trends for the samples 193 to 177 indicates a return to, if not particularly deeper water, then a quieter, lower energy environment.

From sample 177 to 169 the presence of certain taxa indicate a distinct shallowing of the environment. The miliolinids and the spirillinids both reappear and comprise between 5 and 10% of the assemblage. The trochamminids become the dominant species in sample 171 and both *Haplophragmoides* and *Ammobaculites canui* are significant components. The correlation coefficient for *A. canui* and miliolinid species is high which would suggest, on the strength that the miliolinids are indicative of shallower environments, that *A. canui* also has a preference for shallow water. This species is particularly abundant in sample 173. From samples 175 to 171 the epistominids drop in abundance, and would seem to comply with a shallower water model.

From samples 201 to the top of the borehole (sample 169) the major suborders show a cyclical trend. This is interpreted as indicating a variable shallow water environment, probably oscillation between, offshore deeper waters and the transition zone between shoreface and the lower shoreface environment.

7.5.3. Bowden Farm Borehole.

The Bowden Farm Borehole includes the lowest member of the Stour Formation, the Woodrow Clay Member, the junction with the underlying Hazelbury Bryan Formation and spans most of the Hazelbury Bryan Formation (See Fig. 7.2 for details). There are 18 samples in total from this borehole and they are numbered from 144 to 72. Sample 72 is from the Woodrow Clay Member and the remaining samples are from the Hazelbury Bryan Formation. The borehole overlaps with the upper part of the Hartmoor Hill Borehole as shown in Figure 7.5 and Figure 3.18.

7.5.3.1 Faunal Distribution.

The following sections refer to Figs 7.13 to 7.19.

Sample Group 144 to 120.

This sample group is stratigraphically the oldest within the Bowden Farm Borehole. The samples are from predominantly clay lithologies with some silty clay samples. The distribution of the Suborders and Families for this group are fairly consistent as shown in Figures 7.13 to 7.15. *Ammobaculites coprolithiformis* is the most dominant species overall and generally comprises of around 45% of the total assemblage (Fig. 7.16). It is the dominant species for samples 140 to 124. *Epistomina parastelligera* and *E. stellicostata* are the dominant species in samples 144 and 120 respectively, and species of *Epistomina* are the 2nd most dominant species when *A. coprolithiformis* is the dominant (Fig. 7.17). The Textulariina and Robertinina are fairly consistent in their distribution remaining almost steadily fixed at around 50%. Both these suborders decrease in abundance slowly towards sample 120 as the Lagenina start to become a more important part of the assemblage. The Miliolina are present in small numbers and the distribution of *Quinqueloculina horelli* varies from <1% to around 4% of the total assemblage (Fig. 7.13).

The similarity index is fairly constant for most of the samples, and illustrates the difficulty in dividing the samples from this borehole into groups (Fig. 7.18). The groupings within the Bowden Farm Borehole are not as well defined as in some of the other boreholes as discussed in Chapter 6. As a consequence some of the sample groups may be slightly arbitrary. The α index slowly increases from a minimum of around 2.5 to sample 120 where the value is around 5 as shown in Figure 7.19. The other indices do not highlight any

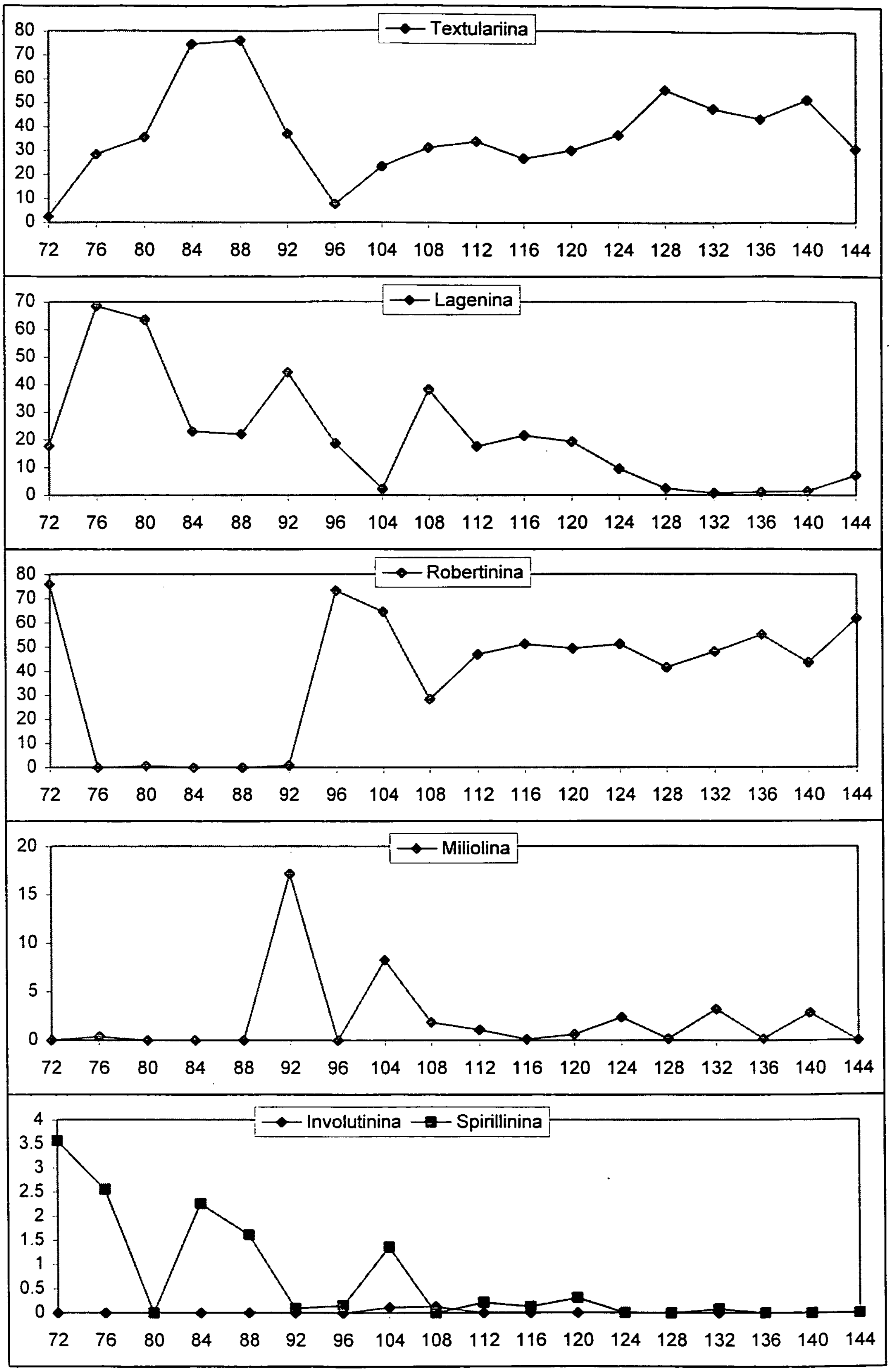


Figure 7.13. Distribution of the Suborders for the Bowden Farm Borehole (x-axis = sample no., y-axis = %).

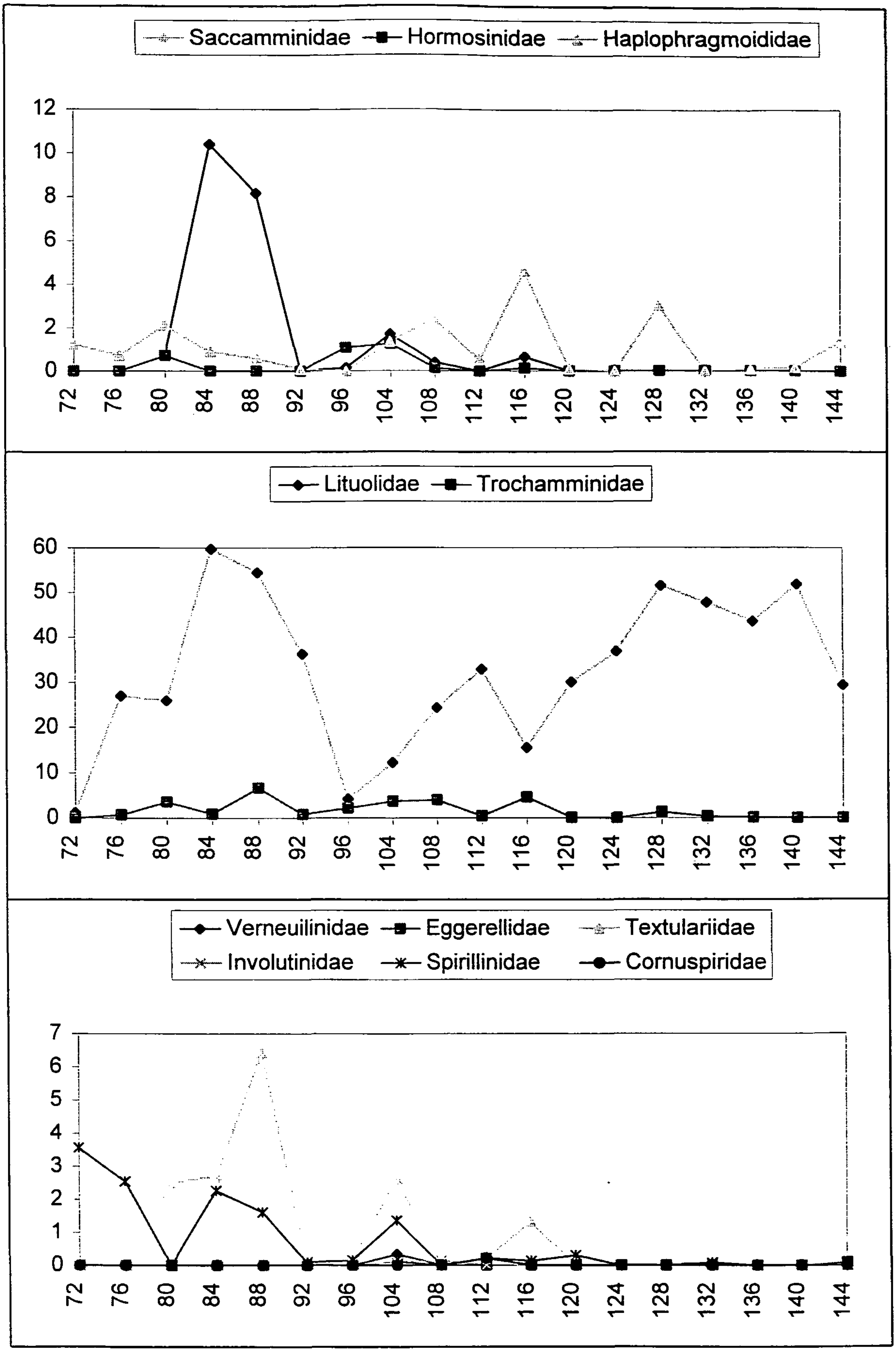


Figure 7.14. Distribution of Families in the Bowden Farm Borehole. (x-axis = sample no., y-axis = %).

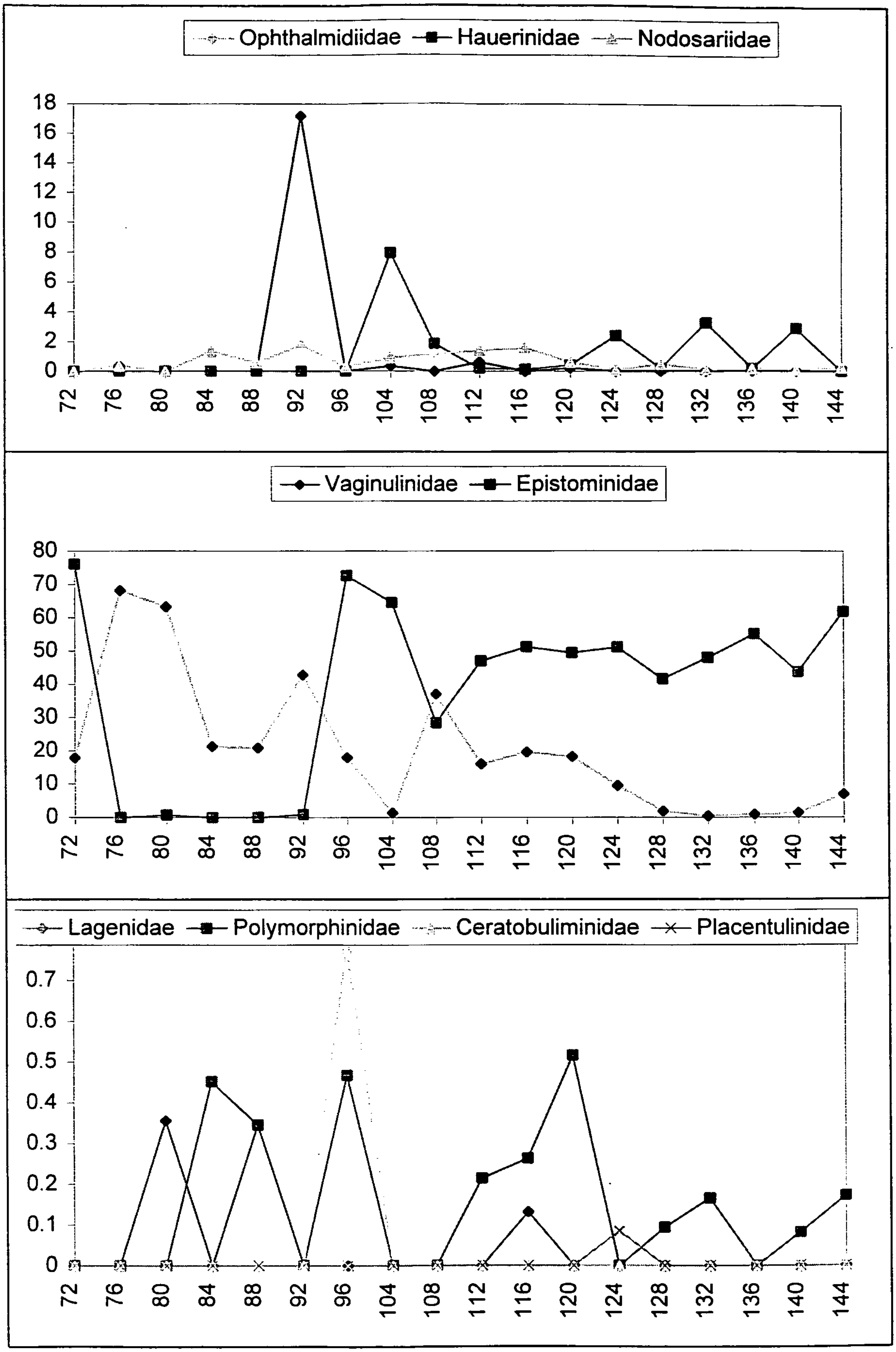


Figure 7.15. Distribution of Families in the Bowden Farm Borehole. (x-axis = sample no., y-axis = %).

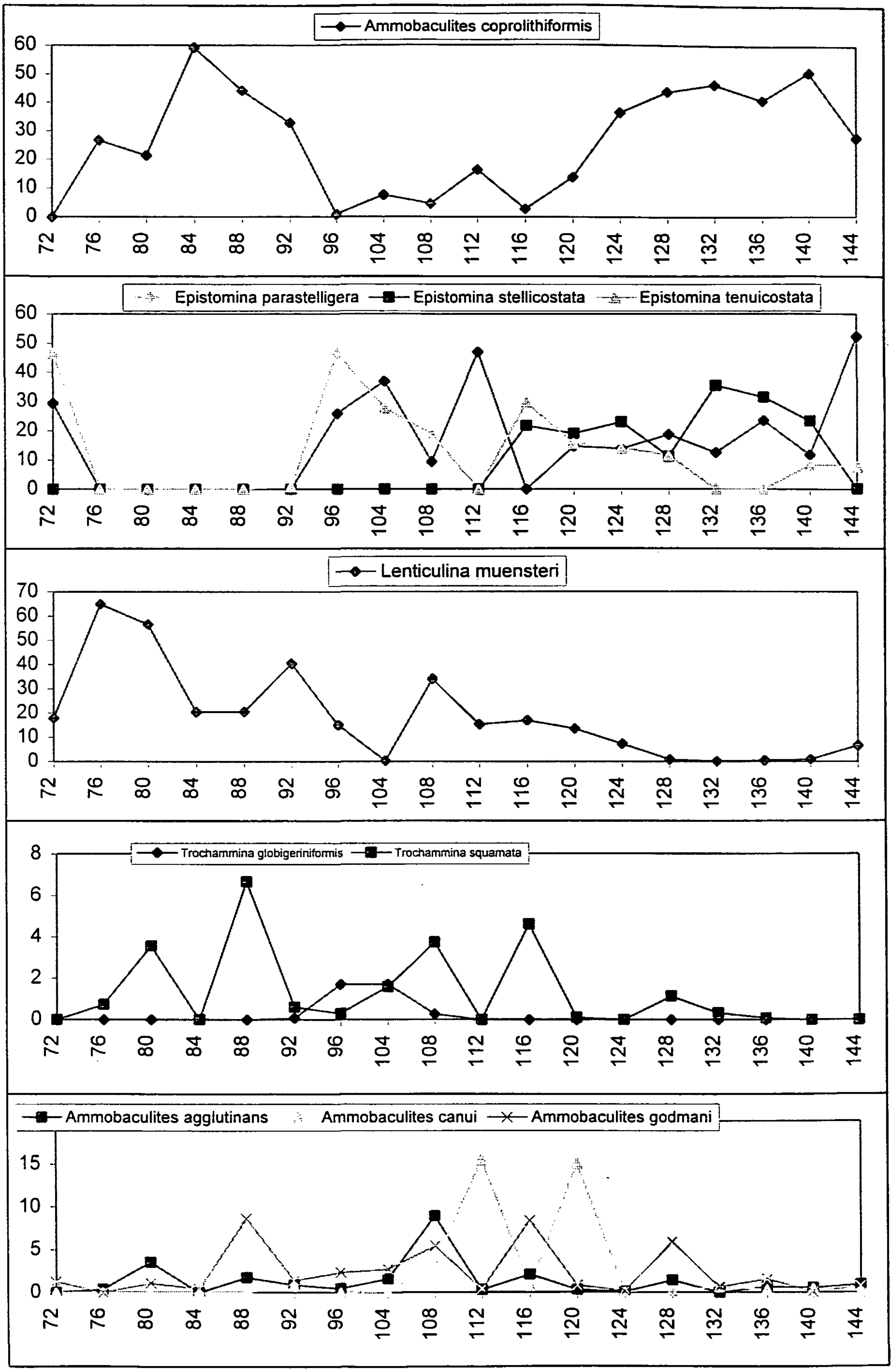


Figure 7.16. Distribution of selected Species from the Bowden Farm Borehole. (x-axis = sample no., y-axis = %).

Sample	Species	Dominant	Subdominant	Species
72	E. tenuicostata	47	29	E. parastelligera
76	L. muensteri	65	27	A. coprolithiformis
80	L. muensteri	57	21	A. coprolithiformis
84	A. coprolithiformis	59	20	L. muensteri
88	A. coprolithiformis	44	20	L. muensteri
92	L. muensteri	40	33	A. coprolithiformis
96	E. tenuicostata	47	26	E. parastelligera
104	E. parastelligera	37	28	E. tenuicostata
108	L. muensteri	34	19	E. tenuicostata
112	E. parastelligera	47	16	A. coprolithiformis
116	E. tenuicostata	30	22	E. stellicostata
120	E. stellicostata	19	16	E. tenuicostata
124	A. coprolithiformis	36	23	E. stellicostata
128	A. coprolithiformis	44	19	E. parastelligera
132	A. coprolithiformis	46	35	E. stellicostata
136	A. coprolithiformis	41	31	E. stellicostata
140	A. coprolithiformis	51	23	E. stellicostata
144	E. parastelligera	52	28	A. coprolithiformis

Sample	Genus	Dominant	Subdominant	Genus
72	Epistomina	76	18	Lenticulina
76	Lenticulina	65	27	Ammobaculites
80	Lenticulina	60	26	Ammobaculites
84	Ammobaculites	60	21	Lenticulina
88	Ammobaculites	54	20	Lenticulina
92	Lenticulina	41	36	Ammobaculites
96	Epistomina	73	18	Lenticulina
104	Epistomina	65	12	Ammobaculites
108	Lenticulina	35	28	Epistomina
112	Epistomina	47	33	Ammobaculites
116	Epistomina	51	19	Lenticulina
120	Epistomina	49	30	Ammobaculites
124	Epistomina	51	37	Ammobaculites
128	Ammobaculites	51	42	Epistomina
132	Epistomina	48	48	Ammobaculites
136	Epistomina	55	43	Ammobaculites
140	Ammobaculites	52	44	Epistomina
144	Epistomina	62	29	Ammobaculites

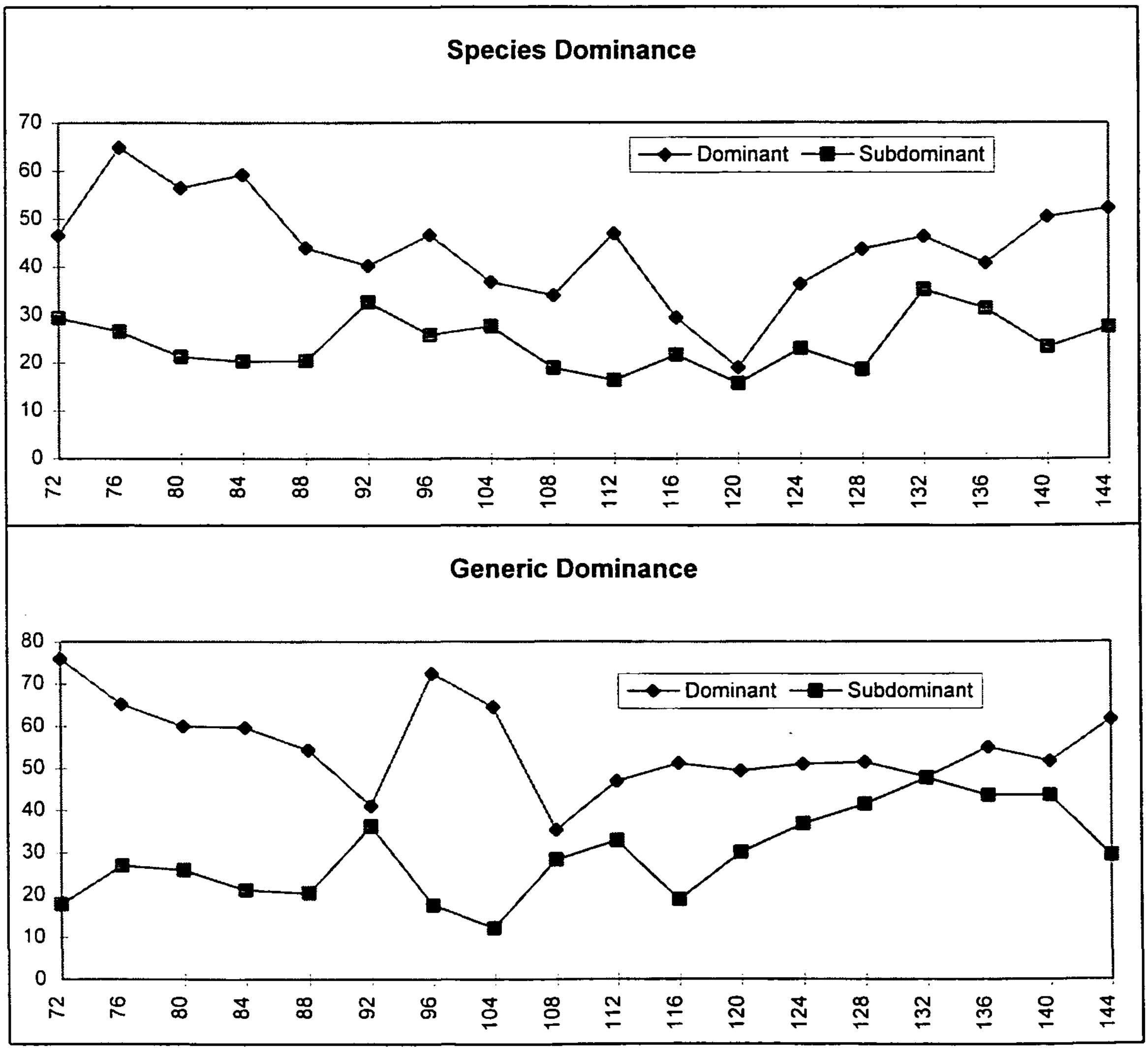


Figure 7.17. Generic and Specific Dominance for the Bowden Farm Borehole.

particular sample as being greatly different from the rest of the samples in this group. Sample 132 however shows a small peak for the Simpson Dominance index which is slightly less evident on the graphs for the other indices. This is due to the predominance of the genera *Ammobaculites* and *Epistomina* (approximately 48% of the assemblage each). The generic and specific dominance charts (Fig. 7.17) indicate that there is, in general, no individual taxon which is dominant and in this sample group the assemblage is evenly distributed. The number of species is quite low compared with the middle section of the borehole (sample group 116 to 96), which is illustrated on the Richness graph (Fig. 7.17) (see also Chapter 6, Table 6.2).

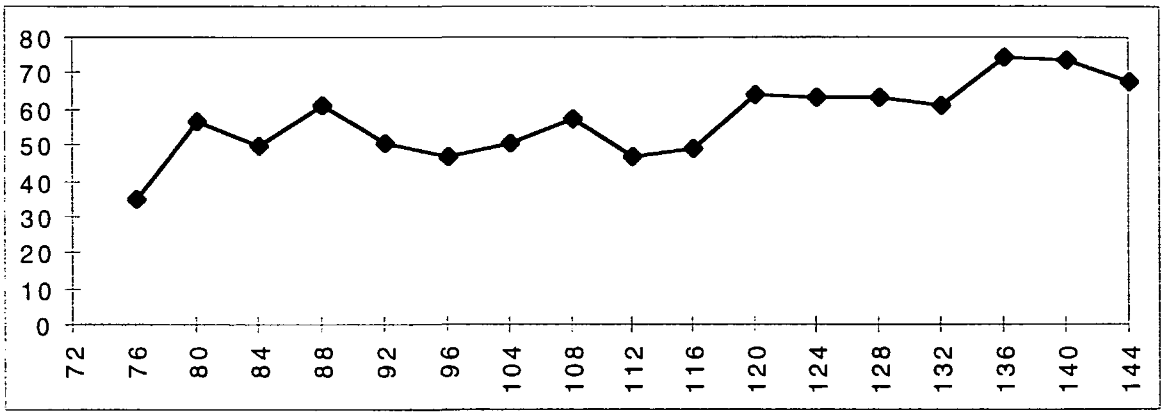


Figure 7.18. Similarity Index (Bray-Curtis) for the Bowden Farm Borehole. (x-axis=sample numbers, y-axis = %)

Sample Group 116 to 96.

Sample 116 is taken from a slightly silty, clay lithology, while sample 112 is from a silt lithology. The other samples are from silt free clay. All are from within the Hazelbury Bryan Formation (Fig. 7.2).

The Textulariina continue to decrease in abundance from the last group until they are only a small component of the assemblage, at around 8%, in sample 96 (Fig. 7.13). The Lagenina increase slowly at first then exhibit a peak of around 40% at sample 108 before dropping almost to 0% in the sample above (104). This trend is mirrored by the Robertinina which are most abundant at sample 96 and show a distinct trough in the graph at sample 108 which coincides with the peak in abundance for the Lagenina. The Miliolina have a steady increase to a major peak at sample 104 (although only 8% of the total assemblage) before

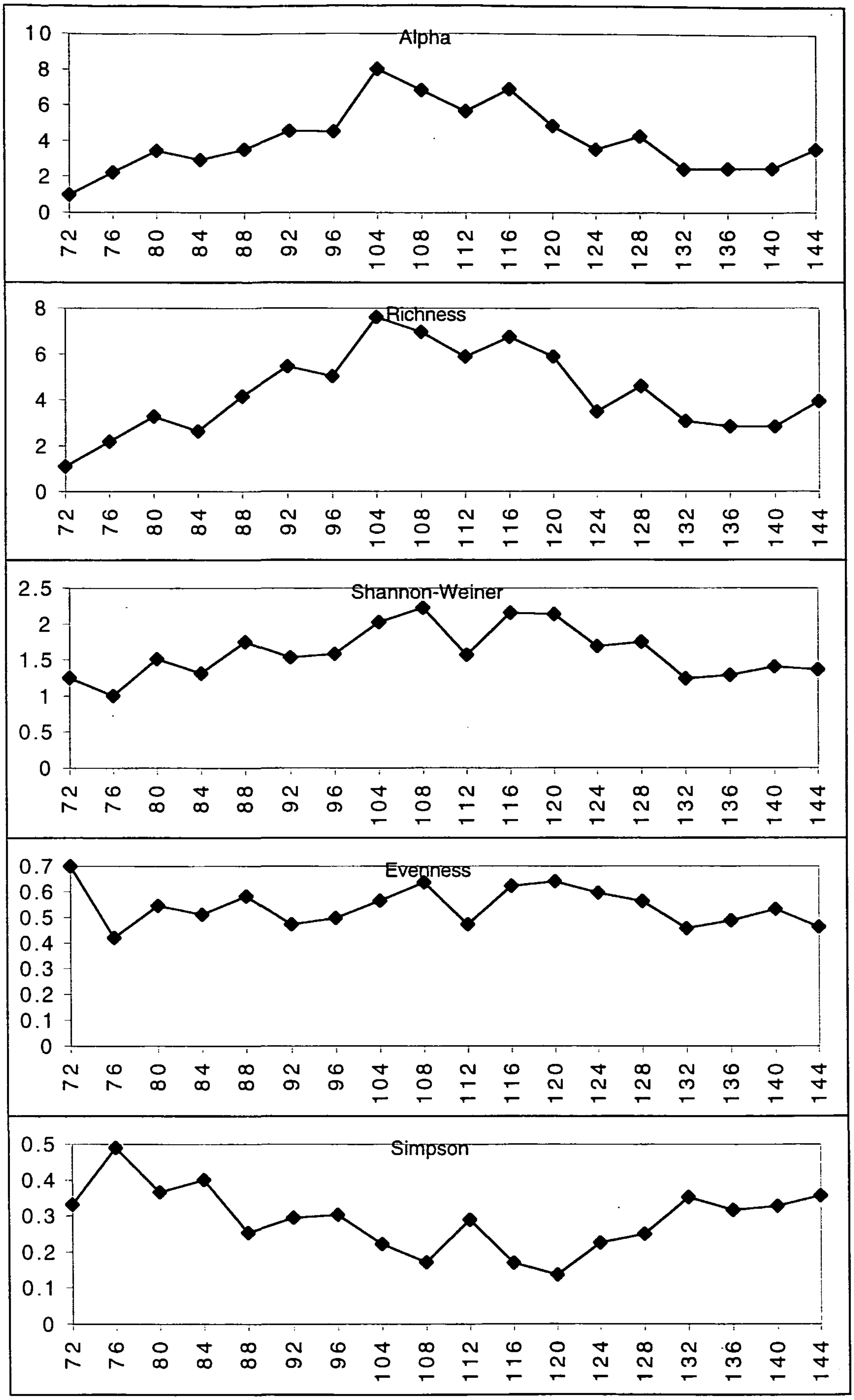


Figure 7.19. Diversity data for the Bowden Farm Borehole.
(x-axis = sample no.)

disappearing at sample 96. Textulariina have their minimum abundance at sample 96 where the Robertinina show a maximum. The trochamminids peak in samples 116 and 108 and the textulariids peak in samples 116 and 104 (Fig. 7.14) with the first occurrence of *Textularia jurassica* in this borehole. This species however does not have a major effect on the abundance of the agglutinated assemblage because the lituolids are the dominant family in the composition of the Textulariina in these samples. *Lenticulina münsteri* again is the most dominant lageninid. The last occurrence of the miliolinid *Quinqueloculina horelli* is at sample 104 where it attains its maximum abundance, although only around 8% of the total assemblage. The assemblage in samples 104 and 96 show an interesting departure from the more evenly distributed taxa from the assemblages of the surrounding samples and are dominated by the genus *Epistomina* which comprises 65% and 73% of the total assemblage in these samples respectively (Fig. 7.17).

These samples all show values of around 50% on the similarity index (Fig. 7.18), which is also illustrated by the poor affinity of the samples on the Cluster Analysis dendrograms and the MDS plots (see Chapter 6, Figs 6.7 and 6.8). The α index reaches its highest value for the borehole at sample 104 and has a value of around 8 (Fig. 7.19). There is a slow increase from sample 116 to sample 104 after which the values decrease. The general trend for the α index within this borehole is for it to increase from the lowest sample (144) to sample 104, then decrease to sample 72 at the top of the borehole. The greatest number of species is recorded for the assemblage at sample 104. The other indices show no major deviations other than a slightly different value for sample 112 (Fig. 7.19). This is probably due to the relatively high abundance of the species *Epistomina parastelligera* (47%) within a large number of species (28) recorded in this sample.

Sample Group 92 to 76.

These samples are taken from the more clay rich lithologies within the large sand body (Sand D) of the Hazelbury Bryan Formation. See Figure 7.2 for details.

This group of samples is distinctively different from the previous groups. The most noticeable trend is the near complete absence of the Robertinina. This is illustrated by a corresponding increase in the percentage of the agglutinated foraminifera and the Lagenina (Fig. 7.13). The Textulariina are dominant in samples 88 and 84 and the Lagenina are dominant in samples 80 and 76. Sample 92 also has a high proportion of the Miliolina (Fig. 7.13) which is recording the first major influx of the Ophthalmidiidae (Fig. 7.15) and in particular *Ophthalmidium strumosum*, which reaches 17% of the total assemblage. Sample 88 shows a peak in the abundance of the trochamminids and the textulariids, although each family comprises only 7% of the total assemblage. These two families follow a similar distribution pattern (Fig. 7.14). Throughout this group there is also an increase in the abundance of the Spirillinina, although they are absent in sample 80 (Fig. 7.13).

The general pattern of species dominance is for the dominant species to increase in abundance throughout this group until sample 76 where *Lenticulina münsteri* comprises 65% of the assemblage (Fig. 7.17). The generic dominance also increases, with *Lenticulina* dominating three out of the five samples, from 41% in sample 92 to 60% in sample 80 to 65% in sample 76. *Ammobaculites* is the dominant genus in samples 88 and 84.

The similarity index shows a similarity of around 50% (Fig. 7.18). The α index decreases from around 5 to just over 2 for sample 76 (Fig. 7.19). The Simpson Dominance Index increases in value to reach its maximum for the borehole in sample 76, the Evenness Index is almost level for these samples.

Sample 72.

Sample 72 is taken from a more clay rich lithology within the Woodrow Clay which is the lowermost Member of the Stour Formation (Fig. 7.2).

This sample is very different from the previous samples in as much as the Robertinina are the dominant group (this Suborder is absent in the previous five samples, Fig. 7.13). *Epistomina tenuicostata* and *Epistomina parastelligera* account for around 76% percent of the total assemblage. The Textulariina are at their lowest abundance for the entire borehole and the Lagenina are also greatly reduced in abundance. The only Suborder apart from the Robertinina to increase in abundance is the Spirillinina although only accounting for 3.6% of the assemblage.

The α index has a value of 1 which is the lowest recorded in the borehole (Fig. 7.19). The Evenness Index increases for this sample because although dominated almost entirely by the genus *Epistomina* the species distribution is quite even, although at 6 species, this is the fewest number of species recorded in a sample in this borehole.

7.5.3.2 General Trends.

Refer to Figures 7.13 to 7.19 for details. The Textulariina show a gradual decrease in abundance throughout the borehole to sample 96. From sample 96 to sample 72 they exhibit a major peak, with their maximum abundance at samples 88 and 84 (Fig. 7.13). The textulariinids show a negative correlation with the robertininids and their minimum abundance coincides with the maximum abundance of the robertininids (samples 96 and 72). The distribution pattern of the agglutinated foraminifera is determined by the lituolids which are the dominant agglutinated family. The other agglutinated families generally account for no more than 10% of the assemblage at their maximum abundance (Fig. 7.14). The Hormosinidae peak in samples 88 and 84 mirroring the overall pattern of abundance of the agglutinating foraminifera. The trochamminids and textulariids have a similar distribution pattern with their maximum peaks of abundance occurring in sample 88 (Fig. 7.14).

The robertininids exhibit a fairly regular dominance for the lower part of the borehole until sample 108 where they drop in abundance to 30%, before reaching a maximum immediately after, at sample 96. From sample 92 to 76 they are almost absent from the assemblage. Sample 72, however, is dominated by the robertininids which reach their maximum abundance for the borehole. The near complete absence of the epistominids in samples 92 to 76 could be due to the lithology, as these samples are from silty horizons. See below for discussion.

The lageninids increase slowly in abundance from sample 144 to 108 but comprise only a small part of the assemblage with their maximum abundance of around 40% occurring at sample 108. Throughout these samples they show a negative correlation with the robertininids. From sample 104, where they reach almost zero, they increase and attain their maximum abundance at sample 76, where they comprise around 70% of the assemblage. In sample 72 they are reduced to around 10%. Overall, there is a negative correlation with the robertininids. The main family contribution to the lageninid abundance pattern is the Vaginulinidae (compare Figs 7.13 and 7.15).

The miliolinids, again, are present only in small numbers but reach peaks in their abundance at sample 104 where they comprise around 8% of the assemblage and then at sample 92 where they reach their maximum abundance of around 17%. The peak at 92 is due to the abundance of Ophthalmidiidae and the peak at sample 104 is due to the abundance of Hauerinidae.

The other suborders comprise less than 4% each of the assemblage at their maximum abundance. They appear more frequently after sample 108.

In general the samples are dominated by the genera *Ammobaculites* and *Epistomina*, especially in samples 144 to 112 (Fig. 7.17). These samples show the dominant and subdominant genera to be fairly close in abundance, generally accounting for around 80% of the assemblage combined. There is a substantial change in the dominance pattern for samples 104 and 96 where the dominant species alone, accounts for around 70% of the assemblage. From sample 92, which has an almost equal dominance of *Lenticulina* and *Ammobaculites*, there is an alternation in dominance between these two genera. Towards the top of the borehole the dominant species steadily becomes more abundant and the subdominant species declines until sample 72 which has *Epistomina* as the dominant genus at around 76% of the assemblage.

The species dominance plot shows that, in general, no one species alone is particularly dominant (Fig. 7.17), although the samples from 84 to 76 are slightly different in that the dominant species comprises around 60% of the assemblage, compared with 30-50% for the other samples.

7.5.3.3. Palaeo-ecological interpretation.

The distribution of the assemblage in this borehole separate the samples into roughly two trends. Samples from 144 to around 96 and the remaining samples. The α index gradually increases in value to sample 104 where $\alpha = 8$, after which it decreases rapidly to sample 96 and then gradually to sample 72, where the value $\alpha = 1$ is the lowest in the borehole. The average α value for all the samples is just over 4, which is relatively low. The other indices indicate relatively even results for this borehole with only sample 112 standing out as different from the others. Sample 72 shows a high value for the Evenness index.

The robertininids are an important component of the assemblage and comprise around 50%, after decreasing in abundance briefly at sample 108, they increase to a maximum at sample 96. The textulariinids show a regular decrease in abundance to sample 96. The lageninids show a regular increase in abundance to sample 108. Taken as a whole, the distribution of the major sub-orders indicates an open marine setting. *Ammobaculites canui* peaks in samples 120 and 112 which is coincident with siltier lithologies. As mentioned above this species is probably indicative of shallower environments. The peaks of the smaller agglutinated families at around 116 to 104 probably indicate a shallowing of the water.

The most abrupt change in faunal composition occurs at sample 92, where the robertininids completely disappear coincidental with a major peak in the Ophthalmidiidae. This sample represents the silty base of one of the major sand units, in this borehole. The environment suggested is a shallower environment than before and is probably deposited within the lower shoreface.

Samples 88 and 84 show peaks in abundance for the genus *Lagenammina* which, according to Murray (1991), prefers a sandy substrate in the Recent. This seems to also be the case for the preference of this species for the Upper Jurassic in this study.

The absence of the epistominids in the samples 92 to 76 may be due to the nature of the lithology. These samples have a reasonably high sand content which, as noted by Hart (1973) and Carter and Hart (1976), affects the abundance of the epistominids, and an inverse relationship with the percentage of sand is indicated. This may be a factor of diagenesis as the sandier lithology would better facilitate the percolation of pore fluids, which would aid the dissolution of the aragonitic tests. The low diversity of these samples may also be attributed to this factor.

Sample 72 is from a more clayey lithology with patches of micrite or calcareous cemented horizons. The robertininids dominate this sample accounting for 76% of the assemblage. The previously rich vaginulinids decline in numbers and *Lenticulina münsteri* comprises most of the remaining assemblage. There are only 6 species recorded from this sample which is the lowest number in the borehole. A low richness may indicate a restricted environment, but as seen previously, the dominant taxa are epistominids. Woody material is found in this sample and may indicate close proximity to the shoreline, with possible estuarine influence, or a tidal flat/ bay fill setting. The low salinities encountered in these settings could account for the low diversity, although in this environment small agglutinated taxa would be expected. *Haplophragmoides* sp. 2 and *Ammobaculites godmani* are present however although they only account for less than 3%.

7.5.4. East Stour Borehole.

Twenty samples are taken from the East Stour Borehole and are numbered 30454 to 30416 (for simplicity only the last two digits are used in the discussion).

Lithostratigraphically the East Stour Borehole spans the units from the Clavellata Beds Formation to the Hazelbury Bryan Formation. The borehole first penetrates the Clavellata

Beds Formation and the underlying Todber Freestone Member of the Stour Formation, although no samples have been taken from these lithologies. The Newton Clay Member, the Cucklington Oolite Member and the Woodrow Clay Member from the Stour Formation are all sampled, although the Sturminster Pisolite Member is not. In the Hazelbury Bryan Formation 9 samples have been taken. From the Woodrow Clay Member, Cucklington Oolite Member and the Newton Clay Member 2, 2 and 7 samples are taken respectively (Figs 7.3 and 7.5).

As mentioned in Chapter 6, there was difficulty in separating these samples into clearly defined groups. However, sample groups have been chosen which best reflect the faunal composition.

7.5.4.1 Faunal Distribution.

The following sections refer to Figs 7.20 to 7.26.

Sample Group 54 to 44.

This group consists of samples from the Hazelbury Bryan Formation and represent the stratigraphically oldest samples from this borehole. Sample 54 to 46 are taken from the uniform clay to slightly silty clay lithologies at the base of the Hazelbury Bryan Formation. Sample 44 is from a similar lithology but represents a clay band from within the first major sand body of the Hazelbury Bryan Formation encountered within this borehole.

The percentage distribution of the Suborders within this sample group are quite erratic from sample to sample although some general trends can be highlighted (Fig. 7.20). The Lagenina show an initial increase in abundance from sample 54 to 52 and then decline in abundance to sample 46 where they comprise less than 5% of the total assemblage. There is a small increase in abundance to sample 44 where they comprise 20% of the assemblage. The agglutinated foraminifera show an exact correlation with the Lagenina and have an inverse relationship. At sample 46 the assemblage is almost completely composed of the Textulariina (Fig. 7.20). In general the Lituolidae and Vaginulinidae are the most dominant families

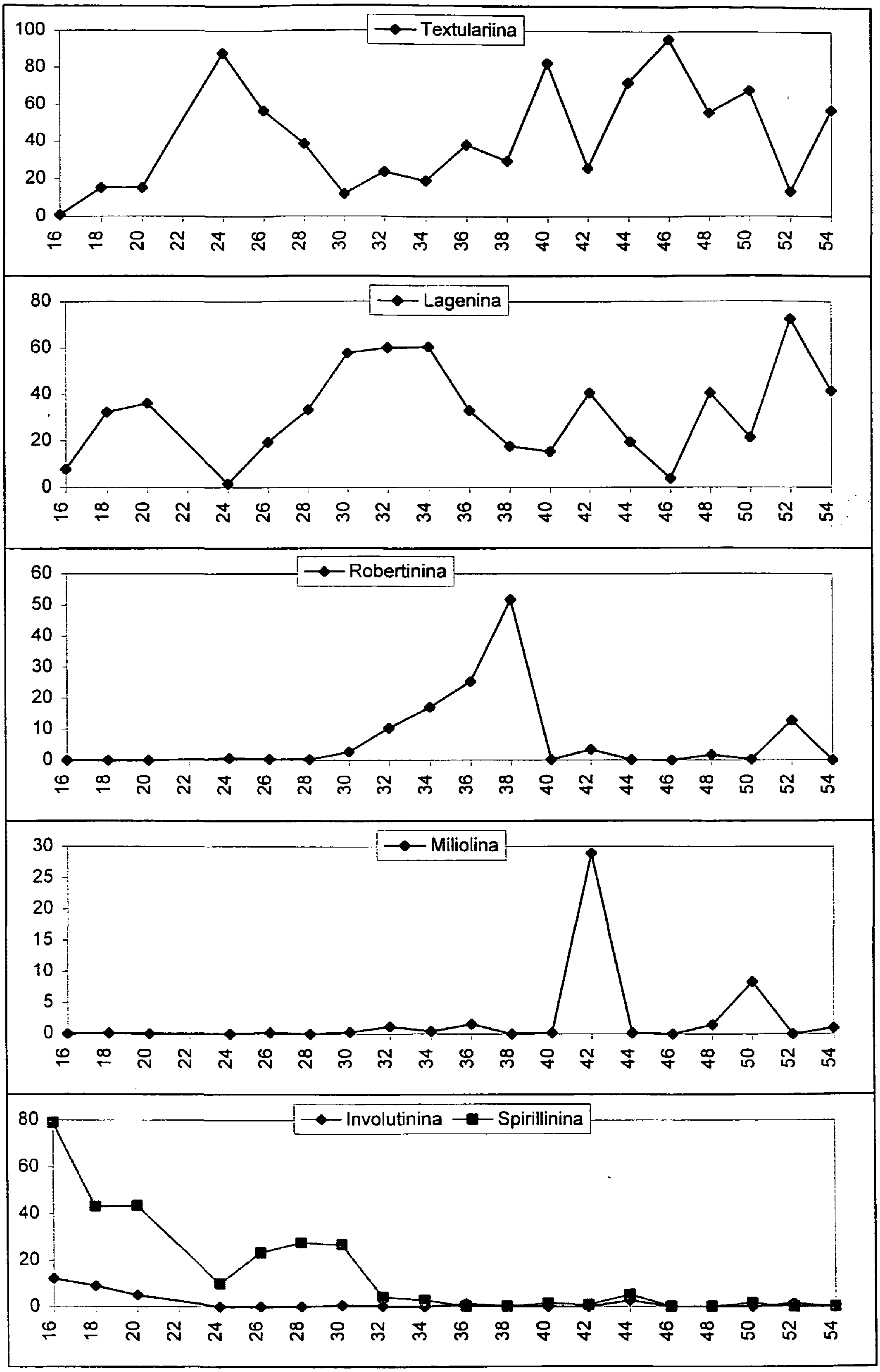


Figure 7.20. Distribution of Suborders for the East Stour Borehole. (x-axis = sample no., y-axis = %).

within this sample group (Figs 7.21 and 7.22). The ubiquitous *A. coprolithiformis* comprises around 23% of the assemblage but it is *Trochammina globigeriniformis* which is the dominant taxon and comprises 55% of the assemblage (Fig. 7.23). Sample 46 also has a large peak in abundance of the Saccaminidae with the species *Lagenammina difflugiformis* reaching nearly 5% of the total assemblage, which although not a large proportion of the assemblage is distinct when compared with its previous abundance (Figs 7.21 and 7.23). The assemblage in this sample is different from previous agglutinated dominated samples in that there is a mixture of species contributing to the overall dominance and it is not totally composed of lituolids (in particular *A. coprolithiformis*-dominated assemblages as seen in previously mentioned sample groups from other boreholes). The diversity of the agglutinated assemblage is also highlighted by the increase in abundance of *Ammobaculites canui* which reaches its maximum abundance of 47% and dominates the assemblage in sample 44 (Fig. 7.23). With *A. coprolithiformis* as the subdominant species, sample 44 has a very high proportion of the genus *Ammobaculites* which comprises approximately 70% of the assemblage. The Robertinina although present in minor amounts in sample 52 do not contribute to the assemblage, and are absent in some samples. *Quinqueloculina horelli* shows a peak in abundance at sample 50 where it consists of around 8% of the assemblage. It does not contribute in any large extent to the assemblage in any of the other samples. Although not a large percentage of the assemblage the Nodosariidae show their greatest abundance in sample 52 (Fig. 7.22), and in general samples 54 to 44 include the greatest abundance of the nodosariids from the entire borehole.

Sample 44 shows a peak in abundance of the spirillininids reaching just over 5% of the total assemblage (Fig. 7.22).

The similarity index shows that most of the samples are around 50 - 70% in similarity (Fig. 7.25). The α index shows a value of around 8 for sample 54 and slowly decreases to sample 48. There is a marked drop in the α value at sample 46 where it reaches a local minimum on the graph of around 2.5. Sample 44 has a value of around 6 (Fig. 7.26).

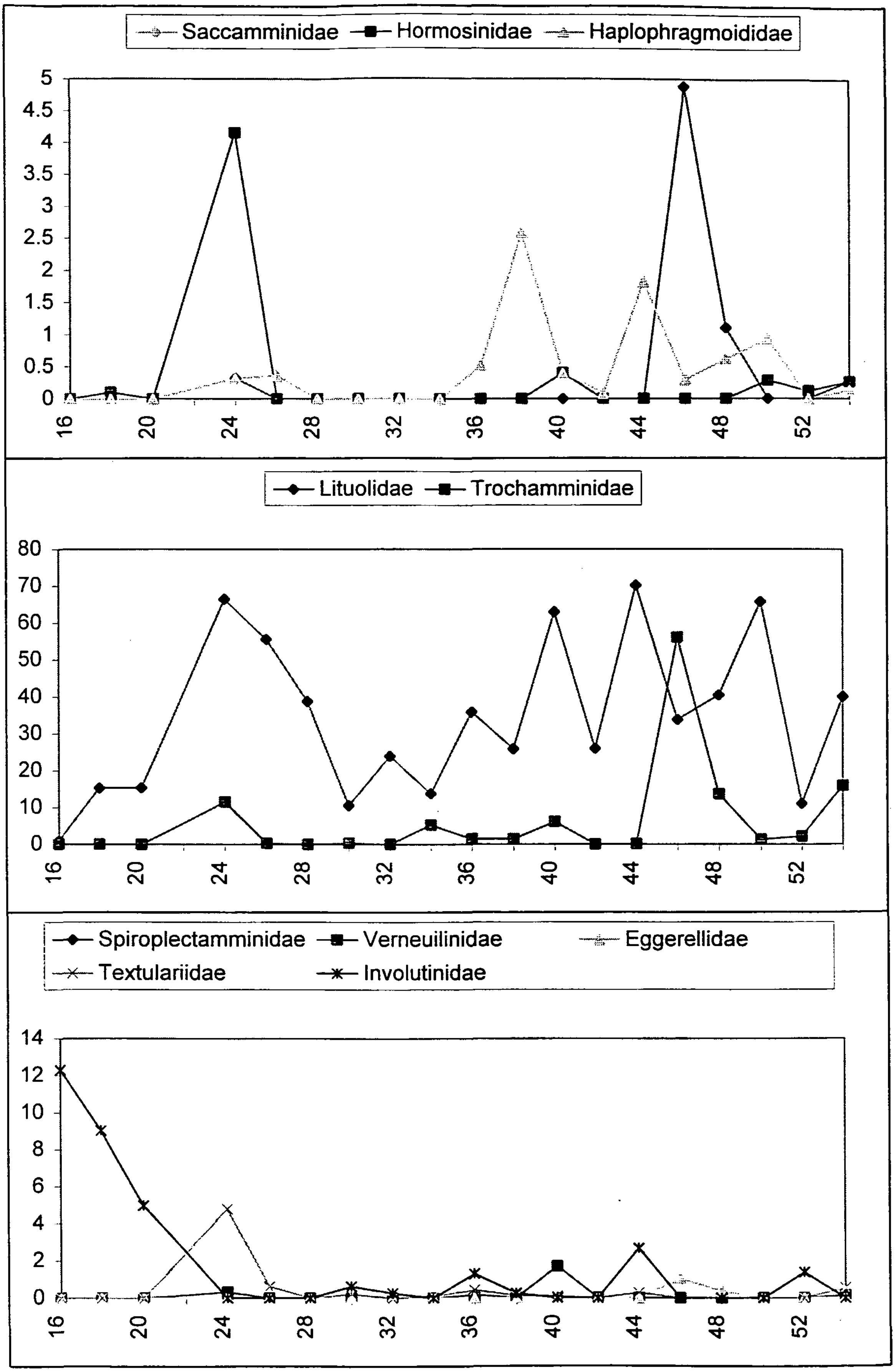


Figure 7.21. Distribution of Families in the East Stour Borehole.
(x-axis = sample no., y-axis = %).

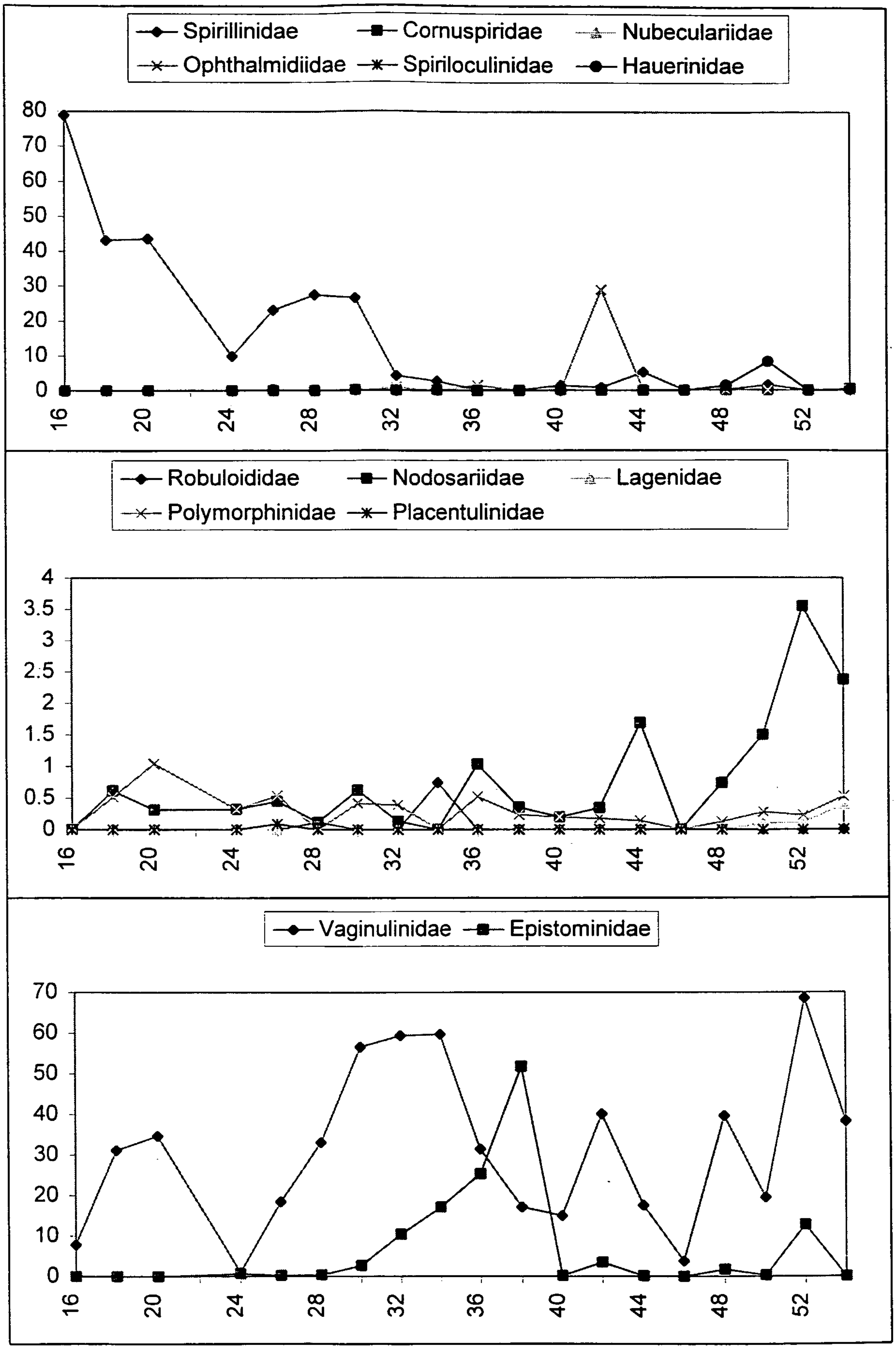


Figure 7.22. Distribution of Families in the East Stour Borehole. (x-axis = sample no., y-axis = %).

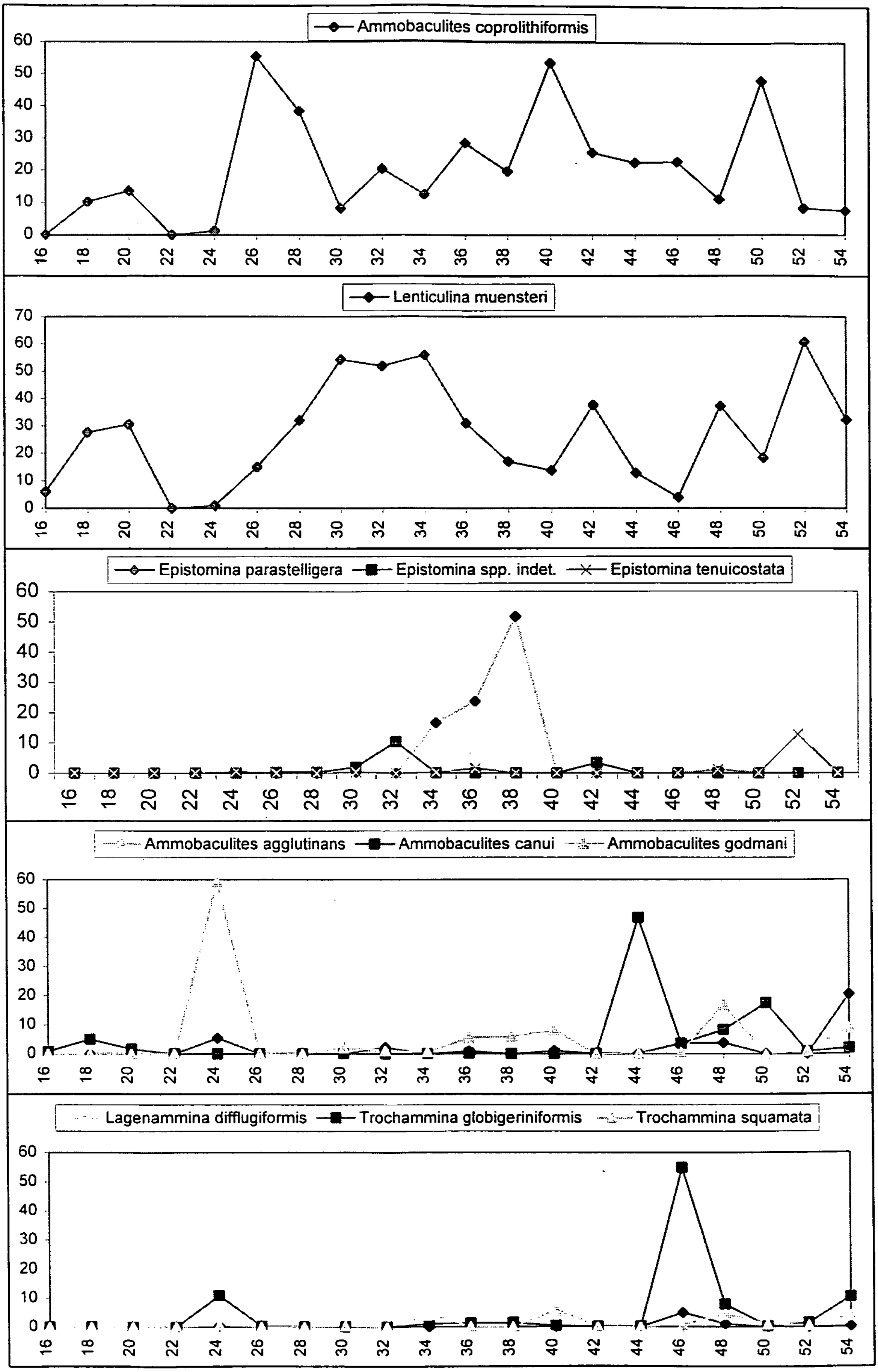


Figure 7.23. Distribution of selected Species from the East Stour Borehole. (x-axis = sample no., y-axis = %).

Sample	Species	Dominant	Subdominant	Species
16	S. tenusissima	71	12	T. nodulosa
18	S. tenusissima	32	28	L. muensteri
20	S. tenusissima	37	31	L. muensteri
22				
24	A. godmani	59	11	T. globigeriniformis
26	A. coprolithiformis	56	20	S. tenusissima
28	A. coprolithiformis	39	32	L. muensteri
30	L. muensteri	54	27	S. tenusissima
32	L. muensteri	52	21	A. coprolithiformis
34	L. muensteri	56	17	E. parastelligera
36	L. muensteri	31	29	A. coprolithiformis
38	E. parastelligera	52	20	A. coprolithiformis
40	A. coprolithiformis	54	14	L. muensteri
42	L. muensteri	37	29	O. strumosum
44	A. canui	47	23	A. coprolithiformis
46	T. globigeriniformis	55	23	A. coprolithiformis
48	L. muensteri	37	17	A. godmani
50	A. coprolithiformis	48	18	L. muensteri
52	L. muensteri	61	13	E. tenuicostata
54	L. muensteri	32	21	A. agglutinans

Sample	Genus	Dominant	Subdominant	Genus
16	Spirillina	79	12	Trocholina
18	Spirillina	43	28	Lenticulina
20	Spirillina	43	32	Lenticulina
22				
24	Ammobaculites	66	12	Trochammina
26	Ammobaculites	56	23	Spirillina
28	Ammobaculites	39	32	Lenticulina
30	Lenticulina	54	27	Spirillina
32	Lenticulina	55	24	Ammobaculites
34	Lenticulina	57	17	Epistomina
36	Ammobaculites	36	31	Lenticulina
38	Epistomina	52	26	Ammobaculites
40	Ammobaculites	63	14	Lenticulina
42	Lenticulina	38	29	Ophthalmidium
44	Ammobaculites	70	13	Lenticulina
46	Trochammina	56	34	Ammobaculites
48	Ammobaculites	40	39	Lenticulina
50	Ammobaculites	66	19	Lenticulina
52	Lenticulina	66	13	Epistomina
54	Ammobaculites	40	36	Lenticulina

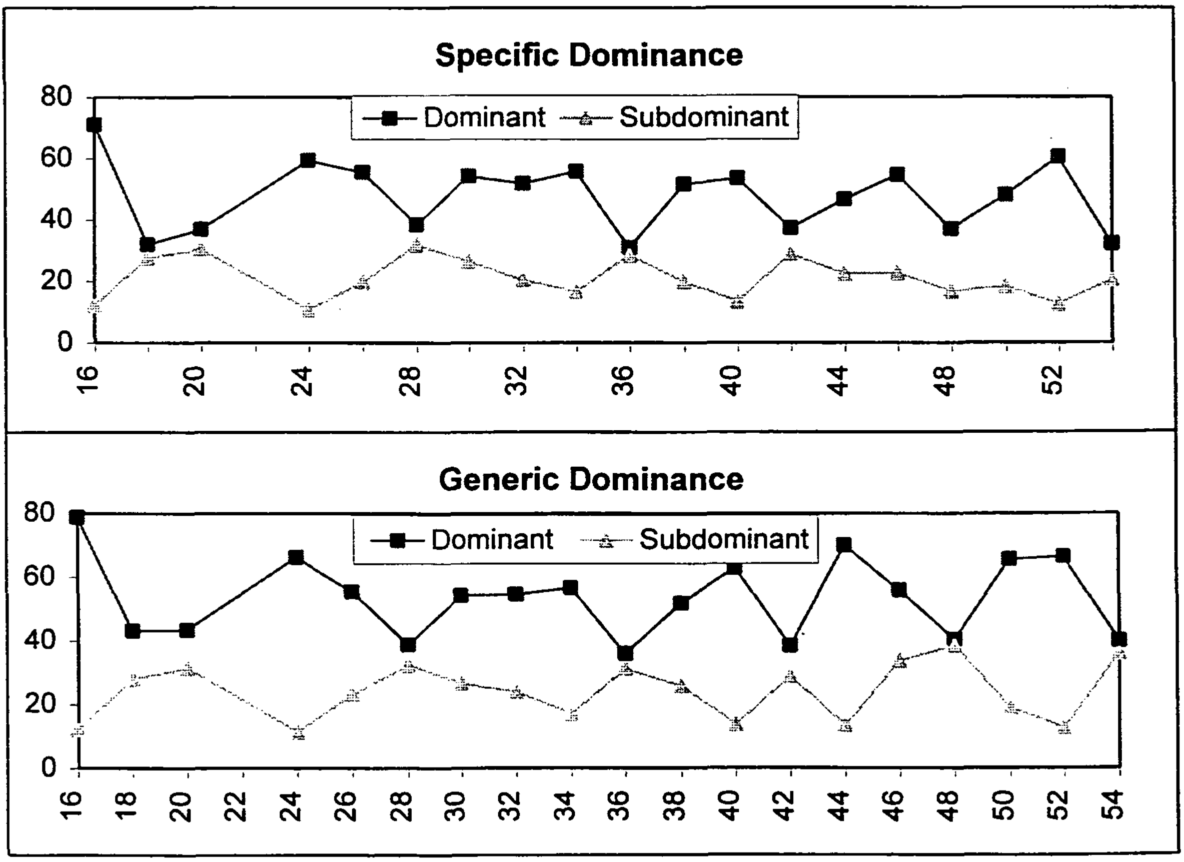


Figure 7.24. Generic and Specific Dominance and Subdominance for the East Stour Borehole.

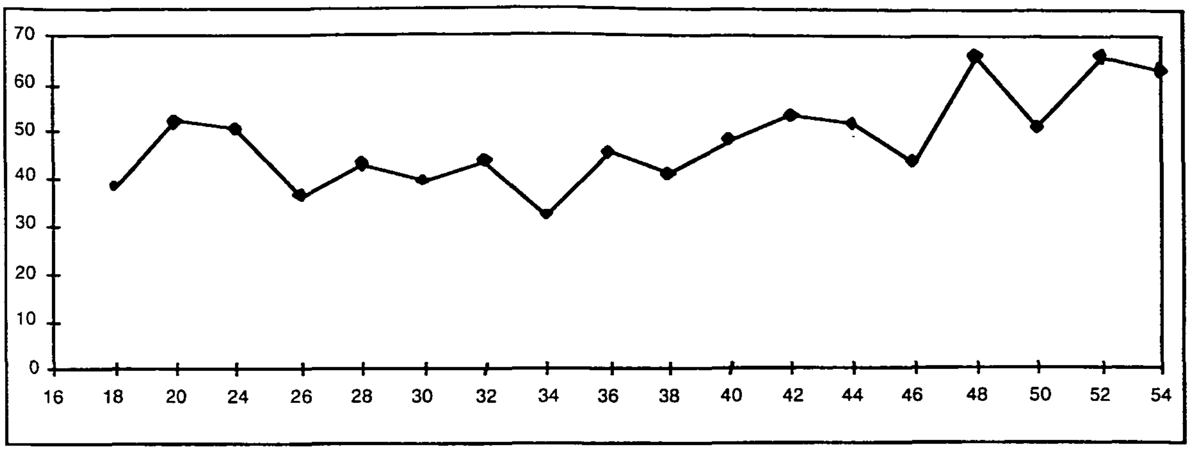


Figure 7.25. Similarity Index (Bray-Curtis) for the East Stour Borehole. (x-axis = sample number, y-axis = %).

Samples 54 and 48 show low Dominance values with corresponding peaks in the Evenness and Shannon Weiner indices. In general this sample group has a high value of Evenness.

Sample Group 42 to 30.

This is a somewhat arbitrary grouping as samples 34 to 30 have plotted outside any of the other groups on the MDS plot and Cluster Analysis dendrogram (Chapter 6, Figs 6.12 and 6.13). Samples 42 to 36 form a natural grouping.

These samples are from various lithologies. Sample 42 to 38 are from the Hazelbury Bryan Formation and are taken from the clay rich lithologies in between the sandy deposits at the top of this Formation. Sample 36 and 34 are from the Woodrow Clay Member and are a slightly silty clay with some carbonate cement. Samples 32 and 30 are from clay-rich layers from within the predominately oolitic limestone sequence of the Cucklington Oolite Member (Fig. 7.3).

The most distinctive aspect of the assemblage is the large peak in abundance of the Miliolina in sample 42 (Fig. 7.20). *Ophthalmidium strumosum* reaches almost 30% of the total assemblage, and is not present in any large proportion for any of the younger samples. This peak coincides with a peak in the Lagenina of 40 % (which is mainly attributed to the abundance of *Lenticulina münsteri*) and a corresponding low agglutinated abundance. Sample 40 is predominantly composed of *Ammobaculites* and the agglutinated component,

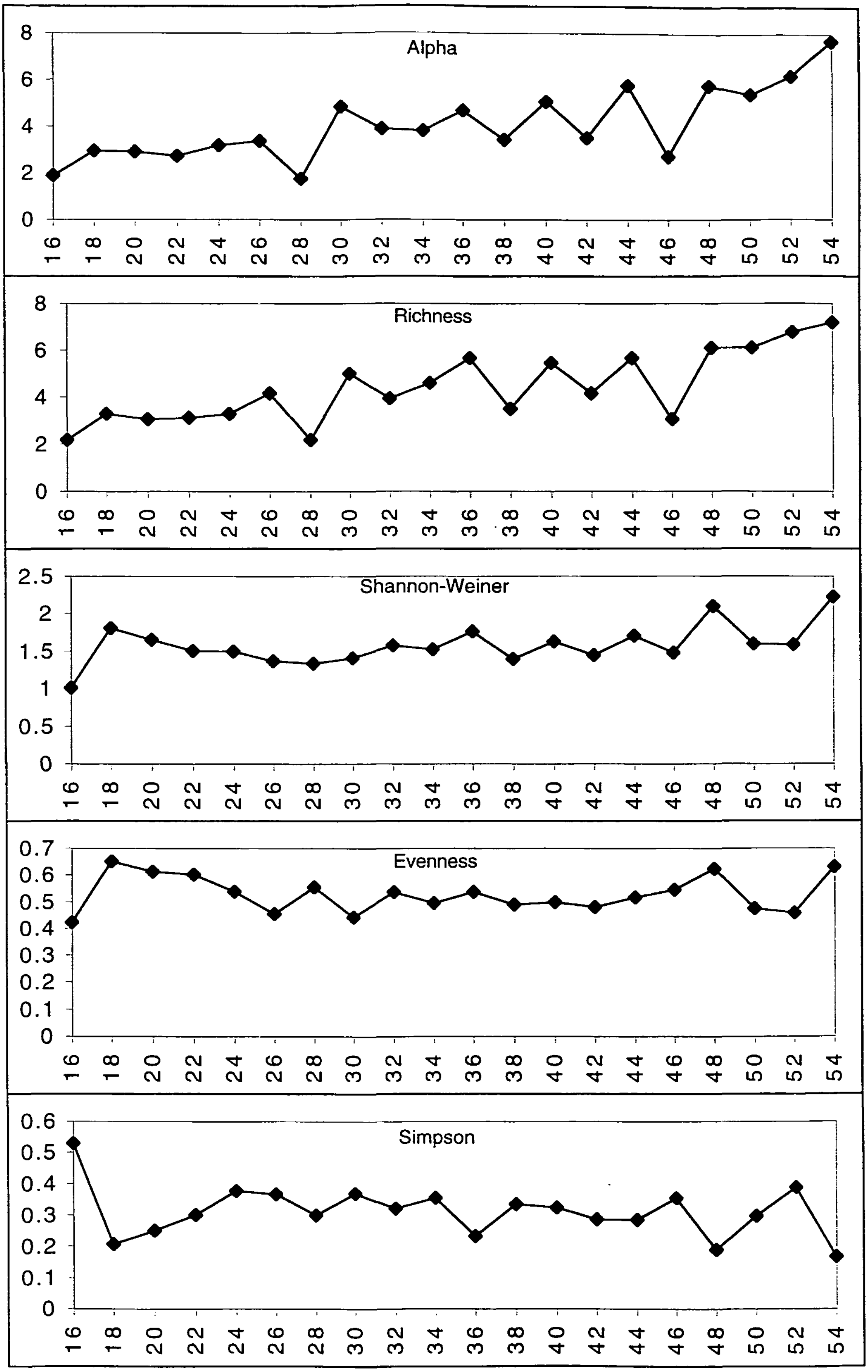


Figure 7.26. Diversity data for the East Stour Borehole. (x-axis = sample no.).

as a whole, comprises 80% of the assemblage. The Robertinina appear at sample 38 and dominate the assemblage; *Epistomina parastelligera* comprise over 50% of the assemblage (Fig. 7.23). From this sample up to sample 30 the Robertinina slowly decrease in abundance. The Lagenina increase over the same range of samples and are the dominant suborder in samples 34 to 30. *Lenticulina münsteri* dominates the assemblage in samples 36 to 30, at around 50% of the total assemblage (Fig. 7.23).

The Textulariina from samples 38 to 30 are generally less than 40% of the assemblage in each sample and show a general decrease in abundance (Fig. 7.20). Although only less than 3% of the total assemblage the Haplophragmoididae show a peak in their abundance at sample 38 (Fig. 7.21).

Sample 30 shows a distinct change in faunal composition with the sharp increase of the Spirillinina (Fig. 7.20). The species *Spirillina tenuissima* comprises almost 30% of the assemblage in this sample, and is second only in abundance to *L. münsteri*. Prior to this the Spirillinina have only been present in very low numbers (<1%).

Overall, these samples show a low similarity (Fig. 7.25). The α index is fairly regular and fluctuates around $\alpha = 4$. Sample 36 shows a lower Dominance Index value than the rest of the samples (Fig. 7.26).

Sample Group 28 to 16.

These samples are taken from the Newton Clay Member and are composed of clays, silty clays and slightly sandy clays. They represent the stratigraphically youngest samples from this borehole (Fig. 7.3).

The agglutinated foraminifera increase in abundance in sample 28 and continue to increase until they reach a maximum abundance of around 90% in sample 24 (Fig. 7.20). *A. coprolithiformis* is the most abundant species in samples 28 and 26 but in sample 24 the minute species *Ammobaculites godmani* is dominant at around 60% of the total assemblage

(Fig. 7.23). The peak in abundance of the agglutinated foraminifera in this sample (24) is also augmented by the maximum abundances of the trochamminids and hormosinids, represented by the subdominant *Trochammina globigeriniformis* at 11% and *Reophax* genera comprising around 4% of the assemblage (Fig. 7.23). From sample 24 the Textulariina rapidly decrease in abundance and are barely represented in sample 16. Although the lituolids (Fig. 7.20), as a whole, decrease from sample 24 in keeping with the agglutinated assemblagel trend, sample 18 shows a peak in the abundance of the agglutinated species *Ammobaculites canui* at 5% (Fig. 7.23).

The Lagenina are inversely proportional to the Textulariina and are extremely rare in sample 24 but increase in abundance to sample 20 where *Lenticulina münsteri* is the second most dominant species.

The most striking aspect of this faunal group is the abundance of the Spirillinina. Present only in minor quantities before sample 30, they become the subdominant and then the dominant taxa in this sample group (Fig. 7.24). *Spirillina tenuissima* and to a lesser extent *Spirillina infima* increase in abundance from sample 24 to sample 16 where *S. tenuissima* consists of 71%, and with the inclusion of *S. infima* the genus is dominant at nearly 80% of the total assemblage. Another important feature is the increase in abundance of *Trocholina nodulosa* from sample 24 to sample 16 where it is the second most dominant species comprising 12% of the total assemblage.

The similarity index does not reveal anything interesting about the assemblages in this sample group; most samples show a similar, low level of similarity (Fig. 7.25).

The α index is lowest at sample 28 with a value of < 2 and remains constant at around 3 from samples 26 to 18, sample 16 shows a decrease in the value to 2. Samples 28 and 16 have the fewest species in the entire borehole and this is reflected in the drop in the Richness index for these samples. A marked decrease in the Shannon Weiner Information index and Evenness index for sample 16, and a sharp increase in the Simpson Dominance index is shown, probably due to the low number of species and the complete dominance of the Spirillinina, in particular the species *S. tenuissima* (Fig. 7.26).

7.5.4.2 General Trends.

Refer to Figures 7.20 to 7.26 for details. The Textulariina are again a dominant suborder in the samples from this borehole. Initially the samples show a somewhat irregular distribution of the agglutinated foraminifera in that no smooth trend is observed. In general this group increase in abundance to sample 46 where they achieve almost 100% dominance and then decline to a sharp trough at sample 42. There is another strong peak at sample 40. Following this the agglutinated foraminifera slowly decline in abundance to sample 30. There is an increase and then a decrease in abundance with the maximum reached at sample 24 where they comprise around 90% of the assemblage. Again the dominant family within the Textulariina is the Lituolidae. The trochamminids, however, show a major peak at sample 46 where they account for almost 60% of the assemblage. Throughout the rest of the borehole the trochamminids comprise only a minor part of the assemblage, but do exhibit smaller peaks in their abundance; 12% in sample 24 and 16% in sample 54. The rest of the agglutinated families do not account for more than 5% of the assemblage in any given sample.

The lageninids show a negative correlation with the textulariinids, and exhibit their lowest abundance coincident with the peaks in the textulariinid abundance. Both the textulariids and the lageninids decline in abundance towards the top of the borehole, from samples 20 to 16. The lageninids have a maximum abundance of around 70% at sample 52, and of around 60% for samples 34 to 30. The vaginulinids are the dominant family with the Nodosariidae as the other main component (Fig. 7.20). This family, although comprising at maximum 3.5% of the assemblage, is more abundant in the lower samples (54 to 44) and gradually declines in abundance throughout the rest of the borehole.

The Robertinina are conspicuously absent from the majority of samples from this borehole. Apart from a small peak in abundance in sample 52, this suborder only appears from sample

38 to 30. The epistominids have their maximum abundance at sample 38 and decline to almost zero by sample 28 (Figs 7.20, 7.22 and 7.23).

The miliolinids peak at samples 50 and 42. The first, smaller peak is due to the family Hauerinidae and the second larger peak (around 30%) consists of the Ophthalmidiidae (Figs 7.20 and 7.22).

The most striking aspect of the samples from this borehole is the appearance of the Spirillininids as a dominant component of the assemblage. From sample 30 they slowly increase in abundance and reach their maximum at sample 16 at nearly 80% of the assemblage (although there is a small decline in abundance at sample 24). The Involutinina also increase in abundance from sample 20 to 16 although only peaking at less than 10% of the assemblage (Fig. 7.20).

The generic and specific dominance patterns show a distinct cyclical trend (Fig. 7.24). Approximately every three samples the dominant species is elevated to around 60-70% in abundance with the subdominant species declining to around 15%. The intervening samples show the dominant and subdominant taxa to be similar in abundance.

7.5.4.3. Palaeo-ecological interpretation.

The α index values for the samples of this borehole show a steady decrease from sample 54 to sample 16. The values decrease from $\alpha = 7.7$ to around $\alpha = 1.9$, with the lowest value $\alpha = 1.74$ for sample 28. In a general sense the decrease in the α value indicates a change from a "normal" marine environment to a more restricted one; probably a shallower environment. The other indices indicate fairly even values with not much deviation from one sample to the next, although sample 16 seems to indicate a difference from the samples immediately below and has the highest Simpson dominance value for the whole borehole.

The near complete absence of epistominids in samples 54 to 40 is probably indicative of a shallow environment. Their low abundance, however, may be due to the presence of a relatively high sand content in these samples, as discussed previously. However, other indications of a shallow environment of deposition are also present. The major influx of the Ophthalmidiidae at sample 42 may indicate the shallowest water environment so far discussed. Other indications are the dominance of *Ammobaculites canui* at sample 44, the dominance of *Trochammina globigeriniformis* at sample 46 and *A. agglutinans* and *A. godmani* as the subdominant species in samples 54 and 48 respectively. The inference of a large abundance of these small agglutinated foraminifera, especially when comrprising almost 100% of the assemblage, as in sample 46, is that the environment is shallow, and perhaps slightly lowered in salinity. The recording of the bivalve *Pecten*, however, would tend to suggest well oxygenated bottom waters. The drop in abundance of the Nodosariidae towards sample 46 suggests that the environment was slightly deeper initially, as these foraminifera tend to be associated with deeper environments. The abundance peak of *Lagenammina difflugiformis* at 5% is again indicative of a shallow sandier environment. A relatively abundant vaginulinid assemblage, particularly *Lenticulina münsteri*, may be indicative of a shifting sandy substrate.

Sample 38 shows a return of the robertininids and may represent a return to deeper water environments after the sand dominated facies below. The dominant and sub-dominant species are closer in abundance than previously recorded, so a more equitable environment is envisaged. The robertininid abundance decreases by half in sample 36 and from then slowly declines to effectively disappear in sample 28. By this sample the spirillinids had become an important component and probably indicate a shallower water environment. Spirillinids have been reported as being attached forms common on hard substrates (stones or shells) or "weeds" Murray (1971, 1973, 1991). Clinging taxa may be more resilient in a higher energy environment, so the increase in the spirillinids towards the top of the borehole (where they become dominant; samples 20-16) is taken to indicate a shallow, higher energy environment, such as the lower shoreface. The abundance of the small simple agglutinated foraminifera (e.g. *Ammobaculites godmani*, 59% sample 24) and the trochamminids also indicate a shallow environment. The low number of species could also suggest a lowered salinity environment, which would also fit with the increased abundance of the smaller agglutinated species. The distribution of the assemblage may also represent deposition within an estuarine environment.

7.5.5. Hallett's Farm Borehole.

The Hallett's Farm Borehole covers the youngest sequence of strata in the study. It starts within the Ringstead Waxy Clay Formation and includes the junction with the Sandsfoot Formation. Below this the Clavellata Beds Formation is sampled, although only one sample is taken from this Formation. The Stour Formation is penetrated and samples are taken from the Todber Freestone Member and the Newton Clay Member, where the borehole terminates. In total there are 25 samples in the Hallett's Farm Borehole, numbered from 10 to 58. Five samples are from the Ringstead Waxy Clay Formation, 12 samples from the Sandsfoot Formation, 1 from the Clavellata Beds Formation, 2 from the Todber Freestone Member and 5 from the Newton Clay (Figs 7.4 and 7.5).

7.5.5.1 Faunal Distribution.

The following sections refer to Figs 7.27 to 7.30.

Sample Group 58 to 46.

This group represents the stratigraphically oldest samples from the Hallett's Farm Borehole. Samples 58 to 50 are taken from the silty clay lithologies of the Newton Clay Member and many of these samples have a slight carbonate cement. Samples 48 and 46 are from the clay rich layers of the predominately oolitic limestone of the Todber Freestone Member (Figs 7.4 and 7.5).

The Lagenina and Textulariina are abundant in roughly equal measures, although the agglutinated foraminifera decrease in abundance towards sample 46 (Fig. 7.27). The Lituolidae are the most dominant family (Figs 7.28 and 7.29) with *Ammobaculites coprolithiformis* the most abundant species (Fig. 7.30). The agglutinated foraminifera consist mainly of the lituolids and although a small peak is indicated in sample 56 by the

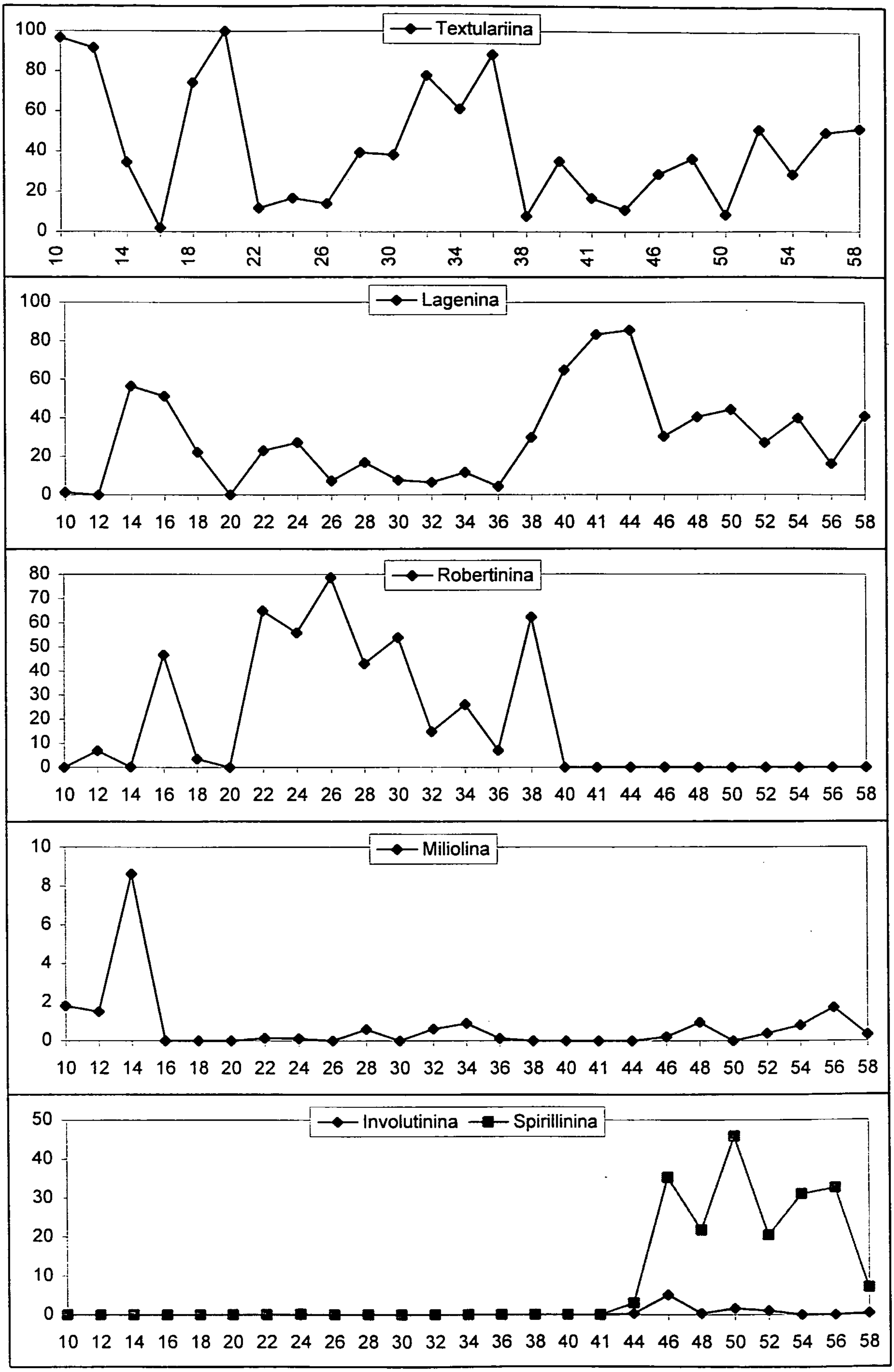


Figure 7.27. Distribution of Suborders fro the Hallett's Farm Borehole. (x-axis = sample no., y-axis = %).

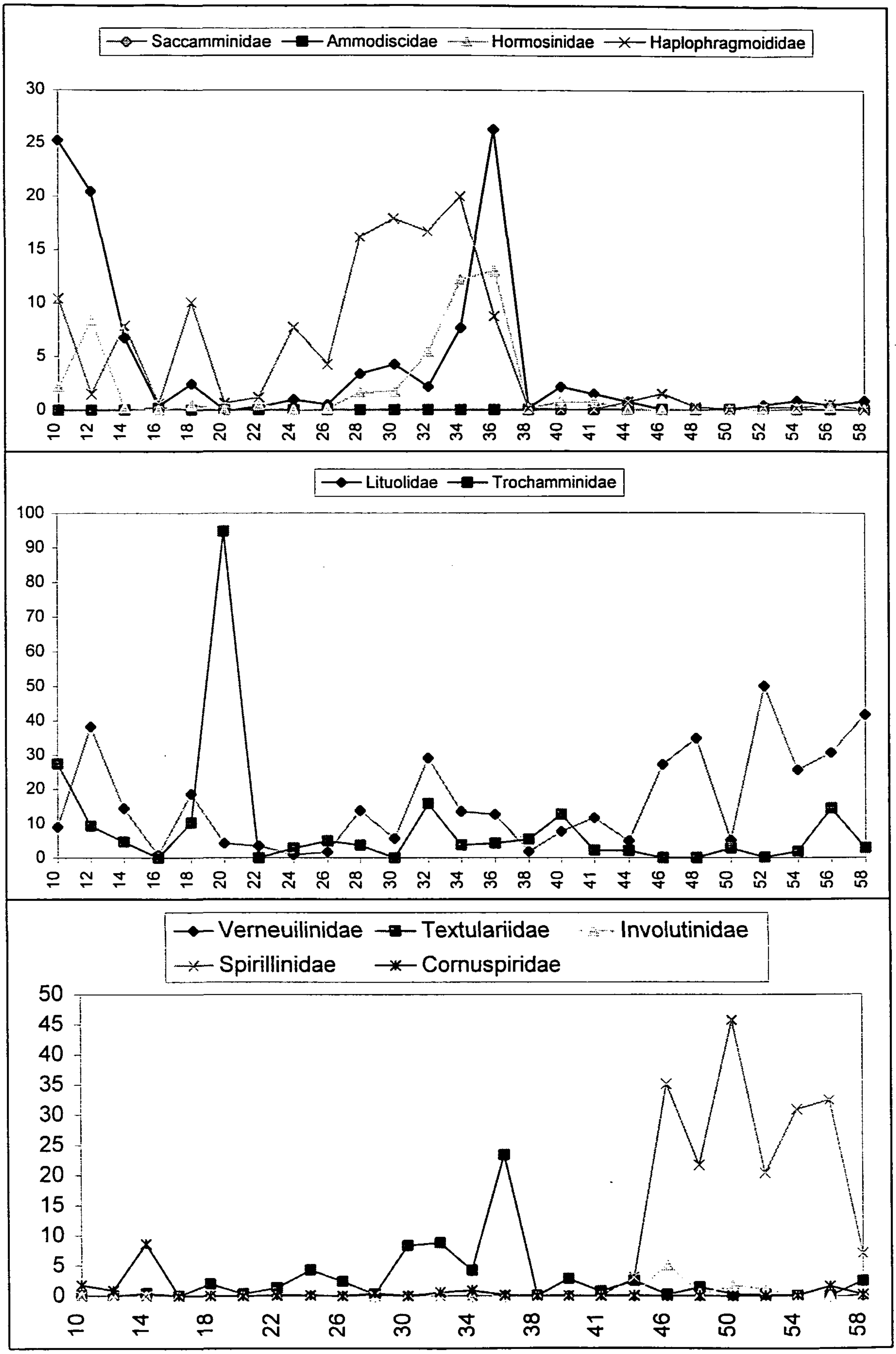


Figure 7.28. Distribution of Families in the Hallett's Farm Borehole. (x-axis = sample no., y-axis = %).

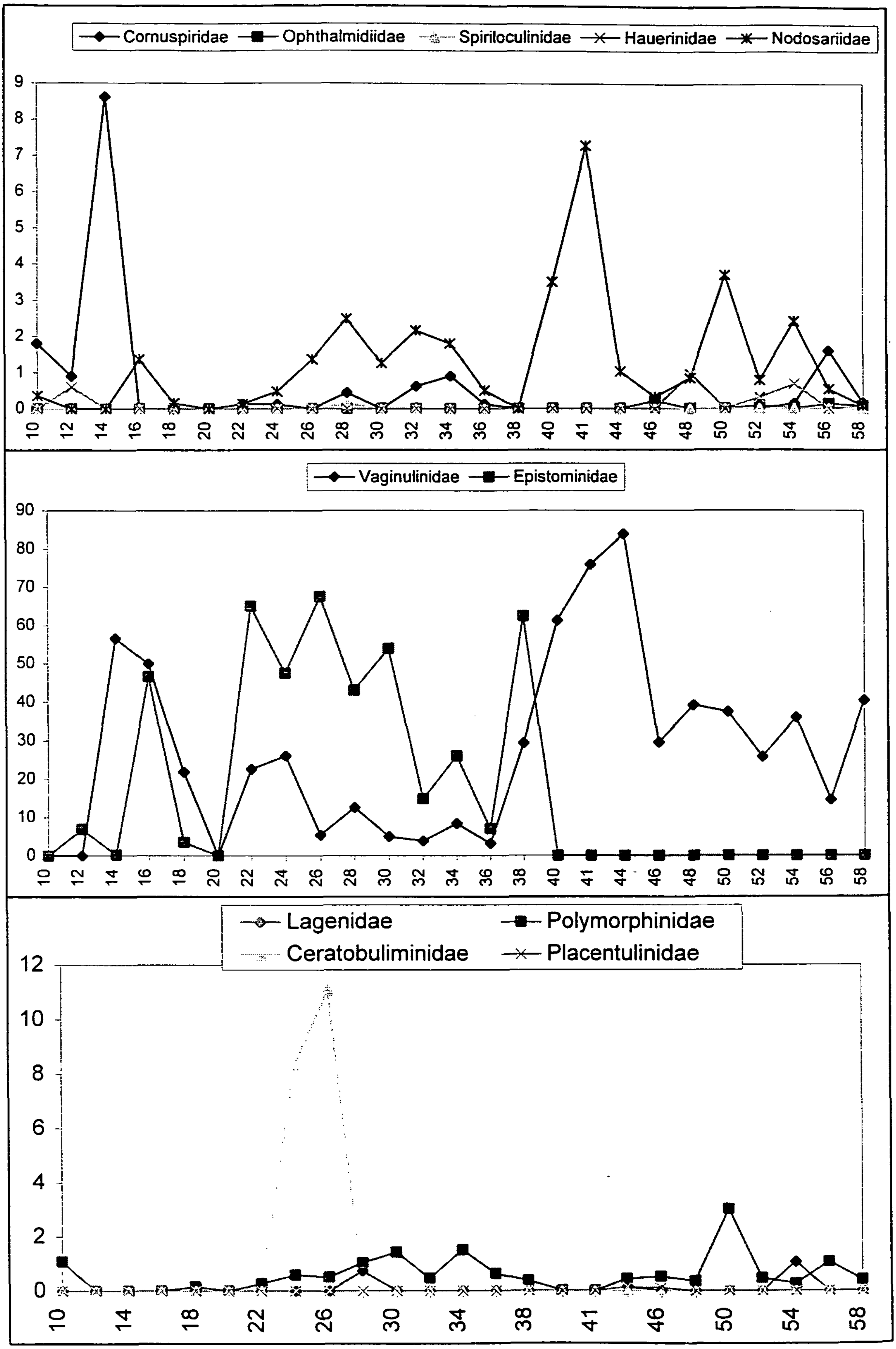


Figure 7.29. Distribution of Families in the Hallett's Farm Borehole. (x-axis = sample no., y-axis = %).

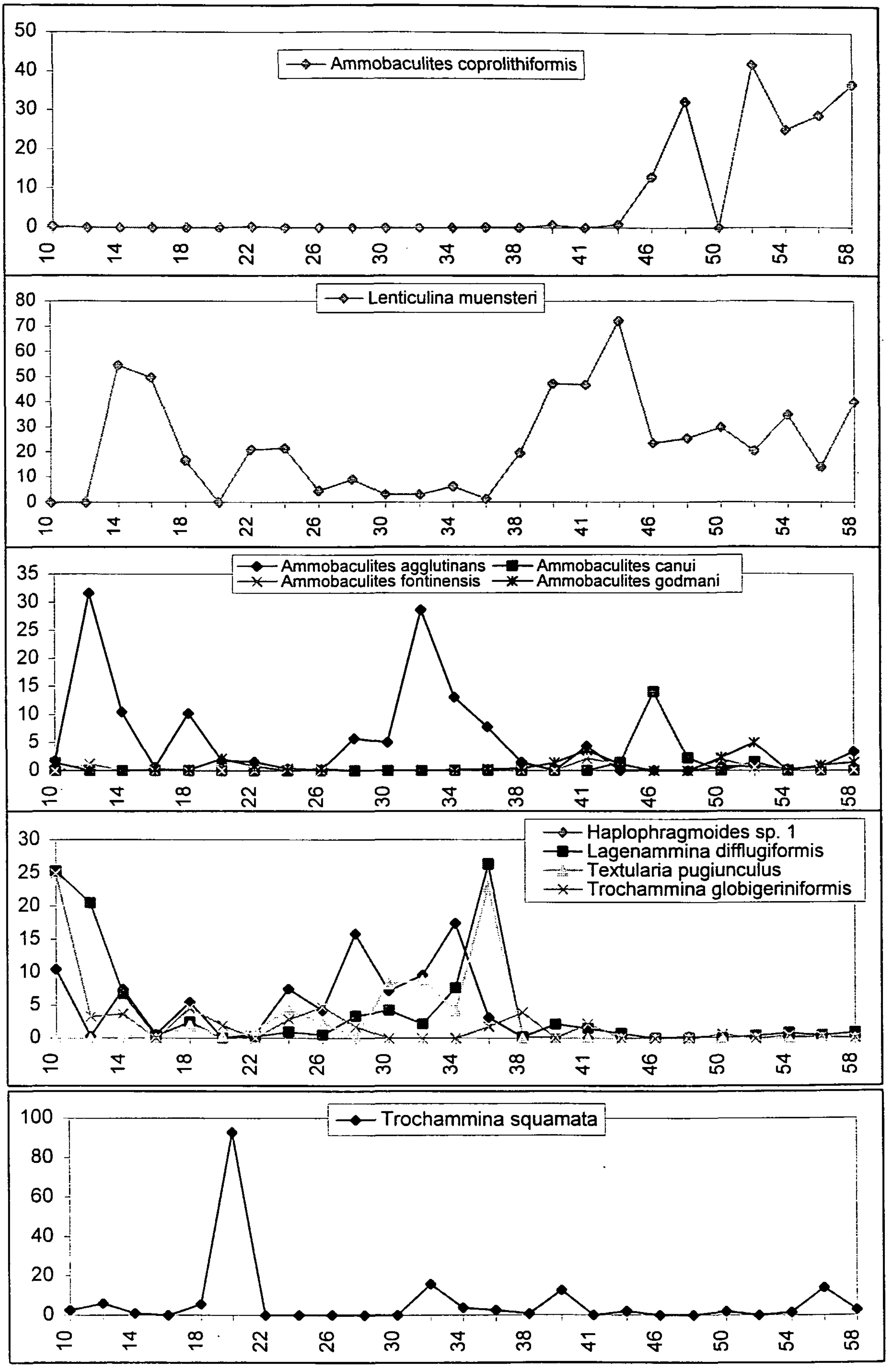


Figure 7.30. Distribution of selected species for the Hallett's farm Borehole. (x-axis = sample no., y-axis = %).

trochamminids this does not account for greater than 15% of the assemblage.

The Lagenina comprise of around 40% of the assemblage and are dominated by the single species *Lenticulina münsteri* (Fig. 7.30).

The Miliolina are present in small numbers and disappear after sample 46. They are dominated by the species *Cornuspira* sp. 2 although it only accounts for less than 2% of the total assemblage.

The most distinctive feature of this sample group is the dominance of the Spirillinina (Fig. 7.27). From sample 56 to 46 *Spirillina tenuissima* and *Spirillina infima* comprise approximately 40% of the assemblage. Although only dominant in samples 56, 50 and 46, *Spirillina* is not represented after sample 44, and is a strong component of this sample group (Fig. 7.31).

The similarity index shows values for the samples at around 50% (Fig. 7.32). The α index shows a peak in value at sample 52 where it reaches 6.5 and decreases for the samples above and below to a value of around 4 for samples 58 and 46 (Fig. 7.33).

Most of the diversity indices show level trends with, in general, a Dominance Index of around 3 and a correspondingly high Evenness value of around 0.6. The number of species recorded is about 25 but increases to 33 at sample 52.

Sample Group 44 to 38.

These samples come from distinctly different lithologies and have correspondingly different assemblages. They are grouped together here as they do not fit with any of the other groups. Sample 44 is taken from a clay rich band within the the Clavellata Beds Formation, samples 41, 40 and 38 are from the silty lithology at the base of the Sandsfoot Formation which may represent the Sandsfoot Clay Member (Fig. 7.4).

Sample	Species	Dominant	Subdominant	Species
10	L. difflugiformis	25	25	T. globigeriniformis
12	A. agglutinans	32	20	L. difflugiformis
14	L. muensteri	55	10	A. agglutinans
16	L. muensteri	50	47	E. parastelligera
18	Hap./Troch. Indet	31	17	L. muensteri
20	T. squamata	93	2.1	A. godmani
22	E. parastelligera	62	21	L. muensteri
24	E. parastelligera	46	21	L. muensteri
26	E. parastelligera	68	11	R. lutzei
28	E. parastelligera	43	16	H. sp. 1.
30	E. parastelligera	54	10	H. hausleri
32	A. agglutinans	29	16	T. squamata
34	E. parastelligera	26	17	H. sp. 1.
36	L. difflugiformis	26	23	T. pugiunculous
38	E. parastelligera	62	19	L. muensteri
40	L. muensteri	47	13	T. squamata
41	L. muensteri	47	8.8	C. tenuicostata
44	L. muensteri	72	4.1	P. bieriana
46	S. tenuissima	24	23	L. muensteri
48	A. coprolithiformis	33	25	L. muensteri
50	S. tenuissima	42	30	L. muensteri
52	A. coprolithiformis	42	20	L. muensteri
54	L. muensteri	35	28	S. tenuissima
56	S. tenuissima	30	29	A. coprolithiformis
58	L. muensteri	40	37	A. coprolithiformis

Sample	Genus	Dominant	Subdominant	Genus
10	Trochammina	27	25	Lagenammina
12	Ammobaculites	38	20	Lagenammina
14	Lenticulina	55	14	Ammobaculites
16	Lenticulina	50	47	Epistomina
18	Lenticulina	22	19	Ammobaculites
20	Trochammina	95	4.2	Ammobaculites
22	Epistomina	65	22	Lenticulina
24	Epistomina	48	22	Lenticulina
26	Epistomina	68	11	Reinholdella
28	Epistomina	43	16	Haplophragmoides
30	Epistomina	54	18	Haplophragmoides
32	Ammobaculites	29	17	Haplophragmoides
34	Epistomina	26	20	Haplophragmoides
36	Lagenammina	26	23	Textularia
38	Epistomina	62	21	Lenticulina
40	Lenticulina	49	13	Trochammina
41	Lenticulina	57	16	Citharina
44	Lenticulina	73	5	Ammobaculites
46	Spirillina	35	27	Ammobaculites
48	Ammobaculites	35	26	Lenticulina
50	Spirillina	46	34	Lenticulina
52	Ammobaculites	50	22	Lenticulina
54	Lenticulina	36	31	Spirillina
56	Spirillina	33	31	Ammobaculites
58	Ammobaculites	42	40	Lenticulina

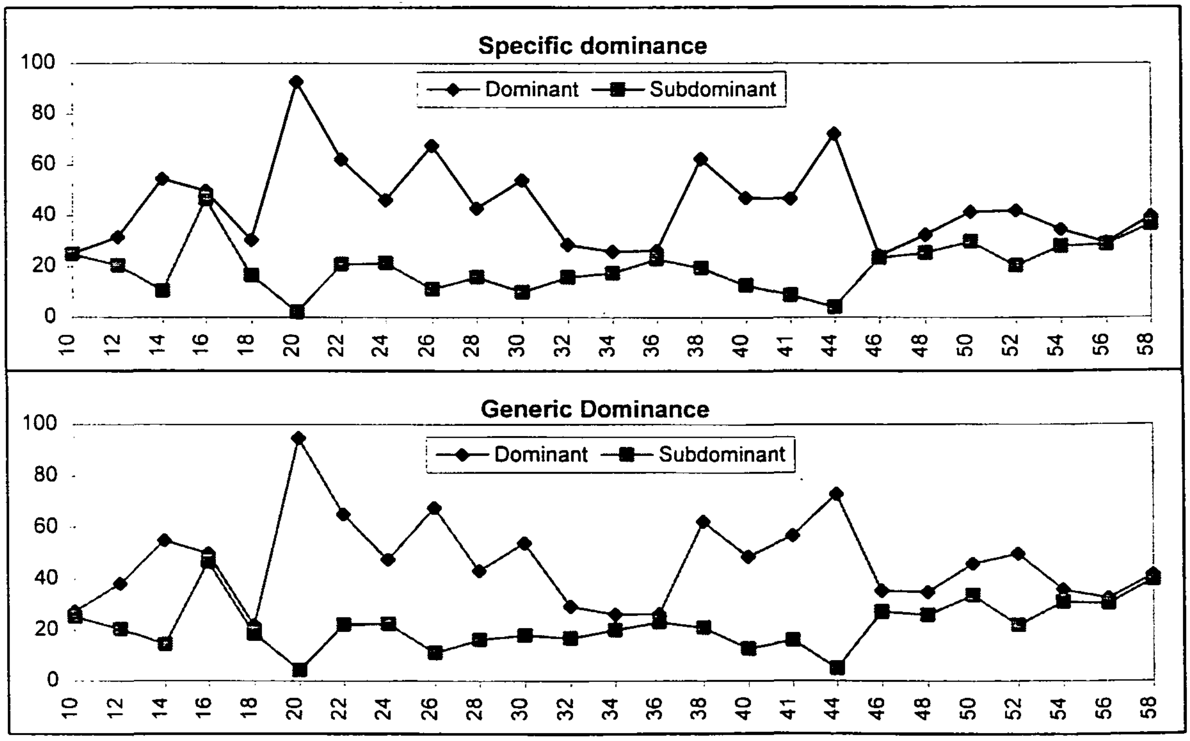


Figure 7.31. Generic and Specific Dominance and Subdominance for the Hallett's Farm Borehole.

Sample 44 has an almost exclusively lageninid assemblage, with *Lenticulina münsteri* dominating the assemblage at 72% (Figs 7.27 and 7.30). The second most dominant species is *Planularia bieriana* at 4% which represents the first occurrence of this species in the borehole.

From sample 44 the Lagenina decrease in abundance to sample 38 where they comprise around 30% of the assemblage although *L. münsteri* is still the second most dominant species in the sample. *Citharina tenuicostata* is the second most dominant species in sample 41 and represents an isolated occurrence of this species (Fig. 7.31).

The Textulariina vary from around 15% in sample 44 to almost 40% in sample 40 to less than 10% in sample 38. The Lituolidae are generally the dominant family although the trochamminid *Trochammina squamata* becomes the second most dominant species in sample 40 and comprises 12% of the total assemblage (Figs 7.27. 7.28 and 7.30).

Prior to sample 38 the Robertinina are not present in the assemblage. However, this sample is dominated by *Epistomina parastelligera* which comprises 62% of the total assemblage. This elevated abundance of the epistominids corresponds with a low abundance of the agglutinated assemblage (Fig. 7.27).

Generally these samples are less similar to the other samples above and below. The similarity index indicates that 41 and 40 are most similar (Fig. 7.32). The α index shows the highest value in the borehole for sample 41 at around 7 after which it decreases to approximately 3.5 at sample 38 (Fig. 7.33).

The samples show a relatively high Dominance index (Fig. 7.33) when compared with the adjacent samples, especially samples 44 and 38. This is also shown on the specific dominance graph (Fig. 7.31).

Sample Group 36 to 22.

Samples 36 to 22 are taken from the predominantly silty clay lithologies of the Sandsfoot Grit Member (Fig. 7.4).

The agglutinated foraminifera from this sample group decline in abundance from sample 36 where they comprise almost 90% of the total assemblage (Fig. 7.27). They gradually decrease as the important component of the assemblage until at sample 22 they comprise only 10 % of the total assemblage. The Textulariina are not dominated by the Lituolidae which has been their common constituent before. The lituolids only comprise 30% of the assemblage at maximum in sample 32. Sample 36 is composed of a mixed agglutinated assemblage with *Lagenammina difflugiformis* accounting for 26% of the assemblage and *Textularia pugiunculous* comprising 23% of the assemblage (Fig. 7.30). This is the first occurrence of the latter species. The genus *Haplophragmoides* is also an important component and the Haplophragmoididae constitute one of the most dominant families in samples 34 to 24 (Fig. 7.28). *Ammobaculites agglutinans* and *Trochammina squamata* are the dominant and sub-dominant species in sample 32. *Haplophragmoides* sp. 1, *Haplophragmoides hausleri* and *Haplophragmoides* sp. 1 are the subdominant species in samples 34, 30 and 28 respectively (Fig. 7.31).

The Lagenina represent only a small component of this sample group but *Lenticulina münsteri* is the second most dominant species in samples 24 and 22 comprising of around 20% of the assemblage.

From 36 to 22 there is a gradual increase in the abundance of the Robertinina which again is inversely proportional to the abundance of the Textulariina. The robertininids reach their maximum abundance at sample 26 where *Epistomina parastelligera* accounts for 67% of the total assemblage. Samples 24 and 26 also include the first and last occurrence of the ceratobuliminid *Reinholdella lutzei* which is the second most dominant species in sample 26 (Fig. 7.29).

Overall the assemblage from each of these samples retains a high degree of similarity as the Similarity index indicates (Fig. 7.32). The α index is more variable and ranges from 7 to around 3.5. Samples 36 and 28 show the greatest values (Fig. 7.33). The Simpson Dominance index shows a gradual increase which also can be seen on the specific and generic dominance graphs. A decrease in the Evenness and the Shannon Weiner index is also observed (Fig. 7.33).

Samples 20 and 18.

Samples 20 and 18 are from pure clay samples in the Sandsfoot Formation (Fig. 7.4).

Sample 20 consists solely of agglutinated taxa and almost exclusively of the species *Trochammina squamata* which accounts for 93% of the assemblage (Figs 7.27, 7.28 and 7.30). The second most dominant species is *Ammobaculites godmani* which comprises only 2% of the assemblage.

Sample 18 is again dominated by the Textulariina, but the assemblage is more mixed. *Haplophragmoides/Trochammina* of indeterminable species are the most dominant group, followed by *Ammobaculites* and the trochamminids. This sample also includes *Lenticulina münsteri* as the second most dominant species which accounts for 16% of the total assemblage (Fig. 7.31).

The monospecific nature of sample 20 accounts for the high peaks in the Dominance index, and troughs for the other indices (Fig. 7.33). The α index is close to 1 for sample 20 and has a value of around 3 for sample 18.

Sample Group 16 to 10.

These samples represent the stratigraphically youngest strata from the studied material, and consist of the clays and silty clays of the Ringstead Waxy Clay Formation (Fig. 7.4).

These samples show an interesting change in assemblagel composition. The agglutinated taxa increase from almost zero in sample 16 to almost 100% of the assemblage in sample 10. *Ammobaculites agglutinans*, *Lagenammina difflugiformis* and *Trochammina globigeriniformis* are the most dominant species (Fig. 7.30).

The Lagenina continue to increase in abundance from sample 18 and peak at sample 14 with an abundance of 55% for *Lenticulina münsteri*. Samples 12 and 10 have almost no lageninid component (Figs 7.27 and 7.30).

The robertininids are the second most dominant suborder in sample 16 with *Epistomina parastelligera* constituting almost 50% of the total assemblage. They decrease in abundance to near absence from samples 14 to 10 (Figs 7.27 and 7.30).

The Miliolina have a marked peak in abundance, although only contributing less than 9% of the total assemblage, it is important as this is the highest occurrence of *Cornuspira* sp. 2 in the whole borehole.

The similarity index indicates an initial lack of similarity between the samples, although they are distinct from those below (Fig. 7.32).

The α index is generally low and varies from 2 for sample 16 to a value of around 3.5 for sample 14 (Fig. 7.33).

These samples show a more even distribution of species which is shown in the high values of the Evenness index and the low Dominance Index values (Fig. 7.33).

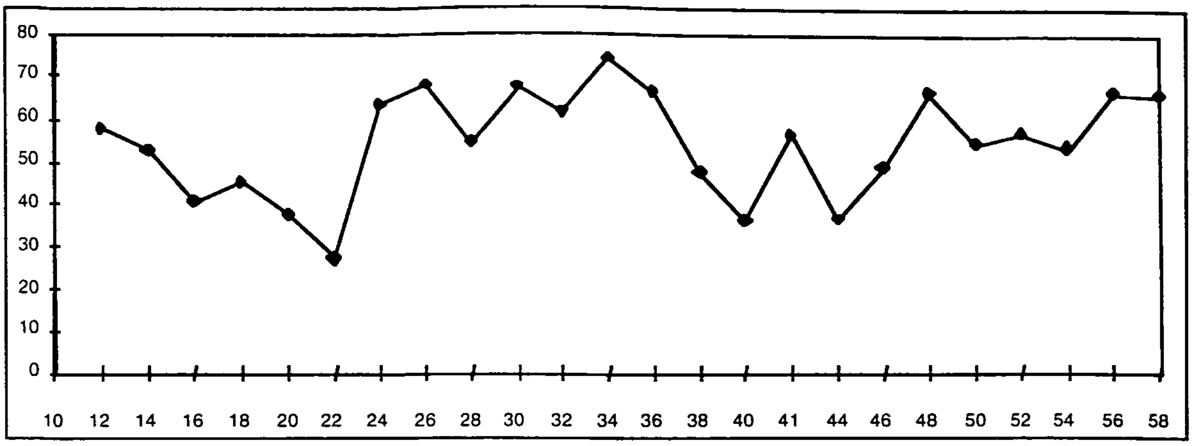


Figure 7.32. Similarity Index (Bray-Curtis) for the Hallett's Farm Borehole (x-axis = sample number, y-axis = %)

7.5.6.2 General Trends.

Refer to Figures 7.27 to 7.33 for details. From samples 58 to 38 the abundance of Textulariina fluctuate from around 50% to 10% and at sample 38 they reach a minimum of 8%. At sample 36 there is a major peak in abundance before a slow decline to sample 22. Again there is a major peak in abundance at sample 20 where the agglutinated foraminifera comprise 100% of the assemblage. There is a sharp decline to sample 16 where the agglutinating foraminifera have almost disappeared at 2%. They increase again in abundance and reach 97% at sample 10. Interestingly, the major abundance peak at sample 36 is composed of a variety of the agglutinated families and the assemblage is mixed, which is different from most of the other assemblages discussed, which are primarily dominated by the lituolids. The distribution of the families includes the first major appearance of the Saccammminidae. At sample 36 the distribution of the agglutinated families is as follows; lituoilids – 13%; textulariids – 23%; hormosinids – 13%; haplophragmoidids - 9% and saccamminids - 26%. Prior to sample 36 the agglutinated component primarily consists of the lituoilids. From this sample upwards the haplophragmoidids are reasonably abundant, and from samples 36 to 24 they comprise from 5 to 20% of the total assemblage. The saccamminids also show large increase in abundance at sample 10 to around 25%. As mentioned in the section above the most striking aspect of the agglutinated components of the assemblage is the 100% agglutinated assemblage at sample 20. The majority of taxa in sample 20 belong to the trochamminids.

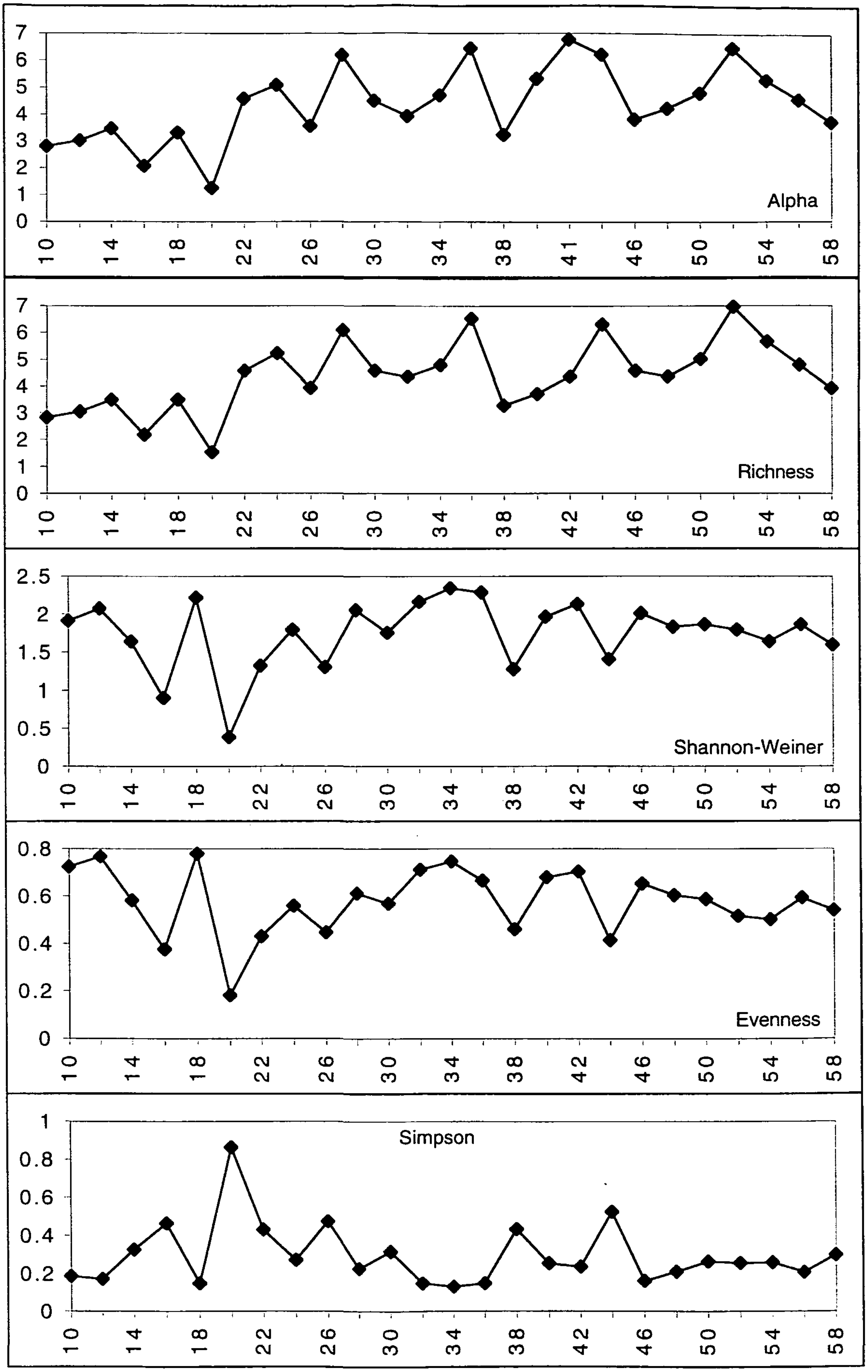


Figure 7.33. Diversity data for the Hallett's Farm Borehole.
(x-axis = sample numbers).

The lageninids show an average abundance of around 30% from samples 58 to 46. They peak in abundance at sample 44 where they comprise around 85% of the assemblage and decline in abundance steadily to sample 36, where the contribute to less than 5% of the total assemblage in this sample. From sample 36 to sample 20 they are a minor component of the assemblage but slowly rise in abundance at sample 14, where they comprise around 50% of the assemblage. There seems to be a correlation with the Spirillinina, because when this group disappears at around sample 44 there is a marked rise in the abundance of lageninids.

The Robertinina are absent from the assemblage up until sample 38, where they make their first appearence in this borehole. They dominate the sample and comprise almost 65% of the total assemblage. From this sample to sample 10 the Robertinina are distinctly negatively correlated with the textulariids.

The miliolinids are a very minor component of the assemblage in this borehole but reach their maximum of around 9% of the assemblage at sample 14.

Another important aspect of the foraminiferal distribution is the Spirillinids. They constitute the major group in the assemblage from samples 56 to 46. On average they comprise around 30% of the assemblage. After sample 44 they disappear.

The Ceratobuliminidae appear at sample 26 and disappear at sample 24, this marks the first and last occurrence of *Reinholdella lutzei.*

The specific dominance graph shows a distinct pattern (Fig. 7:31). Prior to sample 44 the dominant and subdominant species are similar in abundance at around 40%. Between sample 44 and 38, the dominant species increase in abundance and conversely the subdominant species drops to around 10%. From sample 36 where the dominant and subdominant species are almost equal, the abundance of the dominant species increases steadily to sample 20 where *Trochammina squamata* comprises 93% of the assemblage. The dominant and subdominant species after this sample become closer in abundance.

7.5.6.3. Palaeo-ecological interpretation.

The α - index is variable and fluctuates from a maximum of around 6.8 to a minimum of around 1.2. The fluctuation of this index would seem to suggest that the assemblage is indicative of a wide variety of depositional environments.

From samples 58 to 46 the assemblage is composed of abundant *A. coprolithiformis* (apart from sample 50 where it is absent). From sample 44 this species effectively disappears and is not recorded, in any significant numbers, for the rest of the borehole. In general this would indicate a shallowing of the environment, or an environment inhospitable to this large lituolid species (e.g. a very fine-grained substrate). These samples have a high abundance of spirillinids, and after sample 46 they disappear. In these samples there is a positive correlation between *Spirillina* and *A. coprolithiformis* which would indicate a shallow water, perhaps higher energy environment. A shoreface to tidal flat environment is suggested, supported by wavy and lenticular bedding around samples 52 and 50. The presence of miliolinids and smaller agglutinated taxa may also indicate slightly reduced salinity, and the environment may represent an estuarine setting, in particular a low energy shoreface or spit constructed out of a headland within an estuary. The more heterolithic beds may represent a tidal shoal setting, in the mouth of an estuary.

Samples 48 and 46, are similar in faunal composition but with a lower abundance of spirillinids and an increase in *Ammobaculites canui.* This still may represent a shallow water shoreface environment.

Sample 44 has a distinctive faunal composition and is almost exclusively composed of *Lenticulina münsteri*; many broken fragments of macrofossils also occur in this sample.

Samples 41 and 40 mainly comprise *L. münsteri* as before, but the remainder of the assemblage is composed of trochamminids, small *Ammobaculites*, and textulariids.

The lageninids continue to decline and sample 38 is dominated by the first appearance of *Epistomina parastelligera* in this borehole.

Sample 36 has a distinctive assemblage which alters little in composition to sample 22. The epistominids become an increasingly important aspect of the assemblage, reaching around 70% at sample 26. The other important component of the assemblage is small agglutinated taxa including the first occurrence of *Textularia pugiunculous* and a major peak in abundance for *Lagenammina difflugiformis* at sample 36. The haplophragmoidids are also abundant, as are species of *Reophax*. The large component of agglutinated taxa steadily decreases as the epistominids increase. This environment probably represents a restricted marine setting, slowly becoming deeper and less marginal, towards the top of the borehole. Initially the environment may represent a lagoonal or marsh type setting.

Sample 20 however is composed almost completely by *Trochammina squamata*. Previous authors have noted that *T. squamata* tends to become abundant when there is a paucity of other forms, perhaps indicating that this species is more tolerant of harsh conditions. Barnard and Shipp (1981) envisaged a stagnant environment for assemblages almost exclusively composed of *T. squamata*. In this sample this taxon may be representative of the continuation of a lagoonal facies, or salt-marsh environment, because of the very low diversity of the assemblage.

After sample 18 the assemblage reverts back to a similar assemblage prior to sample 20 and probably represents a restricted marginal marine environment, or brackish conditions.

7.6. *Summary.*

To conclude, the environment of deposition is very difficult to ascertain using the foraminiferal data alone. The assemblage does not vary markedly throughout the Corallian and although there is a distinctive change in environments of a cyclical nature, water depths are generally similar. The foraminifera from the Jurassic are long ranging and the dominant forms (*Ammobaculites coprolithiformis*, *Lenticulina münsteri*) are fairly cosmopolitan. Previous authors have reported different environments for the same taxon, and taxa are found in widely different environments from different locations.

In general the assemblage is similar to other assemblages reported form the Oxford Clay and Corallian. *Epistomina* is more abundant in the samples studied than is mentioned in the literature. This is probably the result of using borehole material, which helps offset the problems of weathering which effect this group more readily (due to the original aragonitic test).

As with all foraminiferal studies there is a difficulty in sampling all lithologies. Many of the harder, more lithified, samples have been omitted due to the difficulties in processing. The study of foraminifera in thin-section is one method that may be used to overcome this problem, although it is difficult to achieve satisfactory results (comparing statistical analysis between thin-sectioned samples and processed samples is almost impossible). The criteria for recognising taxa has to change when examining fauna in a thin section and there is a lower probability of correctly identifying forms to specific level. It is therefore difficult to combine these two methods. A more realistic, although time-consuming answer, would be to try and process these harder samples. Unfortunately methods that effect the harder cemented limestone samples generally have an adverse affect on the assemblage. This also means that the results will probably be statistically unreliable and certainly very difficult to compare with results from argillaceous samples.

The assemblage encountered is typical of an Oxfordian assemblage and corresponds to all types (a, b and c) of Gordon (1970).

In general the interpretation of the depositional environment does not differ greatly from the interpretation of the north Dorset area by Bristow *et al.* (1995), but may represent an estuarine setting with the environment varying from an offshore/lower shoreface initial deposition. This is followed by inner estuarine, tidal flat, shoreface/spit and estuary mouth deposits. Following a basal lag deposit the environment becomes restricted marine, changing to lagoonal or marsh, finally reverting to restricted marine, with the offshore shelf clays from the Kimmeridgian as the youngest deposits.

7.7. Conclusions.

The variety of statistical methods employed in this chapter and in Chapter 6 has resulted in a range of charts and graphs which illustrate various aspects of the Upper Jurassic assemblage encountered in the studied sections. In order to compare data between each borehole the following method was chosen to best illustrate the salient features of the data set, and to provide information which can be used to correlate the boreholes. This method may also help to identify certain lithological boundaries which proved problematic in the lithological description of the cores (Chapter 3).

In order to facilitate the ease of correlation only certain graphs were utilised. The criteria on which the graphs were selected was based on the concept of Biohorizons. A Biohorizon is defined in the International Stratigraphic Guide (Salvador, 1994) as follows:

> "A stratigraphical boundary, surface or interface across which there is a significant and distinctive change in biostratigraphic character.....The features on which biohorizons are commonly based in a given stratigraphic section include lowest occurrences, highest occurrences, distinctive occurrences, changes in frequency and abundance, or changes in the character of individual tax (e.g. changes in the direction of coiling in foraminifers or in number of septa in corals)".

Data plots which included potentially useful Biohorizons were chosen and compared between the four boreholes. Each graph was compared with the other graphs from each borehole at the same scale and any correlation noted. Each graph was superimposed on the other graphs until a best fit was established (where distinctive Biohorizons coincided, in terms of geometry this was in the form of peaks, troughs, points of inflection or asymptotic points on the graph).

In order to best illustrate the various results a Graphic Correlation-type method was employed which is described below:

1. The boreholes were compared in pairs, each borehole being positioned along the axis of a graph with ground level (0 meters) of each borehole placed at the origin of the graph.

2. The selected data plots were drawn to scale and orientated alongside the relevant borehole.

3. A line from each chosen Biohorizon was projected onto the graph from each borehole, and where like Biohorizons intersected, a point was marked on the graph. Each Biohorizon was projected and a series of points was established.

4. A "Line of Correlation" was fitted to the points.

5. Sample groupings established by MDS and Cluster Analysis were also compared. Each group was projected onto the "Line of Correlation" and was illustrated by means of different intensity of shading.

6. Key Biohorizons were numbered, and transferred to a diagram illustrating the correlation between each borehole.

This method resembles the Graphic Correlation method of Shaw (1964) who pioneered the concept. Subsequently many authors have used Shaw's method to resolve problems of correlation and stratigraphical interpretations (e.g. Miller, 1977; Edwards, 1984; MacLeod and Keller, 1991 and Mann and Lane, 1995). The resemblance of the present method is, however, only a superficial one, and although it attempts to draw the same conclusion is sufficiently different to merit further discussion.

The Graphic Correlation methods that exist (and computer software packages e.g. GraphCor) tend to rely on data input which consists of the ranges of selected or all taxa; i.e. first and last occurrences of species. The method employed in this thesis involves data from a range of sources, including palaeo-ecological data. The basic premise is that the biohorizons chosen are assumed to occur over the entire studied area and are not local occurrences. This concept is also central to the ideas of Event Stratigraphy, and in particular the Ecostratigraphic Events described by Kauffman *et al.* (1991). These events are defined as representing abrupt changes in population or community structure resulting from changes in environment (e.g. temperature, climate and substrate character, etc.). The limitations of the method as applied in this study are as follows.

1. This method does not normalise each section to a standard reference section and, therefore, the effects of differing rates of sediment accumulation, faulting, non-sequences, etc., cannot be compensated for. It is possible, however, to gauge, to a limited extent, if sediment accumulation rates are different between boreholes.
2. Biohorizons intersecting indicate a probable correlation provided they follow the "Line of Correlation"; where they do not intersect (or coincide) a number of possible conclusions can be drawn.

a. That any particular Biohorizon representing a "bioevent" (i.e. a distinctive abundance peak) is a local occurrence and does not correlate laterally to any extent.

b. That the particular biohorizon does exist in the strata included in the borehole but that the sample resolution is not fine enough (or does not coincide) to highlight it.

c. That the biohorizon is not a "natural" event and is a feature of mechanical sorting of the sample, preferential weathering, transportation of the assemblage or some other taphonomic effect.

d. That each peak has an "interval of uncertainty" which extends to either side of the peak up to the adjacent points and includes the unsampled interval between the quantitative changes (Edwards, 1995). This area of uncertainty can account for lack of correlation.

3. Due to the fact that each of the sections are not normalised to a standard reference section, there is a wider spread of intersection points, which in turn leads to a variation in the possible placing of the "Line of Correlation".

This method has advantages in that palaeo-ecological data are used, and provided the above limitations are recognised, correlation can be made where the taxa recorded have a long stratigraphical range, as is the case with many Upper Jurassic assemblages.

Figures 7.34 to 7.37 illustrate the possible correlation of the pairs of overlapping boreholes. In each of these figures, the groupings of samples defined in Chapter 6 by MDS or Hierarchical Agglomerate Cluster Analysis, are also shown. In an attempt to correlate the sample groupings they are projected onto the "Line of Correlation" (LOC). Each progressively smaller sample grouping (defined by either MDS or Cluster analysis) is indicated on the figures by a progressively darker colour of shading. In the case of the sample groupings the correlation between boreholes is distinctively affected by the angle of the "Line of Correlation".

In Figure 7.34 the Hartmoor Hill Borehole and the Bowden Farm Borehole are compared. In this figure twelve important biohorizons are recognised, two of which do not correlate with the Bowden Farm Borehole due to the deeper penetration of the Hartmoor Hill Borehole. The "Line of Correlation" is a good fit however, and there is a possibility that the Bowden Farm Borehole succession represents a higher sedimentation rate, and two "possible lines of correlation" are also indicated. The projection of the sample groupings onto the LOC shows that certain boundaries between sample groups appear to correlate.

Figure 7.35 shows the comparison between the Bowden Farm Borehole and the East Stour Borehole. Numbered Biohorizons from the previous figure are continued on this figure and correlated. A good fit is achieved for the LOC. A lithological correlation point is added to the graph due to the identification of the Sturminster Pisolite in both boreholes which helps to fix the position of the LOC. This correlation diagram shows a particularly good coincidence of sample groupings.

Figure 7.36 illustrates the correlation between the Hartmoor Hill Borehole and the East Stour Borehole. Stratigraphically the boreholes do not have a large overlap, and a reasonable LOC is achieved. It is difficult to comment on the fit of the sample groups in this diagram, due to the small overlap of the boreholes.

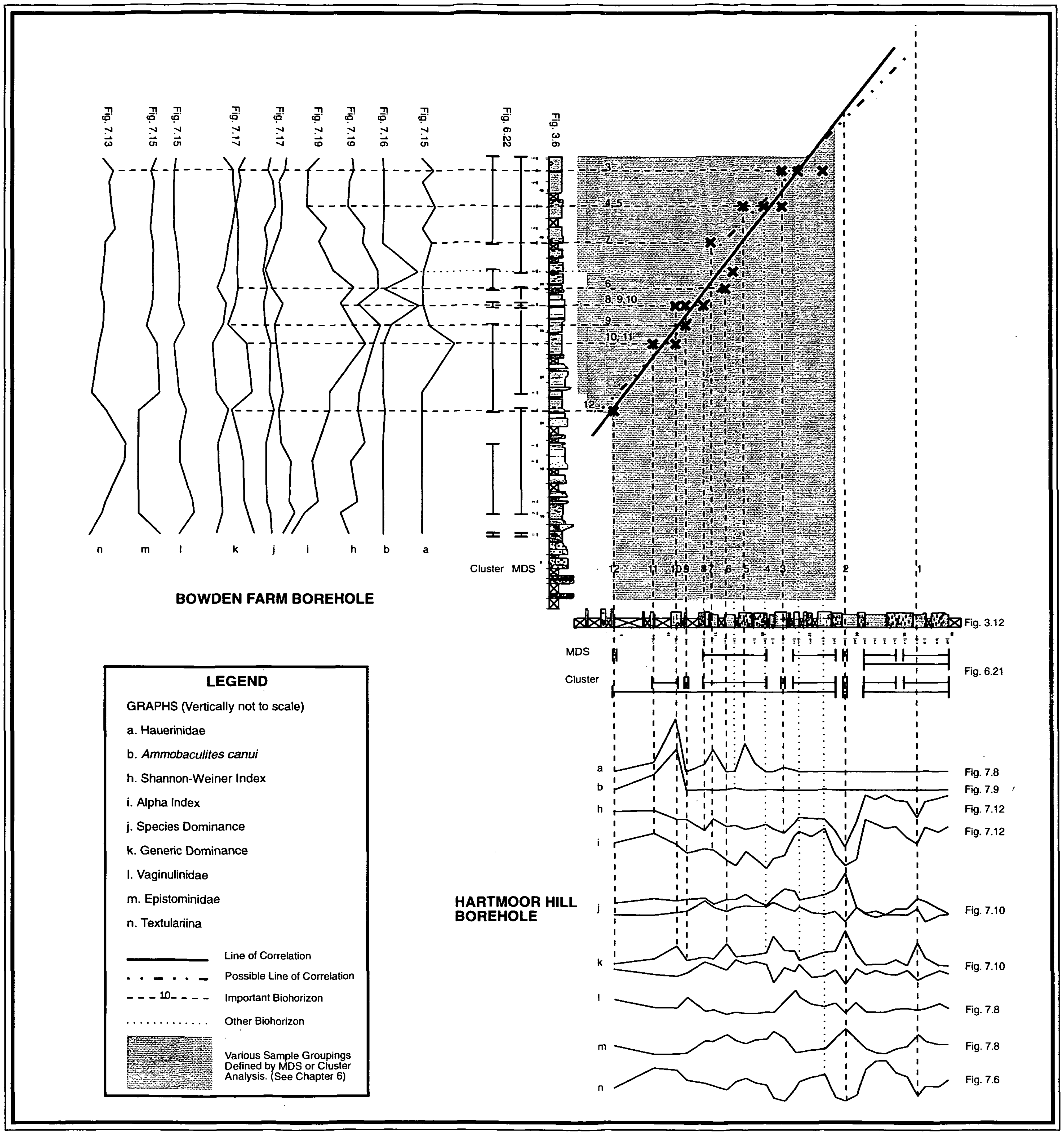


Figure 7.34.

Correlation of the Hartmoor Hill Borehole and the Bowden Farm Borehole using Biohorizons.

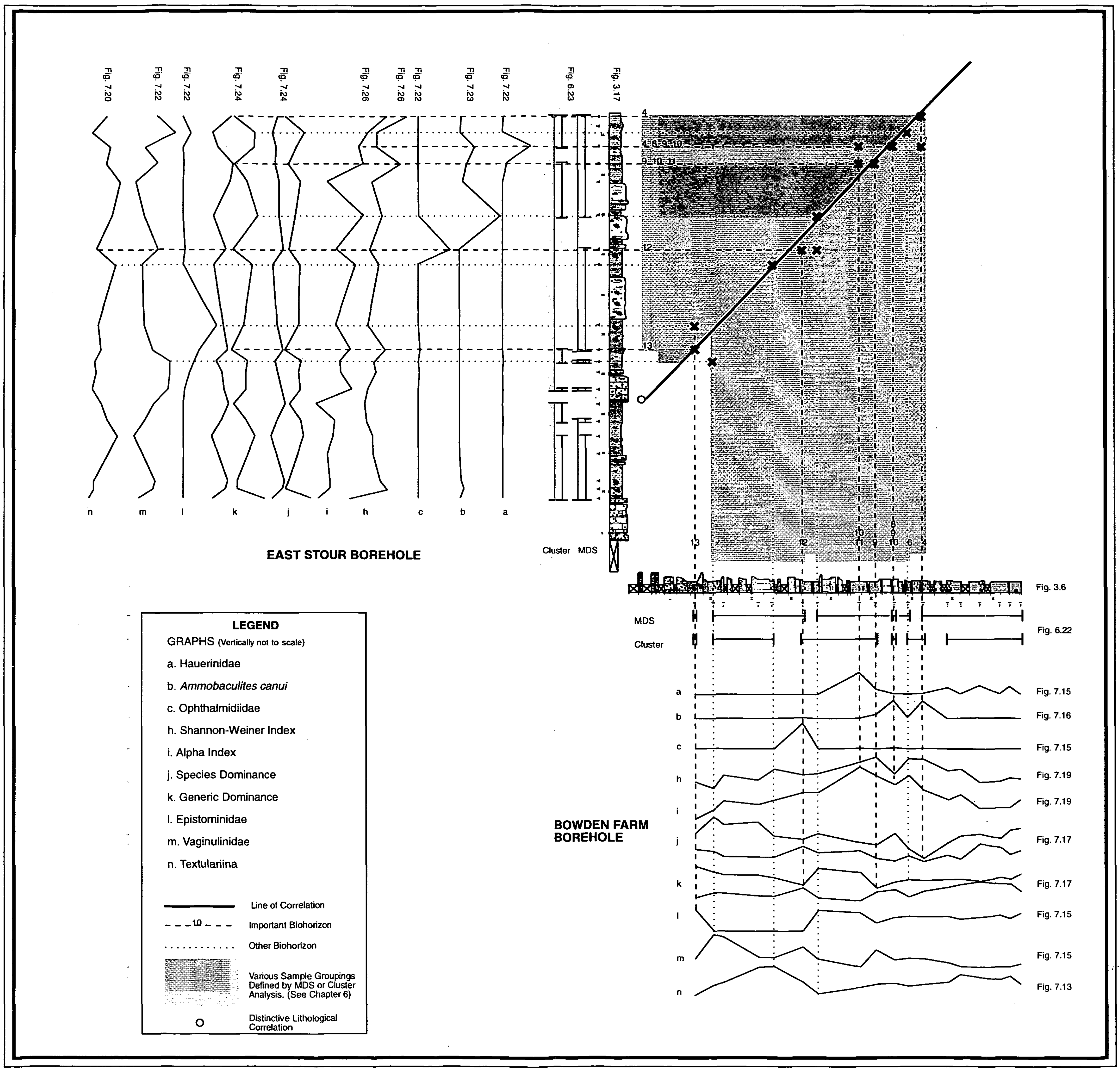


Figure 7.35

Correlation of the Bowden Farm Borehole and the East Stour Borehole using Biohorizons.

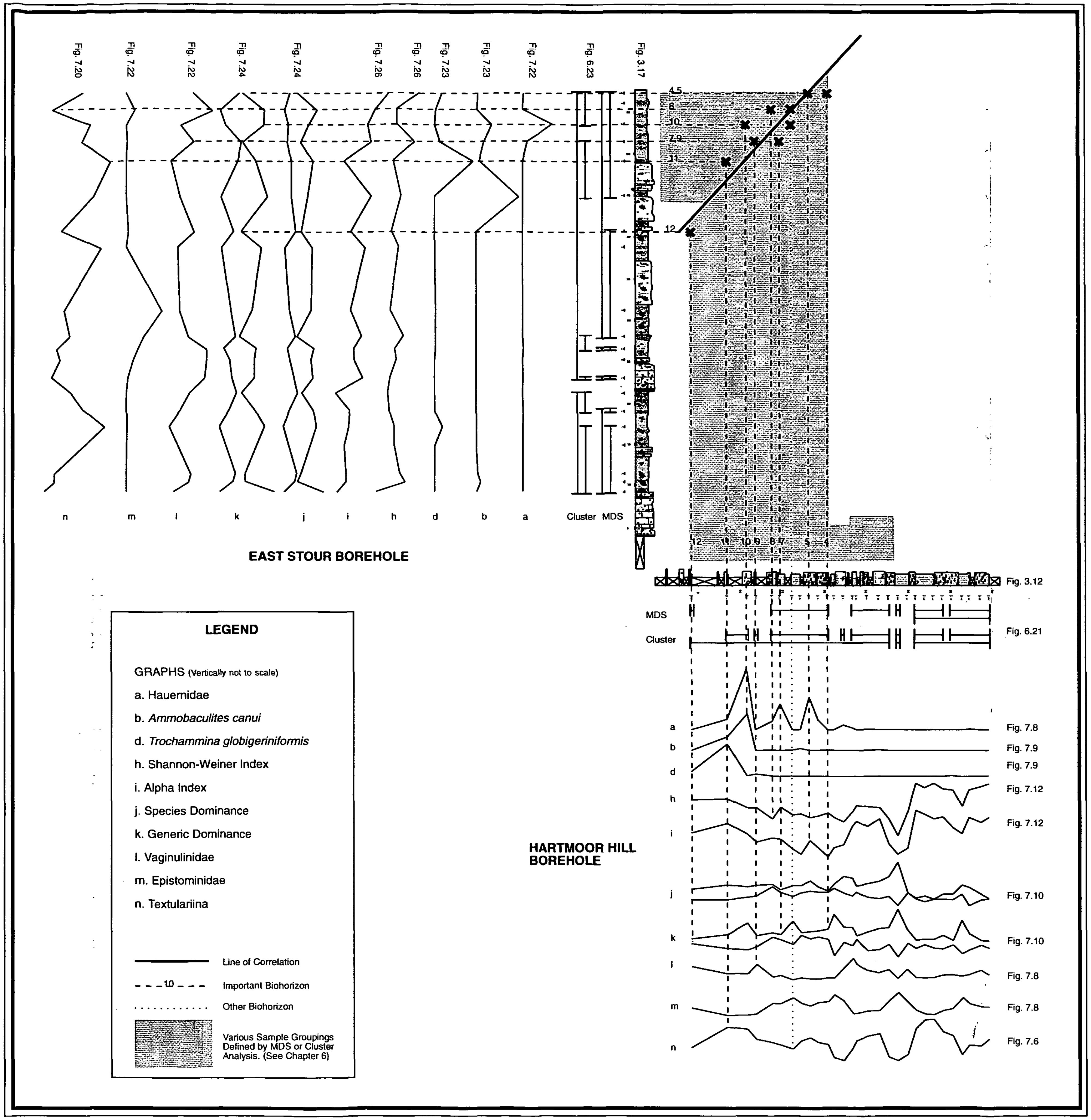


Figure 7.36.

Correlation of the Hartmoor Hill Borehole and the East Stour Borehole using Biohorizons.

Figure 7.37 shows the correlation between the Hallett's Farm Borehole and the East Stour Borehole. Although there is a definite difference in the rates of sedimentation in the two boreholes a LOC is attempted which is fixed in position by another distinctive lithological correlation at the top of the Todber Freestone Member. There is not enough common strata between these boreholes to draw any conclusions from the distribution of the sample groups in this correlation.

Overall, 21 distinctive Biohorizons are recognised, with others plotted but not numbered. In some cases the Biohorizons of one borehole are correlatable with more than one biohorizon from another borehole. This is due to the fact that in one borehole various biohorizons may coincide but are separate in another borehole, perhaps because of sample frequency. This results in certain Biohorizons having more than one number (see also point "2." in the limitations section above).

The most important Biohorizons are plotted onto a correlation diagram containing the four boreholes (Figure 7.38). Where it is obvious that there is a strong lithological correlation, and an obviously different rate of sediment accumulation, then the borehole logs are split to correlate the distinctive lithologies.

The boreholes are correlated using the Biohorizons and are compared with the lithostratigraphy and ammonite subzonation. It can be seen that using certain biohorizons the boreholes can be correlated. Biohorizon 2 is situated close to the junction of the Hazelbury Bryan Formation and the Oxford Clay Formation and indicates a distinctive break in the assemblage. Biohorizon 9 shows a good correlation between Hartmoor Hill Borehole, Bowden Farm Borehole and East Stour Borehole, as does Biohorizon 12. The most readily correlatable feature amongst all the data is the distinctive cyclical nature of the Generic and Specific Dominance graph (j and k). Each narrowing of the generic dominance plot produces a biohorizon which is easy to correlate over most of the boreholes. This feature marks the Biohorizons 4, 9, 12, 13, 14, 17, 19, and 20/21. These Biohorizons are not only

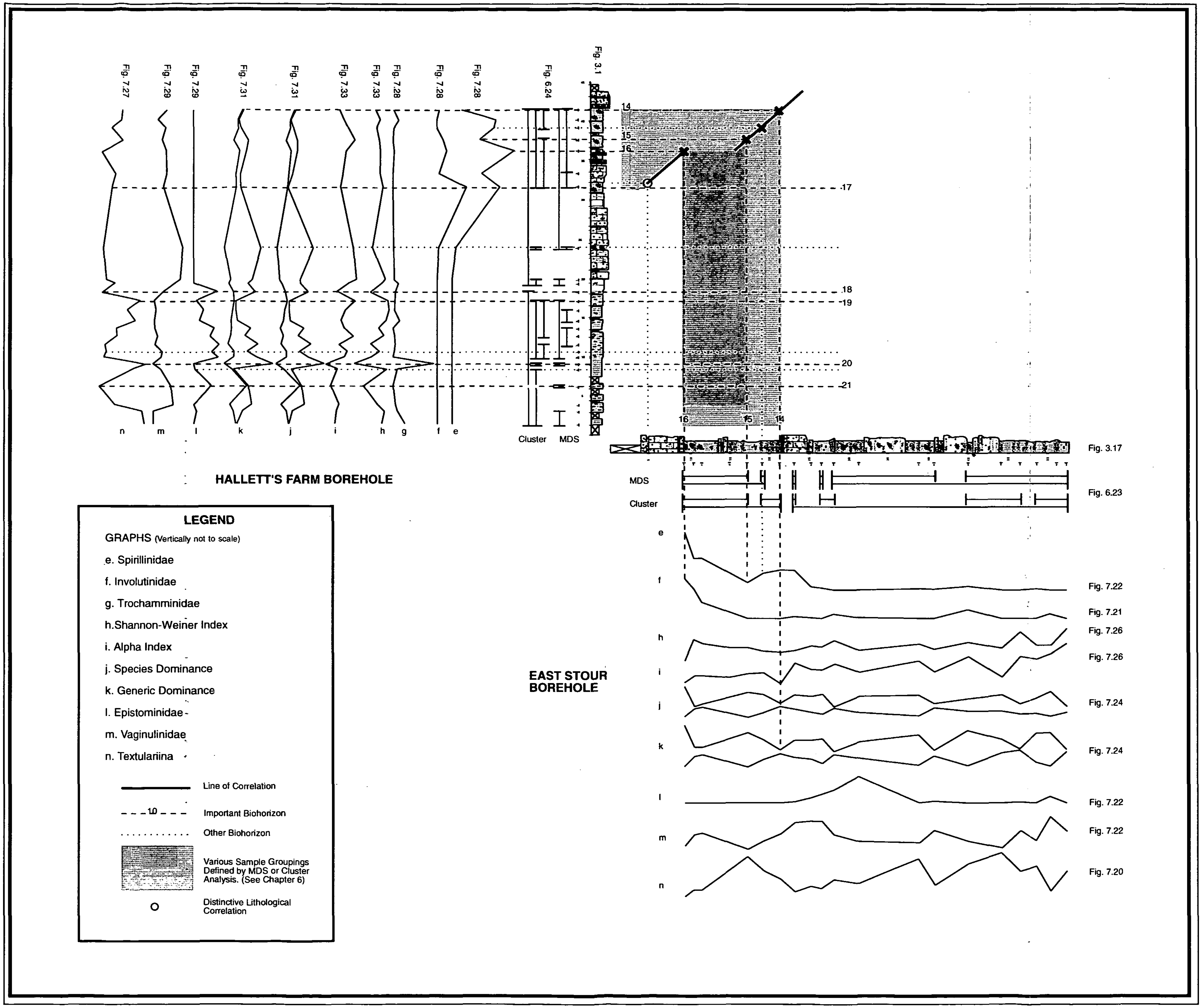


Figure 7.37.

Correlation of the East Stour Borehole and the Hallett's Farm Borehole using Biohorizons

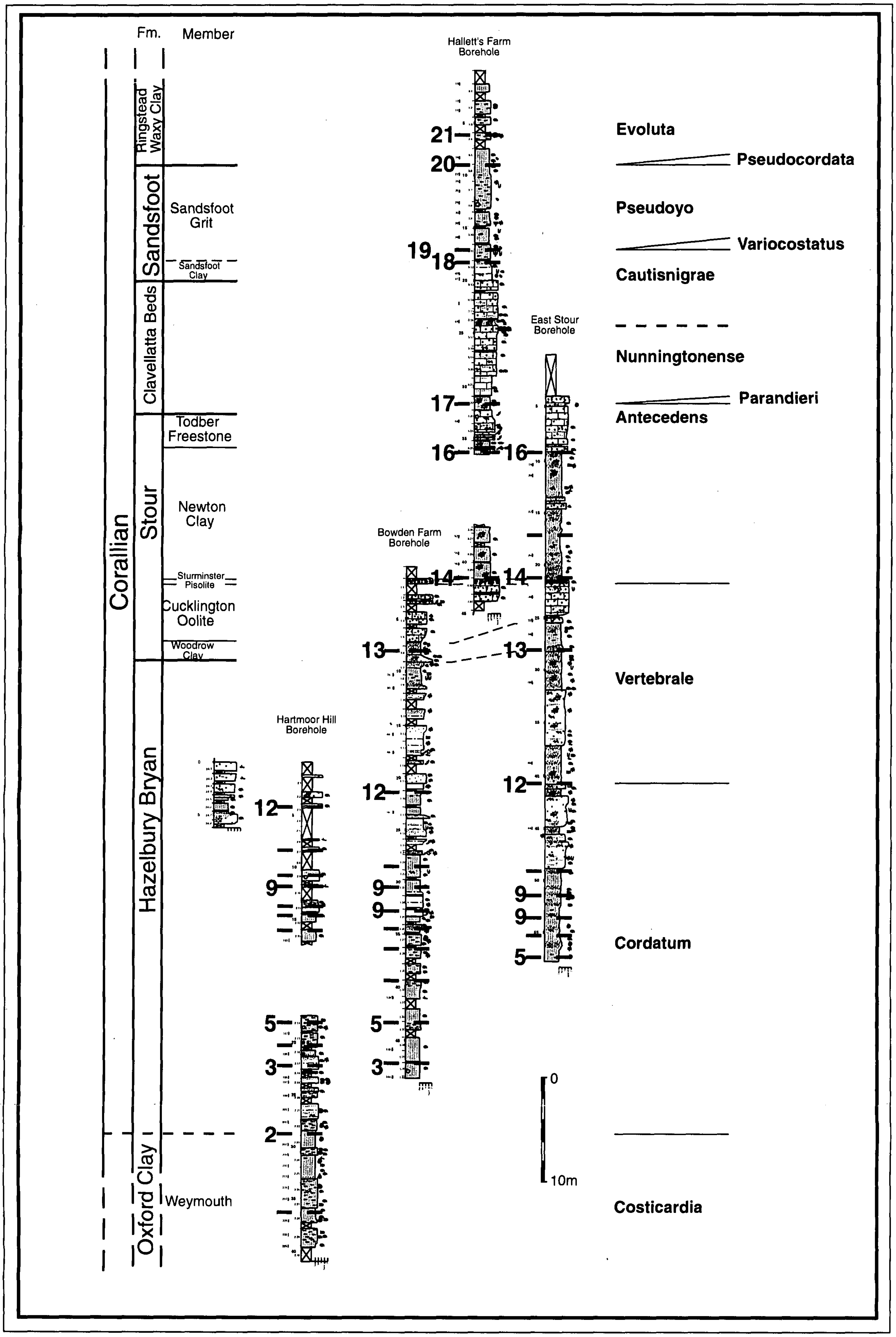


Figure 7.38. Correlation of the Hartmoor Hill, Bowden Farm, East Stour and Hallett's Farm Boreholes using Biohorizons. (Perisphinctid Ammonite Zonation scheme shown).

distinctively correlatable but mark boundaries between lithologies and coincide with ammonite subzonal boundaries. It must be mentioned, however, that the coincidence of the biohorizons with ammonite zones may be a circular argument in as much as the biohorizons follow lithological changes which in turn are marked by ammonite subzonal boundaries. Biohorizon 12, however, coincides with the top of Sand Unit 2, which the BGS correlate with the Preston Grit on the Dorset Coast which marks the boundary with the Vertebrale and Cordatum Zones.

Biohorizon 20 indicates a break in assemblage which may indicate the junction between the Sandsfoot Formation and the Ringstead Waxy Clay Formation.

The Oxfordian of Dorset has been recently studied by Coe (1992, 1995) who divides the succession into 6 sedimentary packages separated by 6 unconformities O1 - O6 (Fig. 3.39). The Biohorizons 2, 17 and 20 mark Coe's Unconformities O2, O5 and O6.

Coe (1992) bases the placement of the unconformities O3 and O4 on Wright's (1981) description of the north Dorset succession. As mentioned before (Chapter 1 and Figure 1.5) the BGS have subsequently altered the lithostratigraphic nomenclature for the succession partly based on Wright's (1981) erroneous definition of a new Member; the Newton Oolite. It is, therefore, possible to amalgamate Coe's O3 and O4 boundaries as one unconformity in north Dorset.

The distinctive pattern of the Generic Dominance curve and the coincidence with the unconformities of Coe would indicate that this feature may be of use in interpreting stratigraphic sequences. A trough, or narrowing of the Dominant/Subdominant curve would indicate an environment which is less restrictive, where the assemblage can survive without any specific adaptive ability needed; i.e. a highly diverse assemblage. In some of the Biohorizons marked by the Generic Dominance curve troughs or narrow bands, there is an associated peak in the diversity curves. Often diversity peaks coincide with peaks in Gamma Ray logs, which are taken to represent Maximum Flooding Surfaces (MFS). The BGS

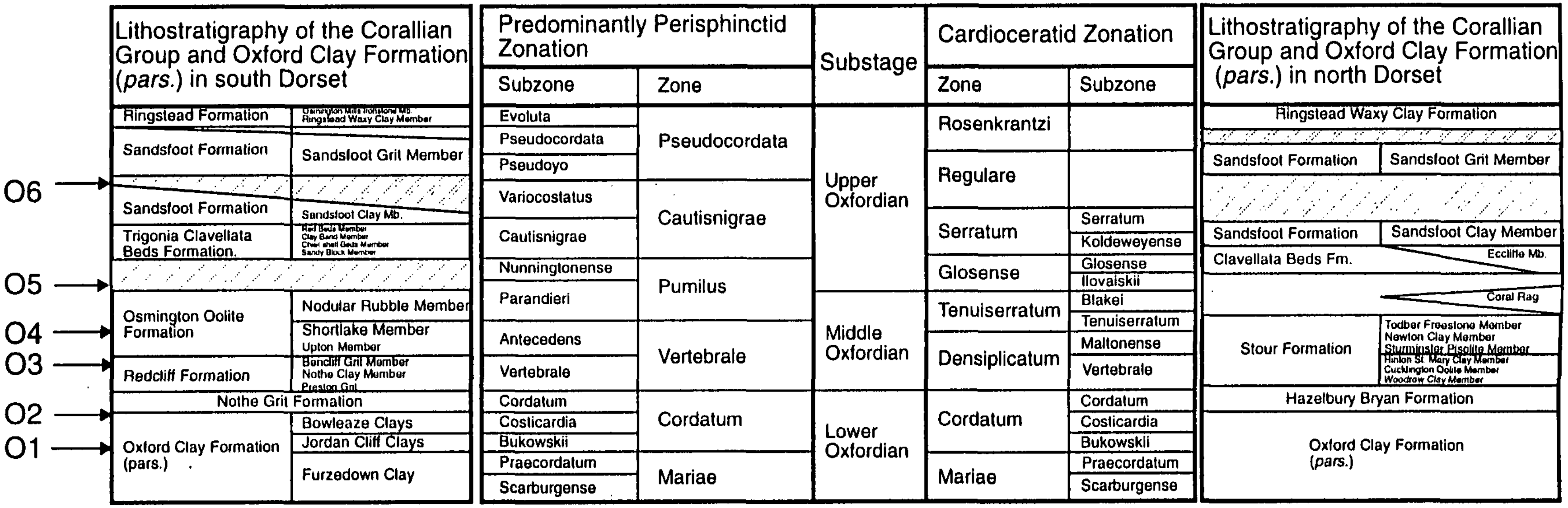


Figure 7.39. Chronostratigraphic subdivision of the Oxfordian Stage showing the different Ammonite Zonation Schemes used and the comparison with the Lithostratigraphy of the Corallian Group and Oxford Clay Formation (*pars.*) of north and south Dorset. Unconformities O1 to O6 are shown after Coe (1992, 1995).
(After Sykes and Callomon, 1979, *emend.*, Birkelund and Callomon, 1985; Bristow *et al.*, 1995 and Coe, 1995.)

Gamma Ray Log for the East Stour borehole (see Talwar, Henderson and Hart, 1992) shows peaks which are coincident with some of the Biohorizons in this study, in particular Biohorizons 13, 14 and 17. If Coe's unconformities for Dorset are actually Sequence Boundaries then it would follow that certain Biohorizons could indicate MFS.

These biohorizons may indicate the return to more favourable conditions directly after a transgressive event, where the environment has become more open marine, or at least normal marine salinities. The cyclical nature of the curve can be attributed to the sequence in north Dorset (and most of the Jurassic) where there is cyclicity in the deposition of the sediment (see also Section 1.4.7.). A gradual change in the sequence from muddy clays (sometimes oolitic) to oolitic limestones at the top followed again by a transgressive clay. In the Hazelbury Bryan Formation the Oolitic limestones are replaced by siliciclastic sands. However, in both cases there is a gradual cleaning-up as clay content decreases from the base to the top of a cycle.

To conclude, the method used to correlate the boreholes is a modified Graphic Correlation method which is perhaps, not as refined, but has certain advantages. To use the true Graphic Correlation method would have proved difficult to apply due to the lack of a comparable section on which to base a Standard Reference Section. Where long ranging taxa dominate the assemblage, by employing a variety of statistical techniques and correlating biohorizons, there is the potential to correlate sequences. This method is unfortunately more reliant on a fine sampling resolution as it is easier to omit a bioevent by a wide sample spacing than it is to overlook an occurrence of a certain taxon. However, if means are available to include palaeo-ecological data in a Graphic Correlation Software package then this method can only be strengthened.

Traditionally Graphic Correlation use biostratigraphic datums in the form of "First Appearance Datums" (FAD's) and "Last Appearance Datums" (LAD's). This biostratigraphic data is compared against another section of a comparable age with a similar dataset of biostratigraphic datums. By comparing the fossil range data a Line of Correlation (LOC) is achieved. A section is then designated as a Standard Reference Section (SRS) which is generally the longest stratigraphic interval. Data from subsequent stratigraphical sections are projected onto the reference section from the LOC. With subsequent repetition of this technique with other sections a Composite Standard Reference Section (CSRS) is gradually built up. The CSRS provides a chronostratigraphic interpretation of future sections and is refined each time data is compared to it.

Graphic Correlation could be expanded to include various biohorizons and other palaeo-ecological data in addition to the traditionally applied FAD's and LAD's.

Palaeo-ecological data would certainly expand the scope of Graphic Correlation but probably limits the application to a single basin (e.g. the Wessex Basin). The change from a marginal setting basinward may even lose some important features for correlation.

The data presented in this thesis are from a localised area of the Wessex Basin and, as such, are limited. If comparable data were derived from the Dorset coastal sections then the techniques employed in this method could be employed over a wider area, and the applicability of this method tested. Material from Normandy would probably be beyond the limits of this method but may provide some interesting results.

The correspondence with some of Coe's (1995) unconformities (O1 to O6) in Dorset may suggest the application of this method to Sequence Stratigraphy, with the possible recognition of sequence boundaries, MFS and the identification of sequences.

Furthermore the cyclical nature of some of the graphs and the recurrence of particular biohorizons are similar in appearance to certain Milankovitch signals (e.g. microrhythms of House, 1985, 1986). Further investigation may reveal a possible connection.

Chapter 8. Biostratigraphy.

8.1 Introduction.

The use of benthonic foraminifera as biostratigraphic markers is not generally as successful as the use of planktonic foraminifera. Benthonic species, by their nature, have to rely on the substrate for survival and are therefore facies-specific. Furthermore, benthonic forms are far more sensitive to ecological changes and sedimentological processes. Benthonic species which are particularly suitable for biostratigraphic purposes (i.e. forms with short, well-defined stratigraphic ranges) tend to be the rarer species. The more abundant species have a tendency to be long-ranging, because they have successfully adapted to a preferred substrate.

Despite these problems there have been many successful attempts to define zonal schemes based on benthonic foraminifera alone. In the Chalk Facies of Britain benthonic taxa are used successfully for zonation (e.g. Hart *et al.*, 1989) due to the uniform deposition of the chalk over an extensive area. Prior to the Cretaceous, benthonic foraminifera are the only option for biostratigraphical purposes because the planktonic foraminifera did not appear (at least in Britain) until the early Cretaceous. Many environments are also dominated solely by agglutinated foraminifera, whether as an original fauna, or through dissolution of the calcitic tests of other foraminifera. In certain environments (e.g. shallow near shore environments) planktonic foraminifera are poorly preserved.

Upper Jurassic foraminifera are particularly long-ranging. The assemblage, while distinctively recognisable from other Mesozoic assemblages, does not vary to a great extent throughout the Upper Jurassic, and many species present in the Oxford Clay Formation range through to the Kimmeridge Clay Formation or have survived from older strata. Often species will be long ranging but at certain horizons will be absent. This is almost certainly due to the facies-specific nature of many of the Upper Jurassic species. Zonation schemes for the Upper Jurassic are rare and those that do exist are not particularly detailed. Most studies merely list the ranges of distinctive species. These ranges often vary quite considerably between areas (which are sometimes geographically quite close) which again emphasises the facies-related distribution patterns of the taxa. The ranges quoted for distinctive Upper Jurassic species in the Stratigraphic Atlas of Fossil Foraminifera (Shipp, 1989) illustrate this point. Most of the species show different ranges for each of the locations in the Jurassic outcrop in England.

8.2 North Dorset Biostratigraphy.

The distribution of the foraminifera encountered in this study is shown in Figures 8.1 to 8.4. Most of the species have ranges which, as quoted in the literature, encompass the stratigraphic sequence in the studied boreholes. However, within the studied succession Last Appearance Datums (LAD's) and First Appearance Datums (FAD's) occur for certain species. When compared with the published literature these ranges are shown to be locally restricted to north Dorset and would not be particularly useful in a wider region. These local LAD's or FAD's are partly due to changes in lithology resulting from an environmental changes which are unfavourable to the particular taxon. An example of this is the LAD in the Hallett's Farm Borehole for *Spirillina tenuissima* and *Spirillina infima* which occurs at sample 44, the youngest sample included within the Clavellata Beds Formation. According to Morris (1982) these species are particularly abundant in limestones and marl sequences, which would help explain their absence from any of the younger samples studied.

The author can only tentatively erect a zonation scheme based solely on the biostratigraphic ranges of the benthonic foraminifera recorded in the north Dorset boreholes. Many of the species recorded have a longer range outside Dorset and therefore the zonation scheme will only be of local application. The local ranges will be useful if integrated into a data set containing the known ranges for other Upper Jurassic assemblages, particularly if used to assist in the compilation of a "Standard Reference Section" (see discussion of Graphic Correlation in Section 7.7).

Although there are many local FAD's and LAD's in the borehole sequences only a few species represent the known upper or lower stratigraphical limits of the species, and in some cases the known ranges of British Upper Jurassic species may be tentatively extended. These

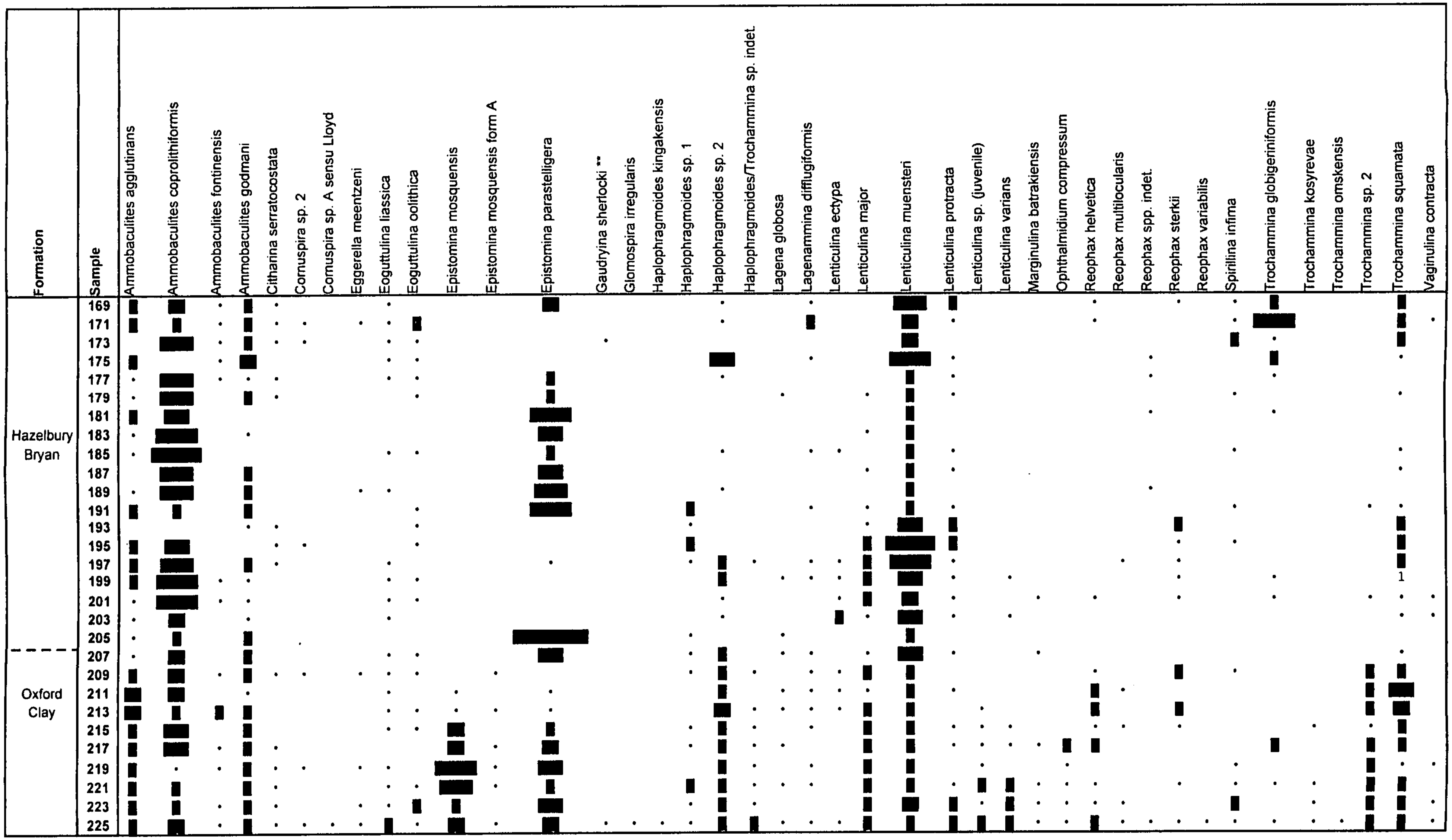


Figure 8.1. -1. Distribution Chart for the Hartmoor Hill Borehole. Important biostratigraphic species denoted by (**).

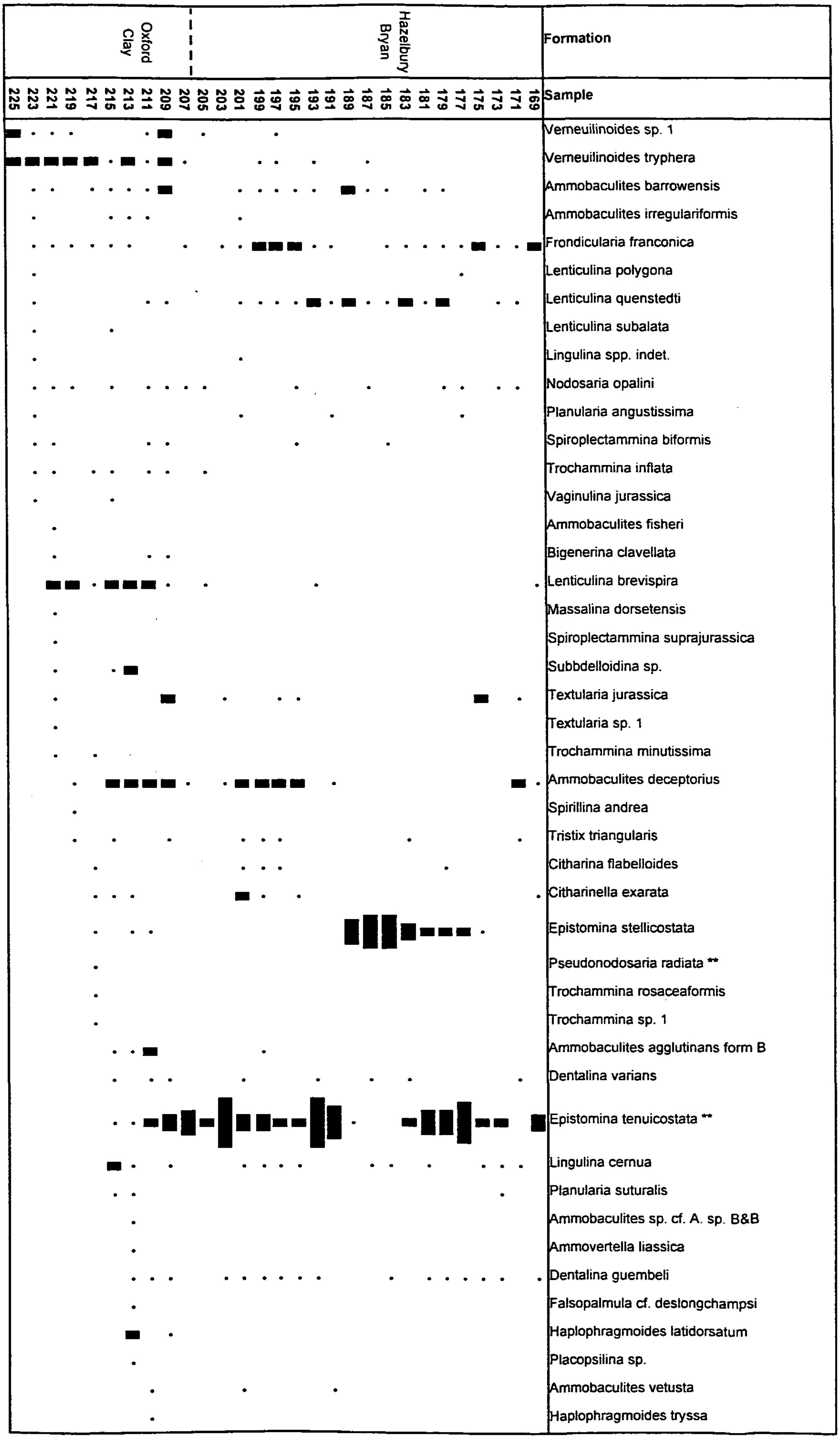


Figure 8.1. -2. Distribution Chart for the Hartmoor Hill Borehole. Important biostratigraphic species denoted by (**).

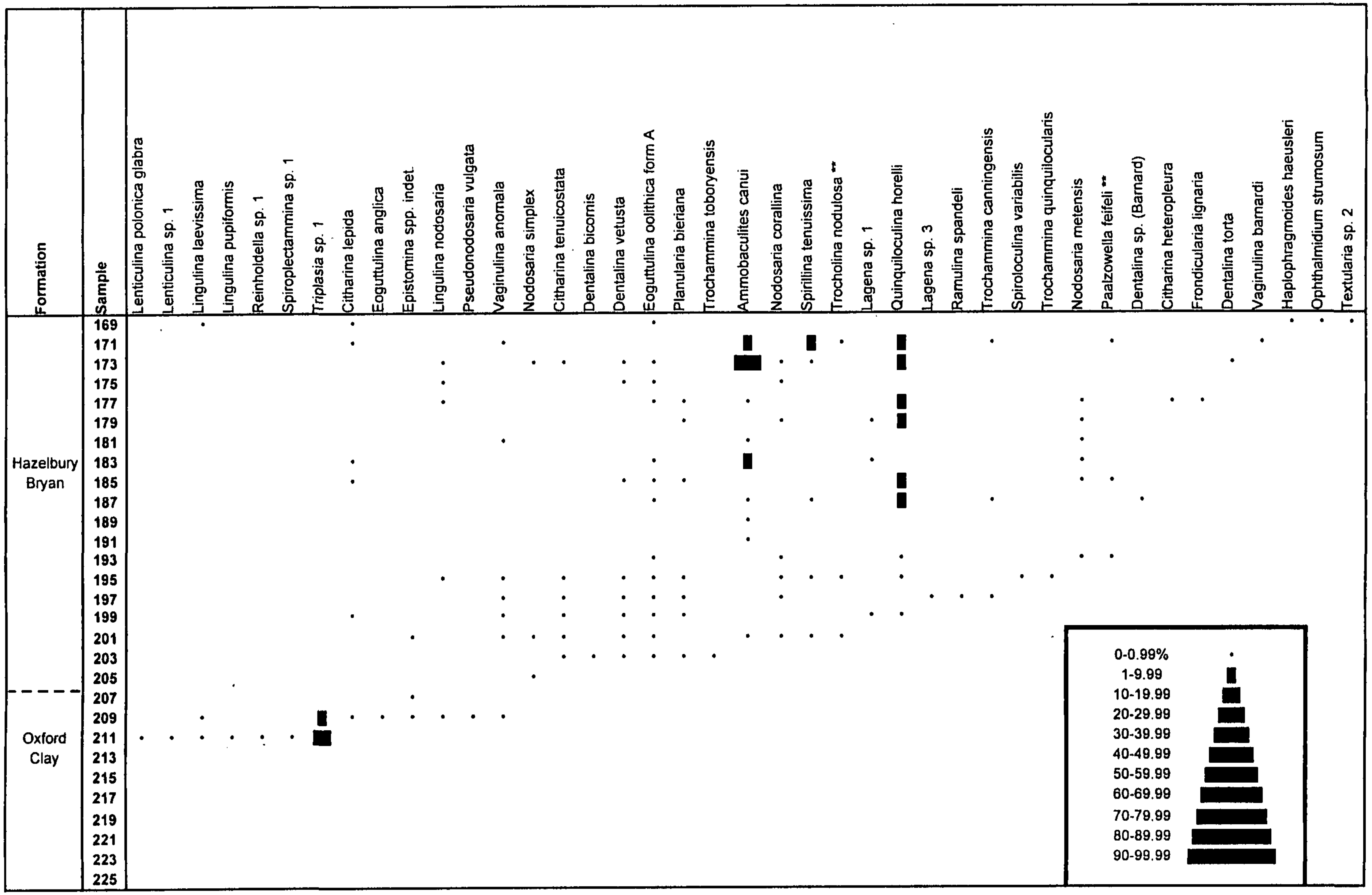


Figure 8.1. -3. Distribution Chart for the Hartmoor Hill Borehole. Important biostratigraphic species denoted by (**).

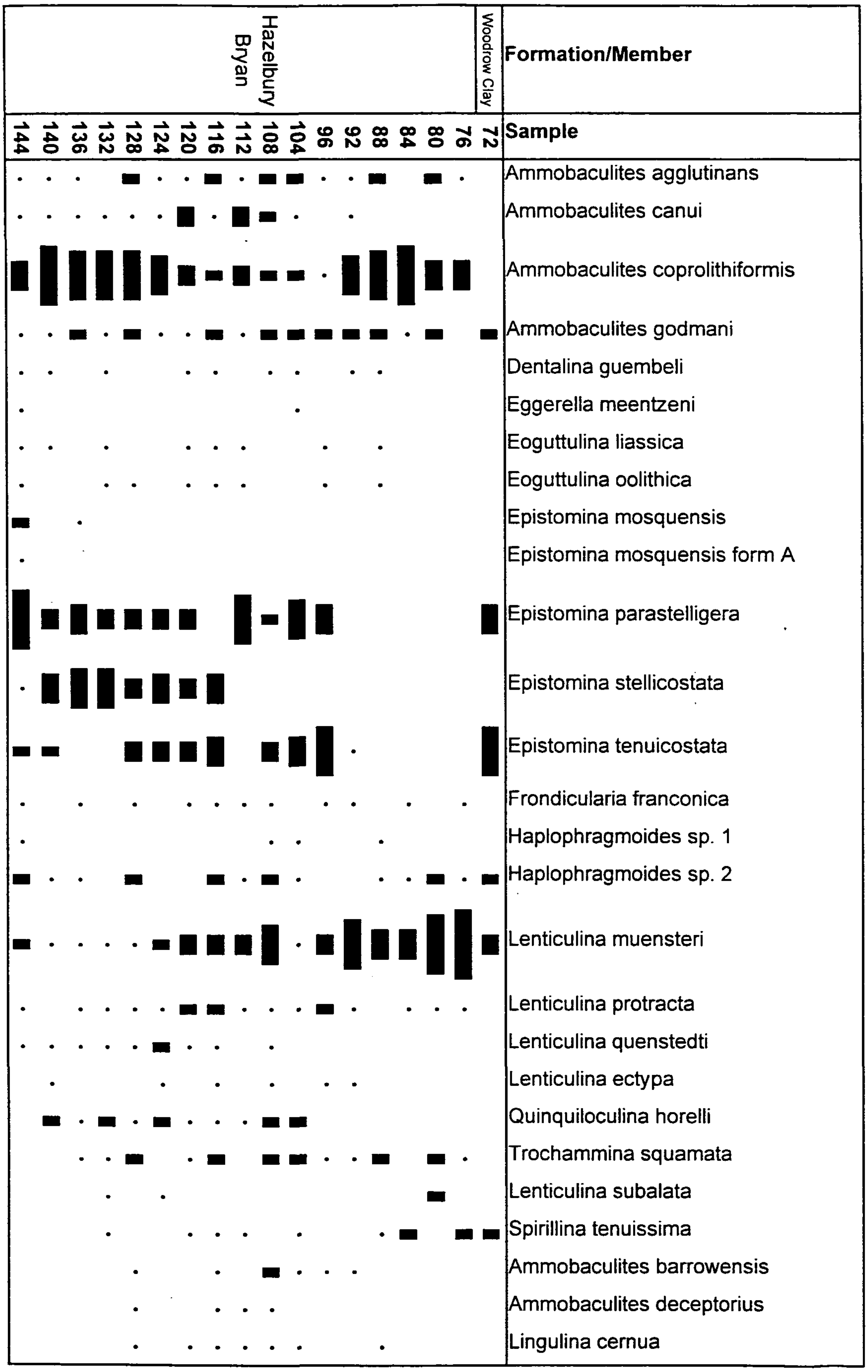


Figure 8.2. - 1. Distribution Chart for the Bowden Farm Borehole. Important biostratigraphic species denoted by (**).

Hazelbury Bryan																	Woodrow Clay	Formation/Member
144	140	136	132	128	124	120	116	112	108	104	96	92	88	84	80	76	72	Sample
				•			•	•		•		•	•					Nodosaria opalini
				•														Textularia sp. 1
				•				•		•								Trochammina inflata
				•														Trochammina quinquilocularis
					•	•	•		•									Citharina heteropleura
					•						•							Lenticulina major
					•													Paalzowella feifeli
					•	•	•		•	•		•	•	•				Tristix triangularis
						•	•		•		•				▬	▬		Citharina lepida
						•			•		•	•	•		▬			Citharina serratocostata
						•	•		•			•	•			▬		Citharina tenuicostata
						•								•				Eoguttulina oolithica form A
						•			•			•						Haplophragmoides tryssa
						•												Lenticulina varians
						•		•										Ophthalmidium compressum **
						•		•		▬	•	•	•	•				Spirillina infima
							•											Ammobaculites fontinensis
							•											Lagena sp. 1
							•		•	▬	•		▬	■	•			Lagenammina difflugiformis
							•			▬	•							Reophax sterkii
							▬	•		▬		•	▬	▬	▬			Textularia jurassica
							•	•										Vaginulina jurassica
								•										Ammobaculites irregulariformis
								•										Cornuspira sp. 2
								•	•									Nodosaria corallina
								•	•									Nodosaria metensis
								•		•		■				•		Ophthalmidium strumosum
								•										Planularia eugenii
								•										Textularia dumortieri
									•									Ammobaculites agglutinans form B
									•			•						Citharinella exarata
									•	•					•			Reophax helvetica

Figure 8.2. - 2. Distribution Chart for the Bowden Farm Borehole. Important biostratigraphic species denoted by (**).

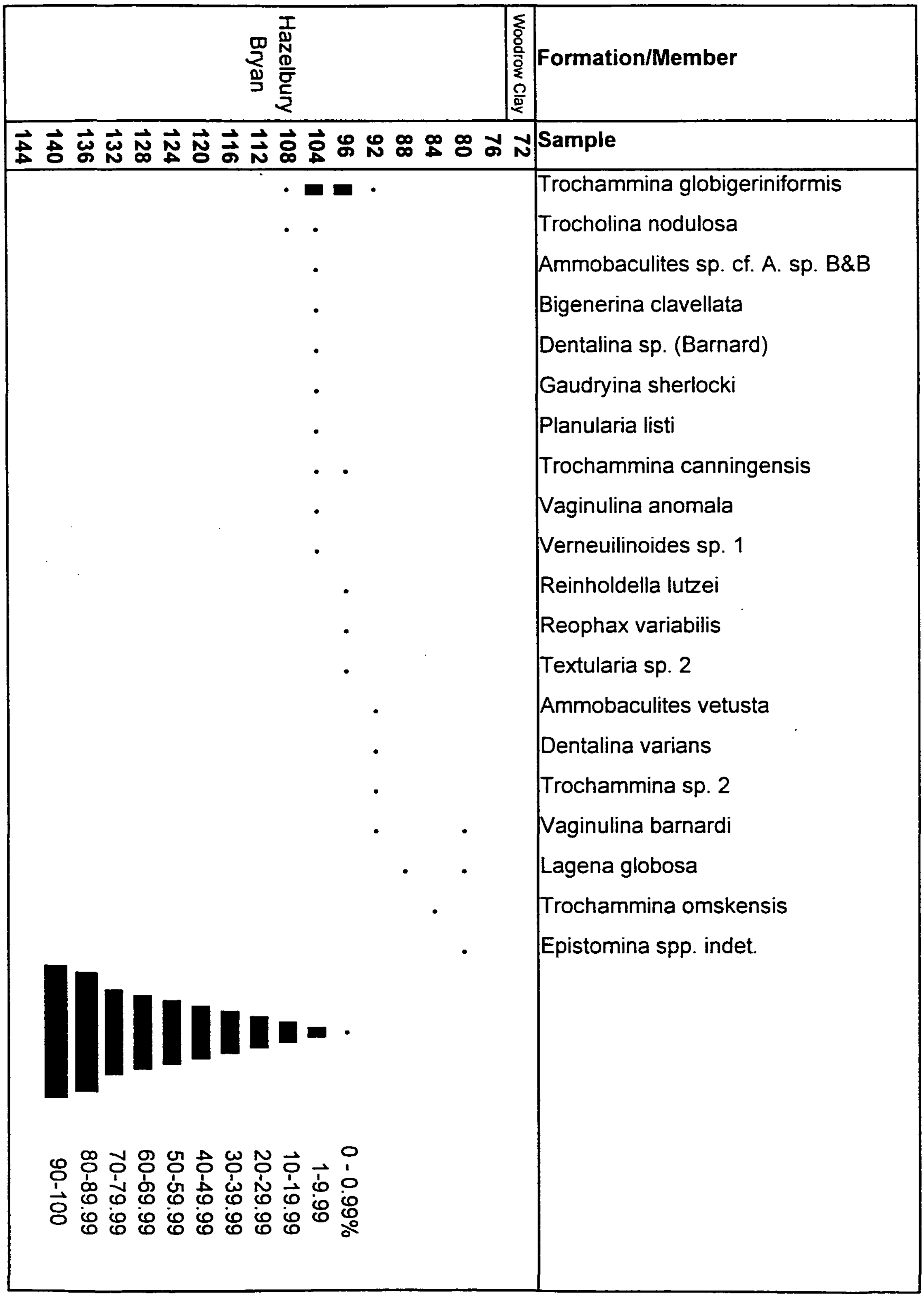


Figure 8.2. - 3. Distribution Chart for the Bowden Farm Borehole. Important biostratigaphic species denoted by (**).

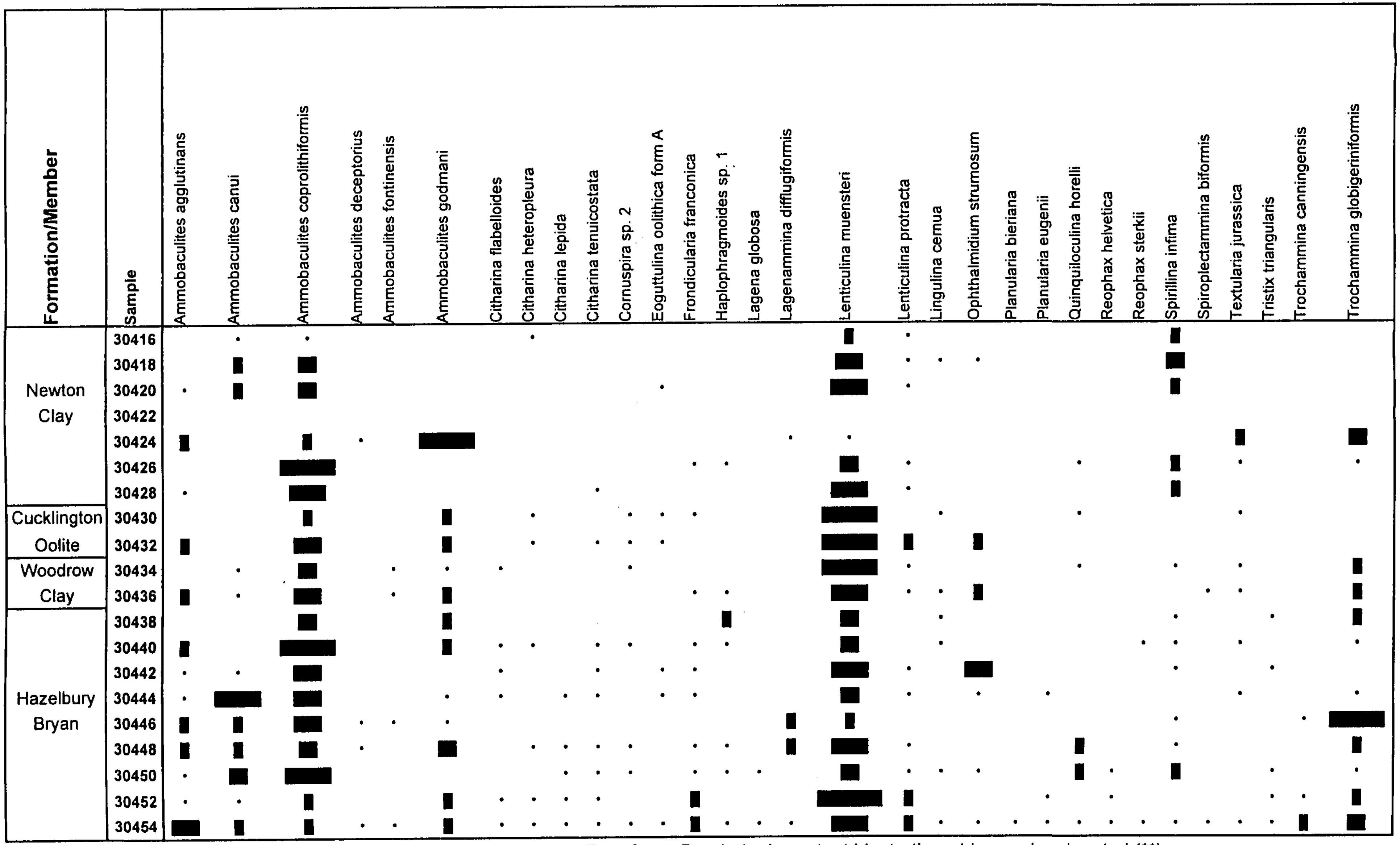


Figure 8.3. - 1. Distribution Chart for the East Stour Borehole. Important biostratigraphic species denoted (**).

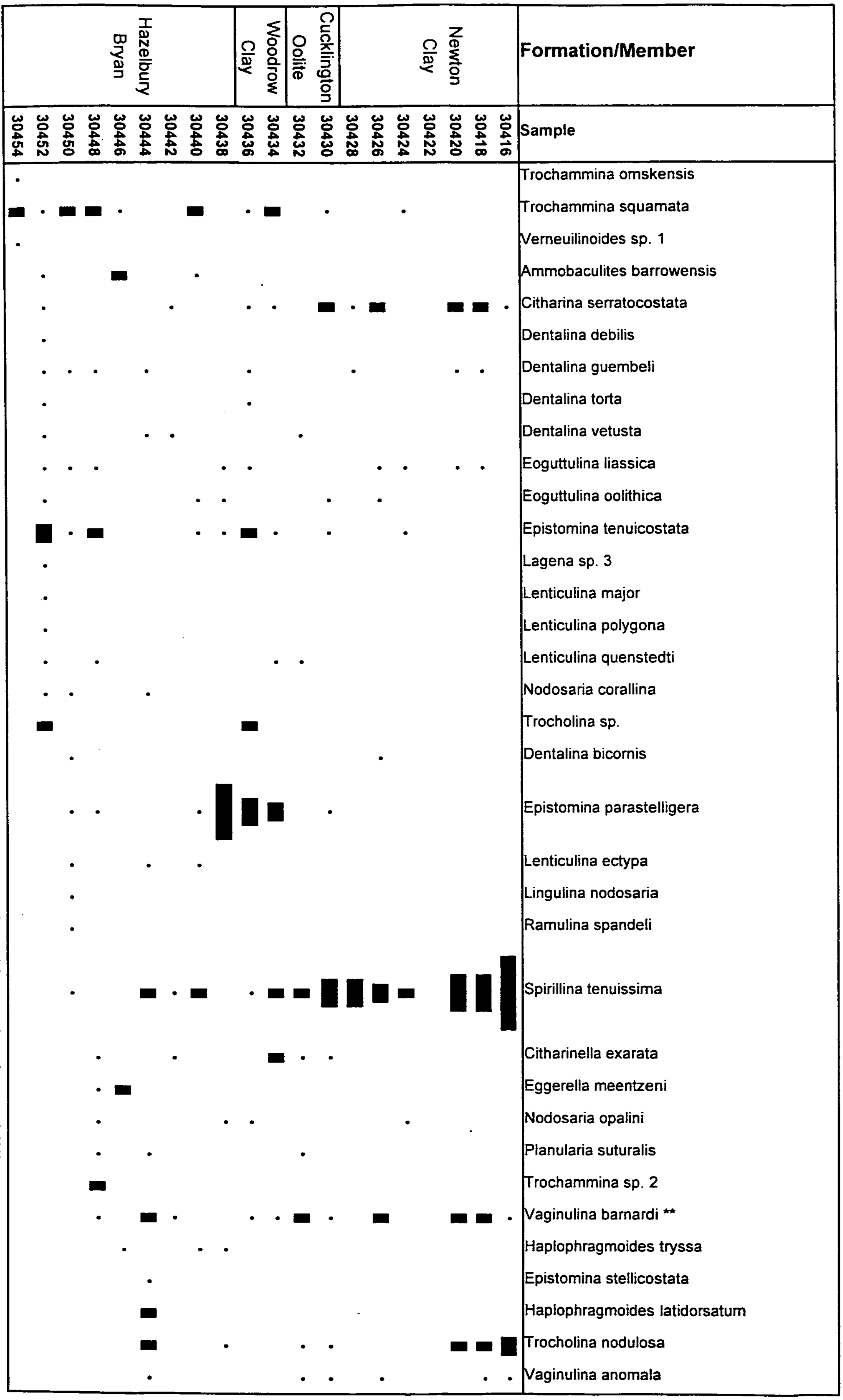


Figure 8.3. - 2. Distribution Chart for the East Stour Borehole. Important biostratigraphic species denoted (**).

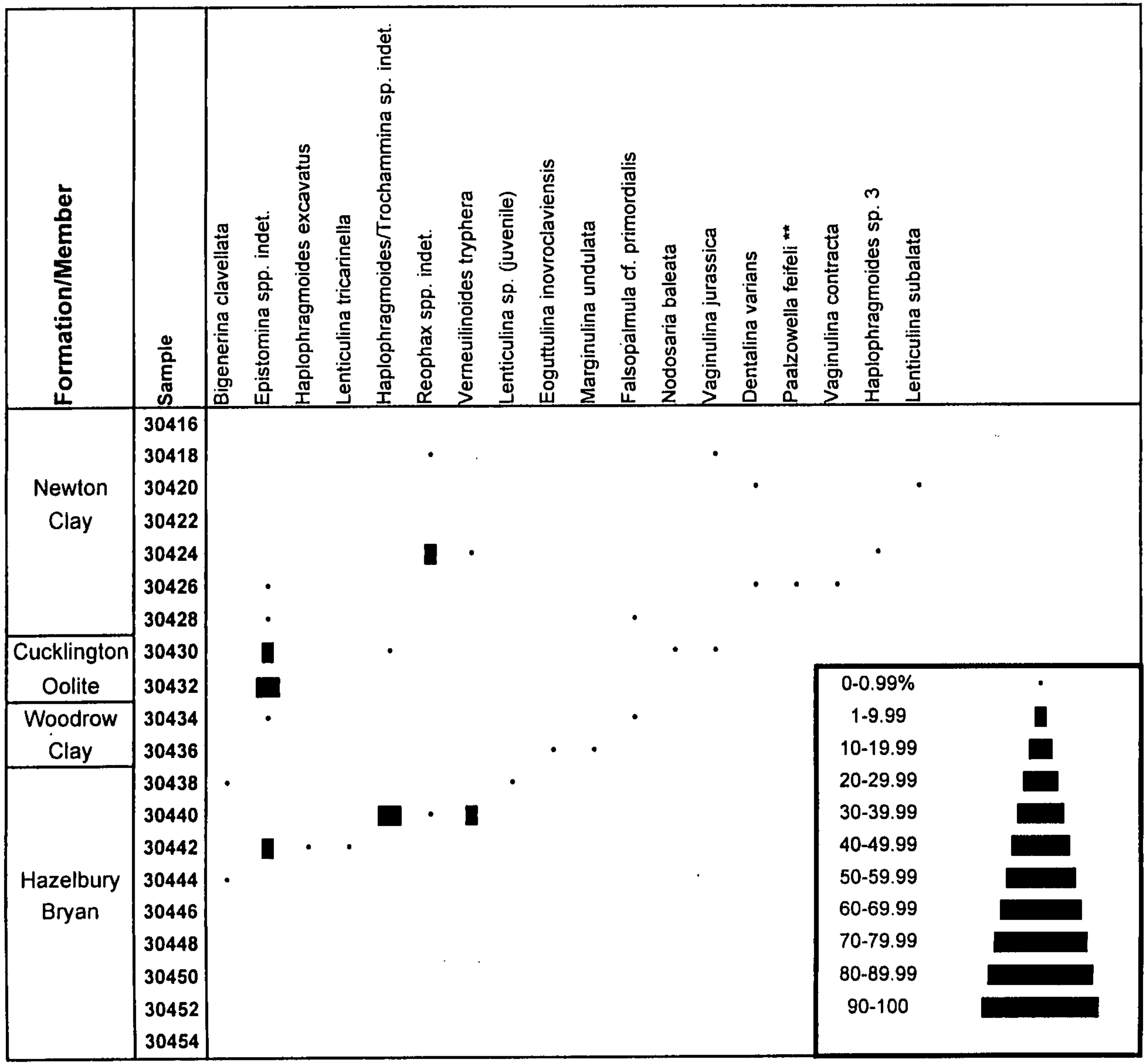


Figure 8.3. - 3. Distribution Chart for the East Stour Borehole. Important biostratigraphic species denoted (**).

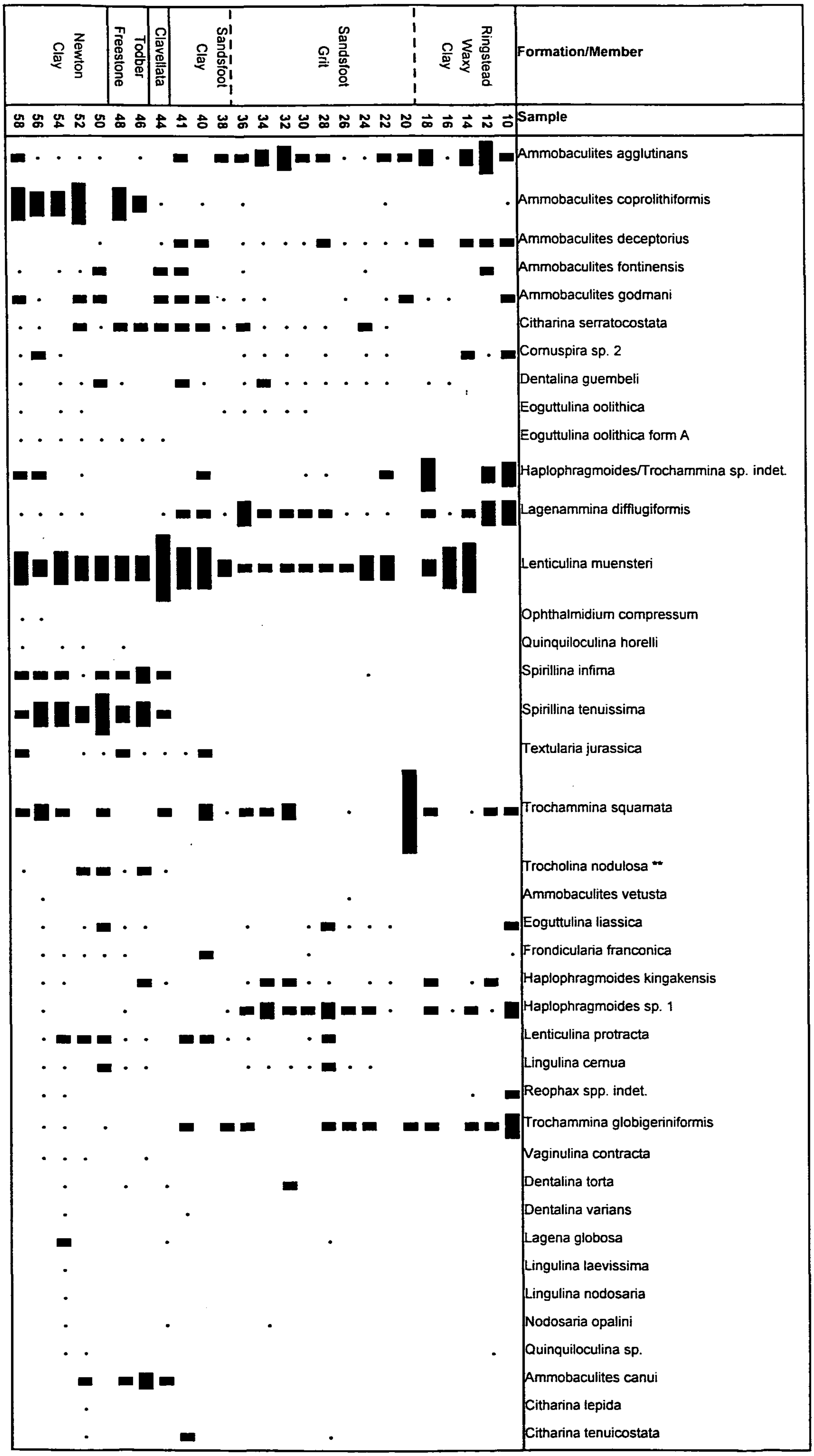


Figure 8.4 - 1. Distribution Chart for the Hallett's Farm Borehole. Important biostratigraphic species denoted by (**).

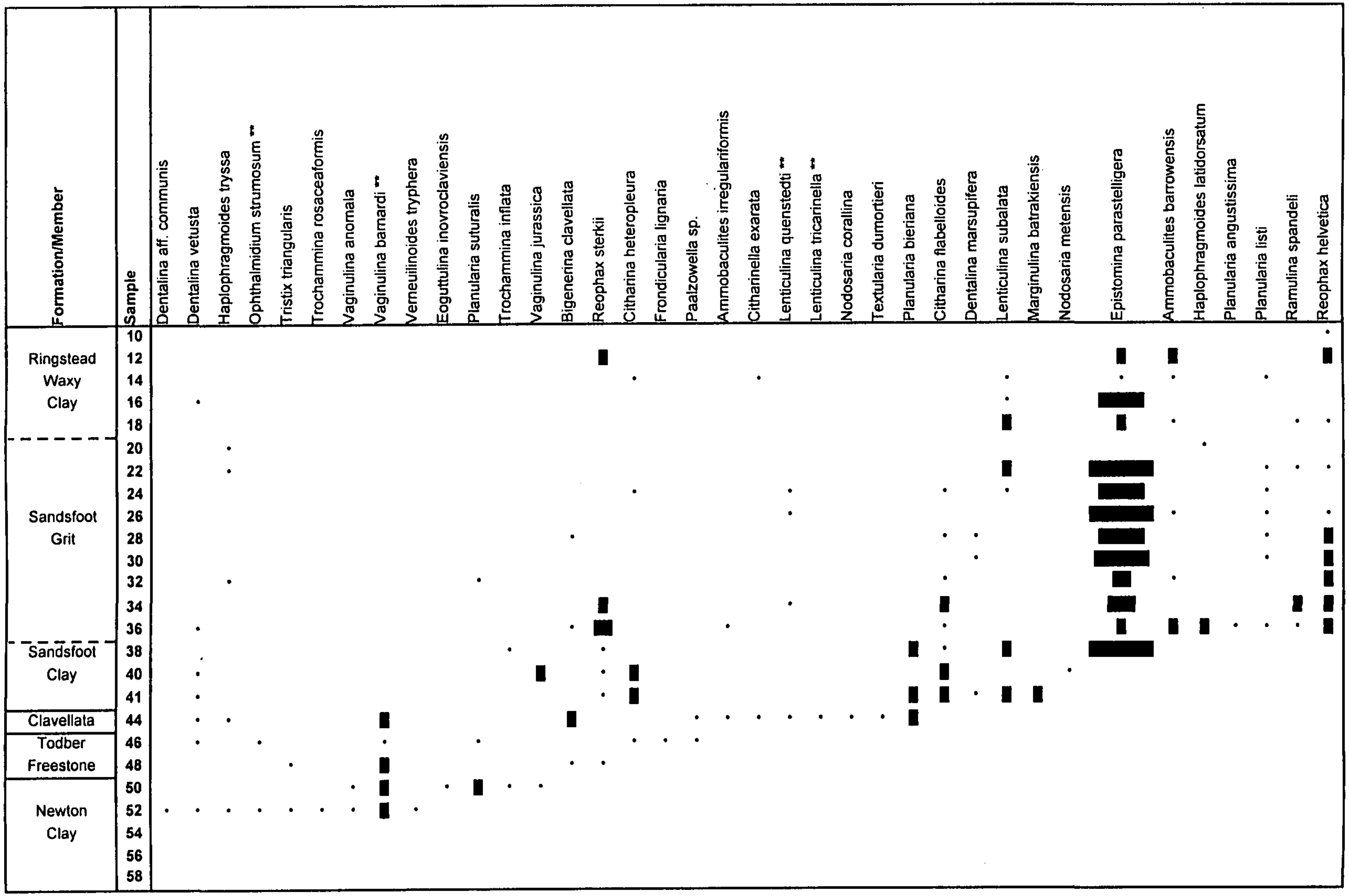


Figure 8.4 - 2. Distribution Chart for the Hallett's Farm Borehole. Important biostratigraphic species denoted by (**).

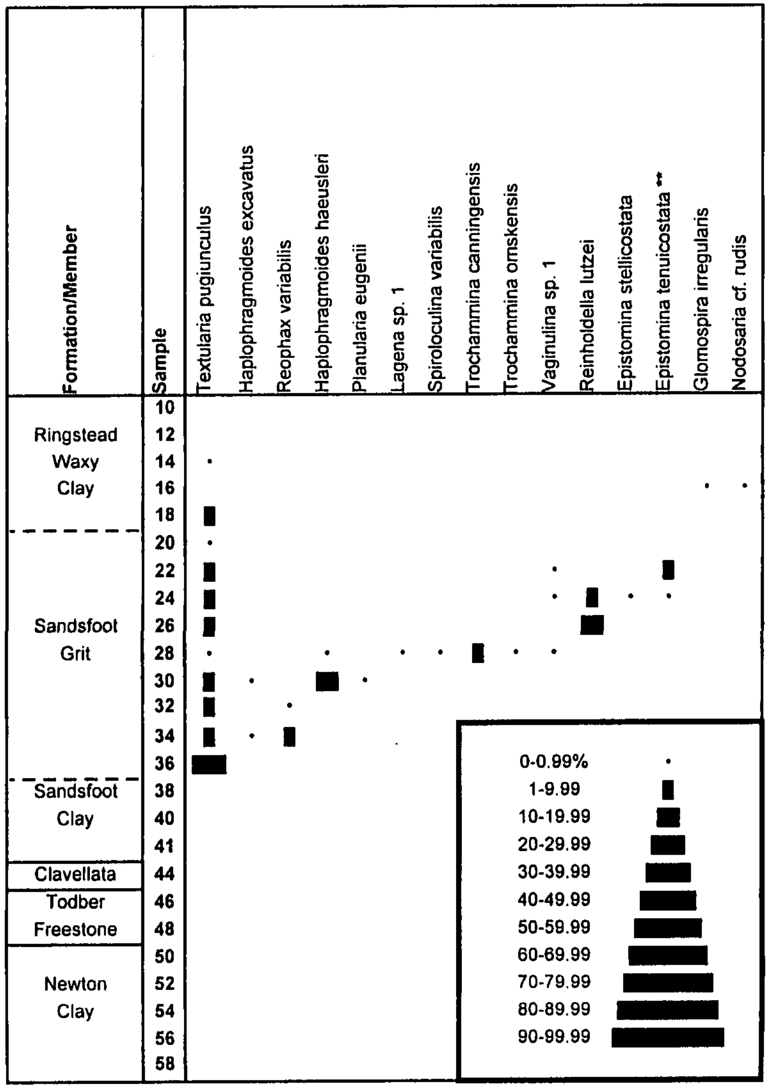


Figure 8.4 - 3. Distribution Chart for the Hallett's Farm Borehole. Important biostratigraphic species denoted by (**).

species are highlighted on the relevant distribution charts (Figs 8.1 to 8.4) and are discussed below.

8.2.1. Important Biostratigraphic Species.

Most of the data is taken from the Stratigraphic Atlas of Fossil Foraminifera (Shipp, 1989) and ranges quoted are for the late Jurassic only. Care has to be exercised when selecting these species as many have ranges which extend into the Middle or Lower Jurassic or up into the Cretaceous. It may still be possible to utilise the range of a particular species even though it occurs in older or younger sediments, if it forms a distinctive range within the Upper Jurassic.

The following species have been identified as having a distinctive range within the Upper Jurassic.

1. *Epistomina tenuicostata* Bartenstein and Brand, 1951.

- Previously recorded British stratigraphic range - Cordatum to Regulare Zones.
- Stratigraphic range in this study - FAD and LAD, sample 215 Hartmoor Hill Borehole to sample 22 Hallett's Farm Borehole (Upper Oxford Clay, Weymouth Member to Sandsfoot Grit Member), ?Costicardia Subzone to Regulare Zone. This species has not been recorded beyond this quoted range in Britain.

2. *Lenticulina quenstedti* (Gümbel, 1862).

- Previously recorded British stratigraphical range - Mariae to Tenuiserratum Zones.
- Stratigraphic range in this study - LAD, sample 24 Hallett's Farm Borehole (Sandsfoot Grit Member), Regulare/?Rozenkrantzi Zone.

3. *Lenticulina tricarinella* (Reuss, 1863).

- Previously recorded British stratigraphical range - Mariae to Preplicomphalus Zones. Although recorded originally from the Lower Cretaceous by Reuss it has a distinctive

Jurassic occurrence and has only been recorded as ranging from the Mariae to the Serratum Zone (Shipp, 1989).

- Stratigraphic range in this study - LAD sample 44, Hallett's Farm Borehole (Clavellata Beds Formation), Serratum Zone. This species is only recorded rarely in the sampled material.

4. *Ophthalmidium strumosum* (Gümbel, 1862).

- Previously recorded British stratigraphical range - Cordatum to Tenuiserratum Zones.
- Stratigraphic range in this study - LAD sample 46, Hallett's Farm Borehole (Clay Unit between Todber Freestone Member and Clavellata Beds Formation), Tenuiserratum/?Glosense Zone.

5. *Trocholina nodulosa* Seibold and Seibold, 1960.

- Previously recorded British stratigraphical range - Densiplicatum to Tenuiserratum Zone.
- Stratigraphic range in this study - FAD and LAD, sample 201, Hartmoor Hill Borehole to sample 44, Hallett's Farm Borehole (Hazelbury Bryan Formation to Clavellata Beds Formation), Cordatum to Glosense/?Serratum Zones. This range seems to represent the known occurrence of this species in Britain.

6. *Vaginulina barnardi* Gordon, 1965.

- Previously recorded British stratigraphical range - Cordatum to Regulare Zone. Only recorded from Britain.
- Stratigraphic range in this study - ?FAD and LAD, sample 30448, East Stour Borehole to sample 44, Hallett's Farm Borehole (Hazelbury Bryan Formation to Clavellata Beds Formation) Cordatum to Glosense/?Serratum.

7. *Paalzowella feifeli* (Paalzow, 1932).

- Previously recorded British stratigraphical range - Cordatum to Glosense Zones.

- Stratigraphic range in this study - sample 193, Hartmoor Hill Borehole to sample 30426, East Stour Borehole (Hazelbury Bryan Formation to Newton Clay Member), Cordatum to Maltonense/? Tenuiserratum Subzone. This species is distinctive, but very rare in the studied material. It is a wide ranging Jurassic species and is quite common in the Lower and Middle Jurassic. It has however, a distinctive Upper Jurassic range.

8. *Ophthalmidium compressum* Barnard, Cordey and Shipp, 1981.

- Previously recorded British stratigraphical range - only recorded from Britain, Mariae to Cordatum Zones.
- Stratigraphic range in this study - from the stratigraphically lowest sample (225, Hartmoor Hill Borehole) to its LAD, sample 112, Bowden Farm Borehole (Oxford Clay Formation, Weymouth Member to the Hazelbury Bryan Formation), Costicardia to Cordatum Subzones. There is a questionable occurrence of this species in the Hallett's Farm Borehole, but the specimens are badly preserved and are probably damaged specimens of *O. strumosum.*

9. *Gaudryina sherlocki* (Bettenstaedt, 1952).

- Previously recorded British stratigraphical range - Mariae to Cordatum.
- Stratigraphic range in this study - from the stratigraphically oldest sample (225, Hartmoor Hill Borehole) to sample 173 Hartmoor Hill Borehole (Oxford Clay Formation, Weymouth Member to the Hazelbury Bryan Formation), Costicardia to Cordatum Subzones. Only a few specimens are recorded of this species. Although this species was first described from the Cretaceous, it has a distinctive recorded range in the Upper Jurassic.

10. *Pseudonodosaria radiata* (Barnard, 1952).

- Previously recorded British stratigraphical range - only recorded from Britain, Mariae to Cordatum Zones.

- Stratigraphic range in this study - only recorded from sample 217 in the Hartmoor Hill Borehole, Hazelbury Bryan Formation, Cordatum Zone. Only a few specimens are recorded in this study which would suggest that it is not particularly useful for biostratigraphic purposes. It has, however, a distinctive morphology.

The LAD's and FAD's of these important biostratigraphic species are plotted on a correlation diagram of the four boreholes and basic stratigraphic zones are indicated in Fig. 8.5.

8.2.2. North Dorset Zonation Scheme.

A zonation scheme is tentatively suggested based on the concept of Interval Zones defined in the International Stratigraphic Guide (Salvador, 1994). This definition is as follow:

> "An *interval zone* is a body of *fossiliferous* strata between two specified biostratigraphic horizons (biohorizons). Such a zone is not itself necessarily the range zone of a taxon or concurrence of taxa; it is defined and identified only on the basis of its bounding biohorizons.....
>
> The base or the top of an interval zone might be marked by
> - the horizon of the lowermost documented occurrence of a specified taxon in any particular section.
> - the horizon of the uppermost documented occurrence of a specified taxon in any particular section.
> - any other distinctive biostratigraphic feature (biohorizon)."

The zonation scheme consists of seven major interval zones which are defined below.

1. *P. radiata* Interval Zone.

The base of this zone is not present in the sections studied. The top of this zone is defined at the LAD of *Pseudonodosaria radiata*. Unfortunately only one specimen was recorded of *P. radiata* so it is difficult to be confident about the top of this zone at present. As mentioned above, this species is very distinctive morphologically, so in some respects is an ideal candidate for a marker species.

1a. Small un-named interval zone.

This zone is bounded at its top by the *E. tenuicostata* FAD and the base is defined as the LAD of *P. radiata*. The interval zone itself is very small and would need a closer sampling

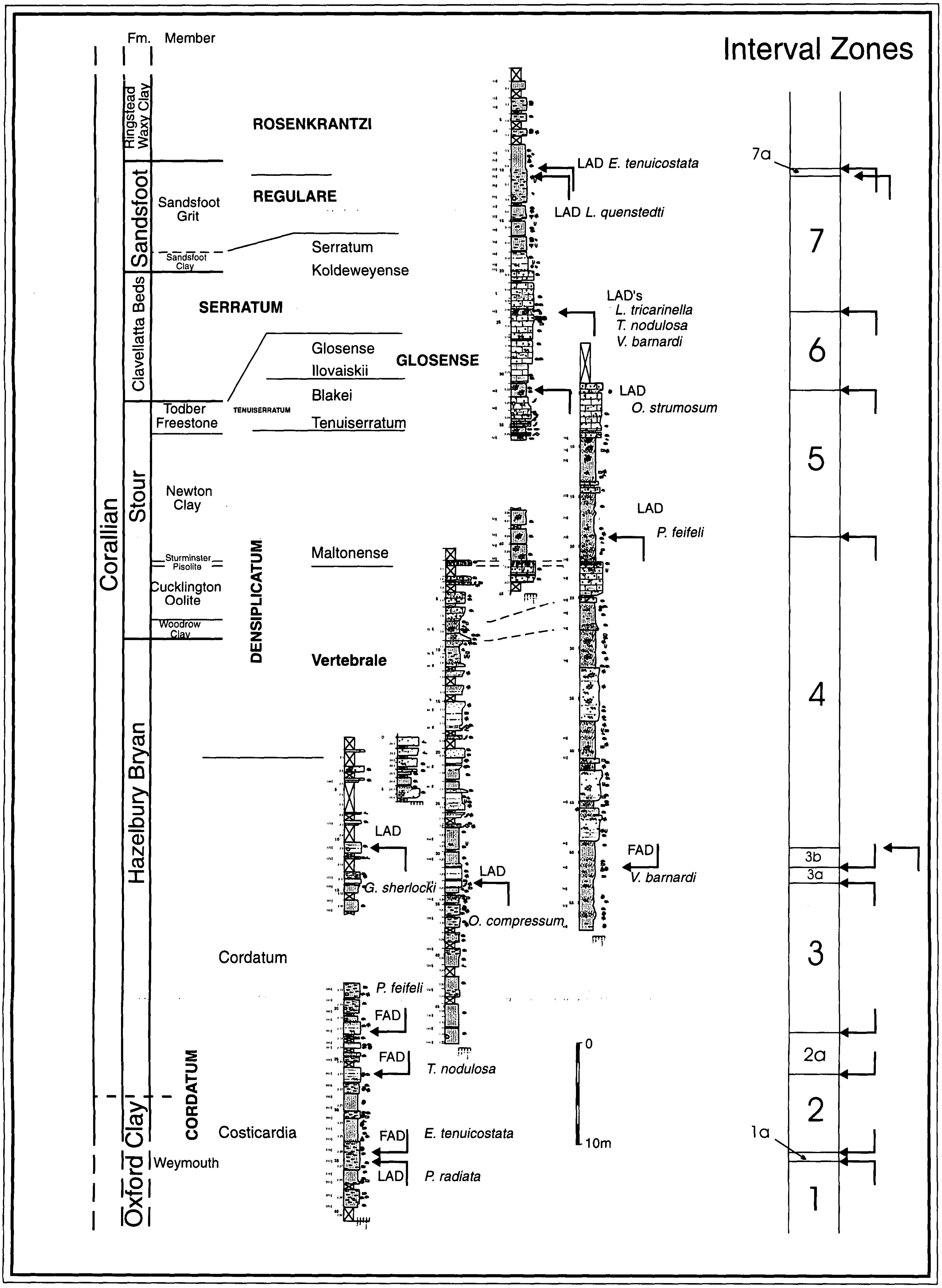


Figure 8.5. Correlation of the Hartmoor Hill, Bowden Farm, East Stour and Hallett's Farm Boreholes showing FAD's and LAD's of biostratigraphically important species, and a suggested foraminiferal zonation scheme. (Cardioceratid Ammonite Zonation scheme shown).

interval to confirm its validity. It may ultimately prove best amalgamate this interval with Zone 1 or Zone 2.

2. *E. tenuicostata* Interval Zone.

This zone is define at its base by the FAD of *E. tenuicostata* and at its top by the FAD of *T. nodulosa*. The susceptible nature of the epistominids to dissolution and their facies-dependency would suggest that a zone based on the FAD of this species would be difficult to apply over a wide area. It is often difficult to distinguish *E. tenuicostata* from other species of *Epistomina* when the preservation of the specimens are poor. The base of this zone is, therefore, not particularly well defined.

2a. Small un-named interval zone.

This zone occurs between the FAD *P. feifeli* and the FAD of *T. nodulosa* it its base. The close proximity of the two FAD's and the data being solely from one borehole mean the validity of this zone is questionable.

3. *O. compressum* Interval Zone.

The base of this zone is defined at the FAD of *Paalzowella feifeli*. Although this taxon occurs frequently in the lower Jurassic it has a distinctive Upper Jurassic range. In the studied sections, however, it appears only rarely. The top of this zone is defined at the LAD of *O. compressum*.

3a. Small un-named Interval Zone.

The base of this zone is defined as the LAD of *O. compressum*. The top of the zone is defined as the FAD of the distinctive Upper Jurassic species *Vaginulina barnardi*. Again, the short interval covered by this zone may be resolved by a closer spacing of samples and/or possible amalgamation with Zone 3 or Zone 4.

3b. Small un-named interval zone.

This zone is defined at its base by the FAD of *V. barnardi* and at its top by the LAD of *Gaudryina sherlocki. G. sherlocki* occurs in the Cretaceous but has a distinctive Upper Jurassic range. However, only a small number of specimens were recorded in this study. As mentioned in Zone 3a, *V. barnardi* is a distinctive species and is abundant in the samples studied. Without greater resolution it would probably be more realistic to ignore the biohorizon defined by *G. sherlocki* and define the base of Zone 4 as the FAD of *V. barnardi.*

4. *P. feifeli* Interval Zone.

The base of this zone is defined by the LAD of *G. sherlocki* and the top by the LAD of *P. feifeli.* Unfortunately both of these species are very rare in the samples studied and this might present problems for the recognition of this zone outside the immediate area.

5. *O. strumosum* Interval Zone.

The base of this zone is defined by the LAD of *P. feifeli* and the top is defined as the LAD of *Ophthalmidium strumosum.* As mentioned above although *P. feifeli* is a distinctive species it is rare in the samples studied. *O. strumosum* is well defined and is generally fairly abundant.

6. *V. barnardi* Interval Zone.

The base of this zone is distinct and marks the LAD of *O. strumosum.* The top is defined by three species, the LAD's of *V. barnardi, L. tricarinella* and *T. nodulosa.* All three species are distinctive and easily identifiable. Their ranges coincide at sample 44, the youngest sample from within the Clavellata Beds Formation, but may extend to the top of this Formation. Unfortunately only the clay rich beds of this Formation can provide a suitable assemblage to analyse. The recognition of benthic foraminifera with simple internal characteristics is difficult from thin section.

7. *L. quenstedti* Interval Zone.

This zone is distinctively defined at its base by the LAD's of *L. tricarinella, T. nodulosa* and *V. barnardi.* The top of the zone is defined at the LAD of *L. quenstedti.*

7a. Small un-named interval zone.

This zone has distinctive upper and lower boundaries but may prove to be amalgamated in Zone 7 if sample resolution is refined. The base is defined at the LAD of *L. quenstedti* and the top at the LAD of *E. tenuicostata*. The distinctly ornamented *L. quenstedti* is easily identifiable

It must be stressed that the zonation scheme suggested here is not intended to be a formal proposal, but merely represents the possibility of recognising potential fossil markers within the north Dorset succession. Although there is a certain amount of overlap in the boreholes there is not sufficient concentration of samples laterally across any particular stratigraphic horizon to have the resolution to firmly base any zonal biohorizons. The same is also true for the temporal spacing of the samples and a finer resolution would alleviate some of these problems. However the limitations of basing a zonal scheme on such a restricted geographical area must be addressed. It must also be realised that a zonation scheme based on benthonic foraminifera for the Upper Jurassic in north Dorset will be difficult to establish using such long-ranging and facies controlled taxa. Other methods need to be employed to overcome these difficulties and an integrated study, combining graphic correlation, Biohorizon correlation, foraminiferal biostratigraphy, ammonite stratigraphy and other micropalaeontological stratigraphy (palynology, calcareous nannofossils, etc.) will be required. Foraminifera, on their own, do not provide the resolution required.

8.3. Calcareous Nannofossil Data.

A complete set of samples from the boreholes was donated to University College, London, and certain samples examined by Patrick Quinn as part of an M.Sc. Micropalaeontology dissertation. The aims of that project were to provide a correlation of the three boreholes (Hartmoor Hill, Bowden Farm and Hallett's Farm) with the coastal succession, using calcareous nannofossils. The results are presented in Quinn (1995).

Quinn points out that the nannofossil biostratigraphy for the Upper Jurassic is particularly poorly constrained and that the zonation schemes are rather coarsely subdivided, achieving a

poorer stratigraphic resolution than the standard ammonite zonation onto which they are correlated. These problems seem to indicate some facies constraints on the flora together with the absence of any biostratigraphically useful taxa in the boreal realm.
Quinn recognises 3 datums.

The LAD of *Stephanolithion bigoti maximum*, the LAD of *Lotharingius crucicentralis* and the FAD of *Vekshinella stradneri*.

According to Quinn (1995) the upper Oxford Clay Formation is present in the Hartmoor Hill Borehole at 37m and in the Bowden Farm Borehole at 46m (due to the presence of the FAD of *Vekshinella stradneri*). The LAD of *Stephanolithion bigoti maximum* at 21m and 36m in the Hartmoor Hill and Bowden Farm Boreholes respectively indicates the presence of the Hazelbury Bryan formation. The Corallian Group is present up to the Ringstead Waxy Clay indicated by the presence of the LAD of *Lotharingius crucicentralis* at 13m in the Hallett's Farm Borehole. The subspecies *Stephanolithion bigoti maximum* is distinguished from *Stephanolithion bigoti bigoti* by its larger rim length. Quinn notes that the abundance of the specimens is poor and the assemblage is of a low diversity and abundance. These factors make the recognition of a taxon based on size difference particularly difficult, and hence the correlation based on the occurrence of this species must be tentative at best.

Although these results of Quinn (1995) are not particularly revealing they do not disprove any of the findings of this study.

Chapter 9. Conclusions.

The conclusions drawn from this research are listed below, and are arranged in the order of the presentation of the thesis.

Stratigraphic/Sedimentological.

1.The author planned, prepared and executed a drilling project to obtain fresh material to be examined from the Upper Jurassic sequence of north Dorset. Three boreholes were drilled in north Dorset, each penetrating to a depth of around 40m. The complete sequence of lithologies from the Weymouth Member of the Oxford Clay Formation through to the Ringstead Waxy Clay Formation was sampled. A continuous section was provided for the Corallian Group in north Dorset an area where it is no longer exposed at outcrop.

2. Sedimentological and stratigraphic data were obtained which provide information on the stratigraphy of a little known area of the Wessex Basin.

3. The contact between the Hazelbury Bryan Formation and the underlying Oxford Clay Formation (Weymouth Member) was penetrated. This contact has not been previously observed in north Dorset at outcrop or by borehole. In the Hartmoor Hill Borehole this contact is gradational and the boundary with the underlying Weymouth Member is placed at the first occurrence of silt. The Hinton St. Mary Clay was not encountered. The entire Clavellata Beds Formation was penetrated and is subdivided informally into 5 units. This subdivision of the Clavellata Beds Formation is similar to the formal division of the Trigonia Clavellata Beds on the coast.

4. The three boreholes were successfully correlated with each other and with the BGS East Stour Borehole using lithostratigraphic criteria alone. The Sturminster Pisolite Member from the Stour Formation and the distinctive sand units within the Hazelbury Bryan Formation proved to be ideal stratigraphically correlatable surfaces.

Taxonomic.

5. A fauna comprising a total of 26 families, consisting of 43 genera and 148 species was recorded and identified. The taxonomy of each species was studied and described or confirmed. A number of species were left in open nomenclature as potentially new species.

The number of species identified during this research is a larger number than previously recorded for the Corallian Group in Dorset. The conclusions are that the examination of fresh material, not subjected to the destructive weathering processes which can hamper micropalaeontological analysis from coastal or inland outcrop, may account for the more diverse fauna encountered. Although a larger number of species were identified the faunal composition is very similar to that recorded elsewhere (e.g. Gordon, 1962, 1965, Shipp, 1989 and Barnard *et al.*, 1981). The majority of species account for less than 2% of the fauna and the same few species are recorded in abundance. These are, in particular, *Ammobaculites coprolithiformis, Lenticulina münsteri, Epistomina parastelligera, Epistomina tenuicostata* and *Spirillina tenuissima;* other species important but less abundant are *Epistomina stellicostata, Trochammina squamata, Ammobaculites agglutinans, Ammobaculites godmani* and *Ammobaculites canui.* In general a larger proportion of the fauna was composed of epistominids and this, again, may be the result of using fresh material. The epistominids are particularly susceptible to dissolution, however, the more marginal aspect of the north Dorset palaeo-environment may be responsible for the increase in epistominid fauna. Epistominid faunas are obviously important palaeo-ecological indicators but are not affected by water depth alone. Also, each individual species seemed to record a different distribution, so the recording of data at family level may not be detailed enough to achieve an idea of the importance palaeo-ecologically. The susceptibility to dissolution that this group also endures further hampers investigation.

The abrupt switch from a dominant epistominid species to another over a series of samples indicates a complex relationship between species. The group as a whole may indicate a preferred niche for particulate material although within this niche there is a specialisation between different species. In other samples, however, the same species co-exist in almost equal abundance.

It is possible that the identification of each individual species may be part of the problem, particularly when preservation is poor. Certain species (e.g. *E. stellicostata, E. tenuicostata* and *E. parastelligera*) are similar in appearance when they have been partly dissolved and/or replaced internally with pyrite. It is important to base conclusions on the distribution of species of *Epistomina* on well preserved specimens. Many of the Jurassic species of *Epistomina* may be in fact, morphological variations of a smaller number of more variable taxa.

6. It is important to examine the smaller fractions as important species have been found in the <150μ fraction. In particular many of the agglutinated species would not have been encountered. In much of the published literature the agglutinated analysis is reserved for the larger species. Most of the previous research has concentrated on the more well known calcareous species. This is probably due to the often bad preservation in which agglutinated foraminifera are found that precludes any detailed taxonomic work on these individuals. Many agglutinated foraminifera are often badly compressed and this makes identification (even to the generic level) difficult. The trochamminids are particularly susceptible to compression which is probably due to the delicate nature of their test. This problem has been reported from the Recent and the common marsh taxon *Jadammina macrescens*, is frequently compressed.

7. Holothurian Sclerites were examined in detail from the East Stour borehole and their use in palaeo-ecology and biostratigraphy assessed. It is concluded that for the interval studied (Oxfordian) Holothurian Sclerites have no particular biostratigraphic use. Palaeo-ecologically sclerites provide a general environment of deposition. A specimen of the genus *Synaptites* was recorded for the first time from the Upper Jurassic of Britain.

Palaeo-ecology.

8. In total sixteen biofacies were determined using a combination of statistical methods. Simple diversity indices, non-metric Multi-Dimensional Scaling (MDS) and Hierarchical Agglomerative Clustering were applied to the assemblages from each of the boreholes. Both the MDS method and the Cluster Analysis produced discrete sample groups, although the Cluster Analysis proved slightly more arbitrary in the designation of groups when compared with the MDS plots. Both methods were cross referenced against each other. Each sample grouping roughly equates to a distinct biofacies. The α Index and the Shannon -Weiner information Function H(S) proved to be the most useful diversity indices in distinguishing biofacies

9. Based on the above methods (points **8**, **9** and **10**) a number of biofacies were identified for each borehole;

Hallett's Farm Borehole	5 biofacies.
East Stour Borehole	3 biofacies
Bowden farm Borehole	4 biofacies
Hartmoor hill Borehole	4 biofacies

10. The north Dorset Upper Jurassic sequence of rocks represents a transitional environment from offshore shelf clays and muds through to an environment nearer shore, possible close to the lower shore face or tidal flat environment. Foraminiferal abundances for certain species indicate the presence of restricted environments, possibly marsh-like or close to marsh environments. The environment envisaged is estuarine with a projectingspit or sand bar with possible lagoonal or marsh influences. The identification of biofacies for each borehole is summarised in Tables 9.1 to 9.4. In each borehole the biofacies are indicated alongside the stratigraphy and lithology and the characteristics of each assemblage are highlighted. The palaeo-environment as implied by the foraminiferal assemblage for each biofacies is indicated. Due to the sample resolution, palaeo-environments can not be adequately inferred for all stratigraphic units. Each biofacies is discribed in order from the oldest to the youngest sample. The salient features are highlighted on the following summary diagram (Fig. 9.1).

Hallett's Farm Borehole.

Bio-facies	Sample Group	Stratigraphy	Lithology	Assemblage Characteristics	Implied Palaeo-environment
A	16-10	Ringstead	Silty clay	Ave. α: 2.83 Ave. H(S): 1.63 *A. agglutinans*, *L. difflugiformis* and *T. globigeriniformis* dominant. Peak in Miliolids.	Restricted marginal marine environment possibly brackish conditions.
B	20-18	Transition	clay	Ave. α: 2.26 Ave. H(S): 1.29 Dominated by an agglutinated assemblage. *T. squamata* 100% in sample 20. Sample 18 - mixed haplophragmoidid and trochamminid assemblage.	Harsh conditions, stagnant restricted environment - /lagoonal or salt-marsh.
C	36-22	Sandsfoot Grit	Silty clay	Ave. α: 4.86 Ave. H(S): 1.87 Textulariids mixed, lituolids only a minor %. *Lagenammina*, *Textularia* and *Haplophragmoides* important components. Lagenina minor component. Robertininids peak at sample 26.	Restricted marine, initially shallow possibly lagoonal/marsh influences becoming deeper towards sample 22.
D	44-38	Clavellata Beds/ Sandsfoot Clay	Calcareous clay/ silty clay	Ave. α: 5.37 Ave. H(S): 1.69 *A. coprolithiformis* absent	Varied enviroments, generally shallow.
E	58-46	Newton Clay/ Todber Freestone	Clay/ silty clay/ calcareous clay	Ave. α: 4.69 Ave. H(S): 1.80 Lituolids important component Spirillininids dominant	Shallow water, high energy environment - shoreface to tidal flat environment or reduced salinity estuarine setting -low energy shoreface or spit in headland of estuary with tidal shoal setting in mouth of estuary.

Table 9.1. Hallett's Farm Borehole biofacies interpretation.

East Stour Borehole.

Bio-facies	Sample Group	Stratigraphy	Lithology	Assemblage Characteristics	Implied Palaeo-environment
F	28-16	Newton Clay	Silty clay/ clay/ some sandy clay	Ave. α: 2.67 Ave. H(S): 1.45 Very abundant spirillinids and *T. nodulosa*.	Shallow water, higher energy environment- lower shoreface or reduced salinity possibly estuarine environment.
G	42-30	Hazelbury Bryan/ Woodrow clay/ Cucklington Oolite	Clay/ silty clay/ calcareous clay	Ave. α: 4.15 Ave. H(S): 1.53 Miliolina peak in sample 42. *Spirillina* peak at sample 30. Low similarity. Low lituoilid frequency.	Abrupt shallowing (42) followed by a deeper water environment , shallow by 30.
H	54-44	Hazelbury Bryan	Silty clay/clay	Ave. α: 5.57 Ave. H(S): 1.78 Lituolids and vaginulinids dominant. *T.globigeriniformis* and *A. canui* peak in abundance at sample 46 and 44. Minor robertininids.	Oscillating environment from "normal" marine possibly ?offshore shelf to a more shallow environment (46-44).

Table 9.2. East Stour Borehole biofacies interpretation.

Bowden Farm Borehole.

Bio-facies	Sample Group	Stratigraphy	Lithology	Assemblage Characteristics	Implied Palaeo-environment
I	72	Woodrow Clay	Silty clay	Ave. α: 0.95 Ave. H(S): 1.25 Robertininids dominant. Low number of species.	Restricted environment. ?reduced salinity- close proximity to shoreline with estuarine influence or possibly tidal flat/bay fill setting
J	92-76	Hazelbury Bryan	Sand/silt	Ave. α: 3.32 Ave. H(S): 1.42 *Lagenammina* peaks No epistominids Major ophthalmidiid peak	Shallow environment - lower shoreface
K	116-96	Hazelbury Bryan	Sand/silt some clay	Ave. α: 6.37 Ave. H(S): 1.90 Small agglutinated families abundant. Lagenid peak.	Normal marine ?relatively deep, stable environment - ?transition between offshore shelf and lower shoreface.
L	144-120	Hazelbury Bryan	Clay some silty clay	Ave. α: 3.36 Ave. H(S): 1.55 Approximately an evenly distributed fauna. *Ammobaculites* and *Epistomina* dominant.	Normal marine ?relatively deep, stable environment - ?transition between offshore shelf and lower shoreface.

Table 9.3. Bowden Farm Borehole biofacies interpretation.

Hartmoor Hill Borehole.

Bio-facies	Sample Group	Stratigraphy	Lithology	Assemblage Characteristics	Implied Palaeo-environment
M	189-169	Hazelbury Bryan	Clays/silty clays some sand and silt (poor recovery)	Ave. α: 4.67 Ave. H(S): 1.66 Miliolina increase. Spirillinids increase. Slow decline in the Robertininids. Lituolids dominant. Trochamminids, haplophragmoidids and *A. canui* significant.	Deepening (and/or quiet, lower energy environment) then distinct shallowing of environment of deposition - lower shoreface.
N	201-191	Hazelbury Bryan	Sands/silts /silty clay	Ave. α: 6.50 Ave. H(S): 1.6 Decline in Lituolids. Lagenids peak. Insignificant robertininids.	Near shore facies, relatively shallow. Transition zone between offshore shelf and lower shoreface or shoreface.
O	207-203	Transition	Clays/silty clays	Ave. α: 3.52 Ave. H(S): 1.23 Very high λ value. Dominant species 83% of assemblage. Abundant *E. parastelligera.*	Restricted environment, condensed sequence?
P	225-209	Oxford Clay Formation	Clays/silty clays	Ave. α: 8.34 Ave. H(S): 2.49 High *J* Dominant and subdominant species show similar low % of assemblage. Abundant attached forms sample 209. Abundant epistominids.	Normal marine , equitable, stable environment, relatively deep (offshore shelf) quiet, becoming shallower by sample 209

Table 9.4. Hartmoor Hill Borehole biofacies interpretation.

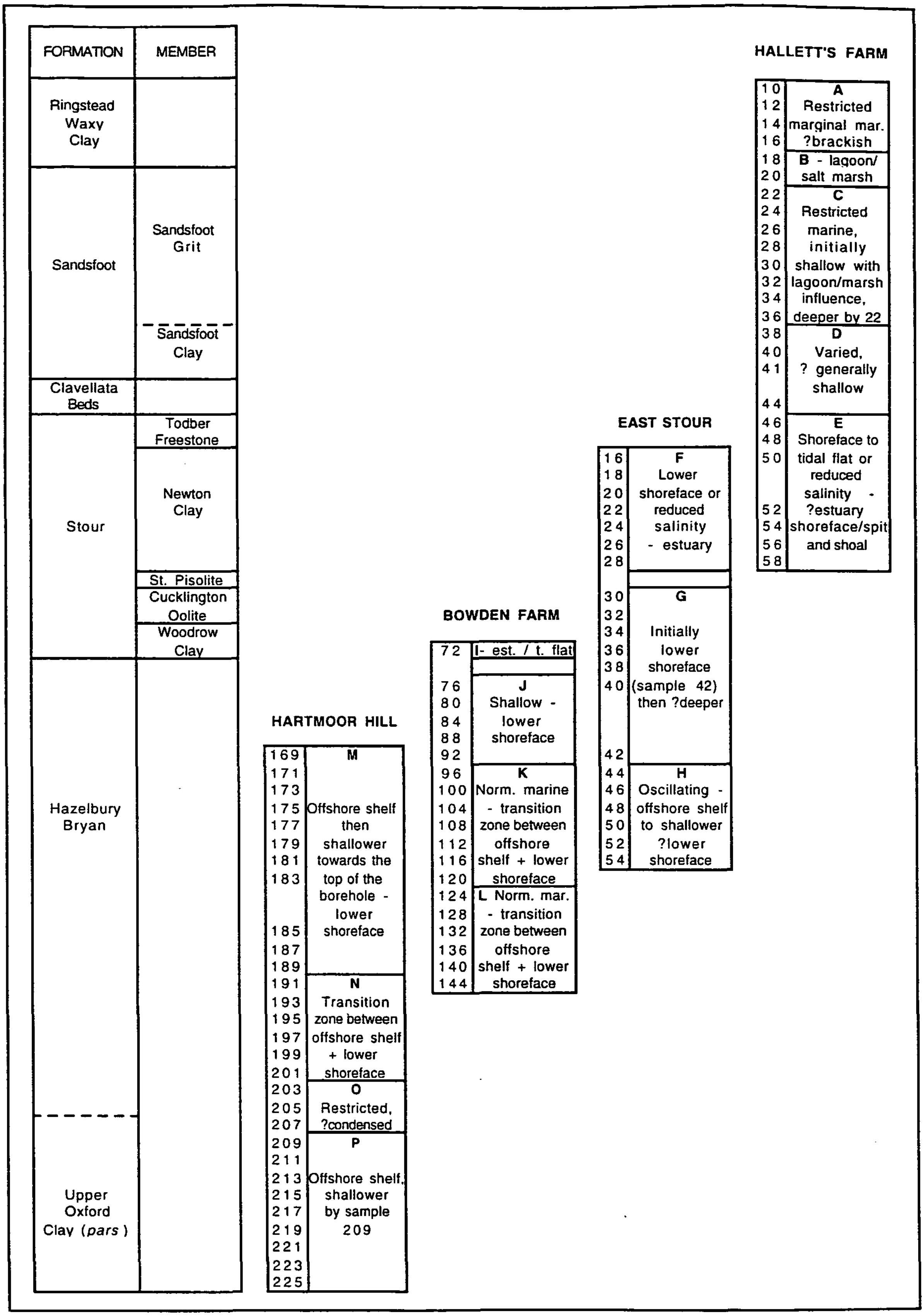


Figure 9.1. Correlation of Hallett's Farm, East Stour, Bowden Farm and Hartmoor Hill Boreholes showing biofacies and implied palaeo-environments. (Not to scale).

11. The Graphic Correlation-type method employed in Chapter 7, provided some interesting results. This method has potential if integrated into a Graphic Correlation Programme.

This method is particularly useful if the taxa are long-ranging and if there are not enough biostratigraphic markers within the stratigraphic section studied. Weight can be placed on different Biohorizons with degrees of importance established for each. This will make correlation easier and will assist in making judgements about those Biohorizons which are not "natural" bioevents but an artefact of sampling.

Within the sections studied correlation was achieved between the boreholes using Biohorizons alone and some particularly difficult (transitional) boundaries were identified.

- The boundary between the Oxford Clay Formation and the Hazelbury Bryan Formation at around sample 205 in the Hartmoor Hill Borehole,
- the transition between the possible Sandsfoot Clay and the Sandsfoot Grit was established at around Sample 38 in the Hallett's Farm borehole and,
- the boundary between the Sandsfoot Formation and the Ringstead Waxy Clay Formation was established at around sample 20 in the Hallett's Farm Borehole.

The generic dominance/subdominance curve proved particularly useful in establishing changes in environment and recognising transgressive boundaries. The results of this method were particularly encouraging and proved to a certain extent that palaeo-ecological biohorizons can be used in correlation in the sections studied. The method does have limitations and it is important to realise that a fully integrated Graphic Correlation would be needed to provide valid results over a wider area.

Biostratigraphical

12. Although the majority of the species encountered within the north Dorset Upper Jurassic are long-ranging, ten important biostratigraphic marker species have been recognised. A tentative zonation scheme has been suggested based on the concept of Interval Zones and seven Zones and four small un-named Zones are defined;

1. *P. radiata* Interval Zone. The base of this zone is not present in the sections studied. The top of this zone is defined at the LAD of *Pseudonodosaria radiata.*

1a. Small un-named interval zone. This zone is bounded at its top by the *E. tenuicostata* FAD and the base is defined as the LAD of *P. radiata.*

2. *E. tenuicostata* Interval Zone. This zone is define at its base by the FAD of *E. tenuicostata* and at its top by the FAD of *T. nodulosa.*

2a. Small un-named interval zone. This zone occurs between the FAD *P. feifeli* and the FAD of *T. nodulosa* it its base.

3. *O. compressum* Interval Zone. The base of this zone is defined at the FAD of *Paalzowella feifeli.* The top of this zone is defined at the LAD of *O. compressum.*

3a. Small un-named Interval Zone. The base of this zone is defined as the LAD of *O. compressum.* The top of the zone is defined as the FAD *Vaginulina barnardi.*

3b. Small un-named interval zone. This zone is defined at its base by the FAD of *V. barnardi* and at its top by the LAD of *Gaudryina sherlocki.*

4. *P. feifeli* Interval Zone. The base of this zone is defined by the LAD of *G. sherlocki* and the top by the LAD of *P. feifeli.*

5. *O. strumosum* Interval Zone. The base of this zone is defined by the LAD of *P. feifeli* and the top is defined as the LAD of *Ophthalmidium strumosum..*

6. *V. barnardi* Interval Zone. The base of this zone is distinct and marks the LAD of *O. strumosum.* The top is defined by three species, the LAD's of *V. barnardi, L. tricarinella* and *T. nodulosa.*

7. *L. quenstedti* Interval Zone. This zone is distinctively defined at its base by the LAD's of *L. tricarinella, T. nodulosa* and *V. barnardi.* The top of the zone is defined at the LAD of *L. quenstedti.*

7a. Small un-named interval zone. The base is defined at the LAD of *L. quenstedti* and the top at the LAD of *E. tenuicostata.*

9.1. Scope for Further Work.

1. Importantly, sample data should be examined from south Dorset to compare with the present data in order to form a useful correlation.
2. Sample data from Normandy should also be examined and compared with the present work and definitely with the coastal sequences of Doset.
3. Data from the studied sections in Dorset should be amalgamated with (1) and (2) and using Graphic Correlation, a Composite Standard Reference Section (CSRS) built up for the Upper Jurassic of the Wessex Basin.
4. Other published data on the Wessex Basin should also be combined to provide a mature CSRS for future correlation.
5. Palaeo-ecological Biohorizons should be combined with the traditional LAD's and FAD's and integrated into the Graphic Correlation method. It is possible that further work may establish that this data may well be an important edition to the sequence stratigraphic study of a section. By integrating palaeo-ecological data into a Graphical Correlation method then a particularly powerful tool may be established to aid previous sequence stratigraphic methods. It is already established that changes in abundance of taxa, increase in diversity of a fauna can be integrated into a Sequence Stratigraphic Framework (e.g. Armentrout, 1987, 1991, 1994, Armentrout and Clement, 1990, Armentrout *et al.* 1990; Shaffer 1987, 1990; Pacht *et al.* 1990a, 1990b and Vail and Wornardt 1990). Cubaynes *et al.* (1990) have also indicated that other palaeo-ecological data (e.g. percentage of uncoiling morphogenera, particular foraminiferal ratios and presence/ absence of particular species) can prove useful to the recognition of different system tracts.
6. The study in north Dorset could be extended stratigraphically and boreholes drilled into the Middle and Lower Oxford Clay and even further into the Callovian. Sampling also should be extended into the Kimmeridge Clay.
7. Further boreholes, preferably with a larger core-barrel diameter, with a similar stratigraphic sequence to those of the present study could be drilled to investigate the lateral extent of lithologies and the lateral variation in foraminiferal abundance.
8. Many published works by Russian micropalaeontologists (Dain, 1972 and authors therein, Azbel and Grigelis, 1991) show that agglutinated foraminifera have not been

neglected, as many plates illustrating agglutinated taxa will testify (e.g. Dain, 1972). There is, however, a problem of taxonomy. Many names assigned to the species studied by Russian palaeontologists may be applicable in Europe and in some cases North America (e.g. Tappan, 1955). There is, however, no definitive taxonomy which can be used. Without examination of the type specimens it is often difficult to base identification on illustrations alone (in the Russia literature specimens are frequently illustrated by drawings and the SEM micrographs are often of poor quality). A synthesis of all Russian literature, with synonymies for European species, would be an enormous task, but if tackled in a similar way to that adopted by the Grzybowski Foundation for the works of Grzybowski, would be an invaluable aid to both oil industry and academic microplaeontologists.

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Plates.

The following section illustrates the species discussed in the taxonomic chapter. Each specimen is listed with a figure number, species name with author(s), comments (if applicable), scale, dimensions and sample number. All specimens are listed in taxonomical order whenever possible. The following abbreviations are used throughout:

d = maximum measured diameter.
h = maximum measured height.
w = maximum measured width.
l = maximum measured length.

All measurements are in microns and are represented by the symbol μ.

Sample numbers will use the following abbreviations:

HH. Hartmoor Hill Borehole.
BF. Bowden Farm Borehole.
ES. East Stour Borehole.
HF. Hallett's Farm Borehole.

Plate 1.

Figs 1-3. *Lagenammina difflugiformis* (Brady). **1.** Coarse-grained form, x200, h = 552μ, w = 295μ, Sample no **2.** Coarse-grained form, x150, h = 587μ, w = 320μ, sample HF/36. **3.** Fine-grained form, x200, h = 419μ, w = 238μ, sample HF/30.

Fig. 4. *Reophax helvetica* (Häusler), x200, h = 581μ, w = 333μ, sample HH/213.

Fig. 5. *Ammovertella liassica* Barnard, attatched to shell fragment, x150,w = 267μ, sample HH/213.

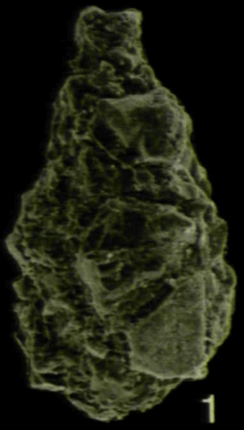
Fig. 6. *Tolypammina virgula* Kosyreva, x350, h = 333μ, w = 233μ, HH/225.

Fig. 7. *Reophax variabilis* Herrmann, x150, h = 827μ, w = 333μ, sample HF/34.

Fig. 8. *Reophax multilocularis* Häusler, broken specimen, x200, h = 448μ, w = 181μ, sample HH/225.

Figs 9-11. *Reophax sterkii* Häusler. **9.** Coarse-grained form, x100, h = 1120μ, w = 460μ, sample HF/36. **10.** Coarse-grained form, x100, h = 920μ, w = 320μ, sample HF/36. **11.** Fine-grained form, x150, h = 667μ, w = 267μ, sample HF/34.

Plate 1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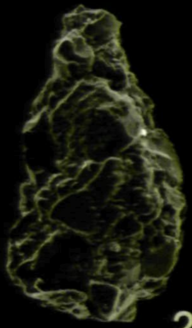
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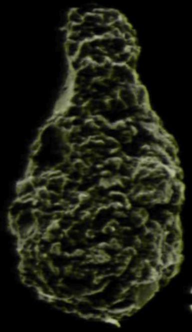
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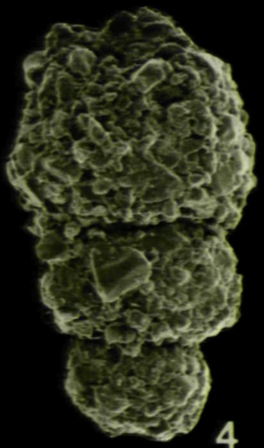
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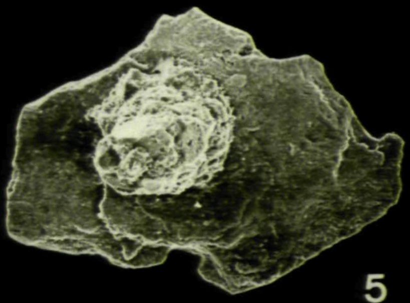
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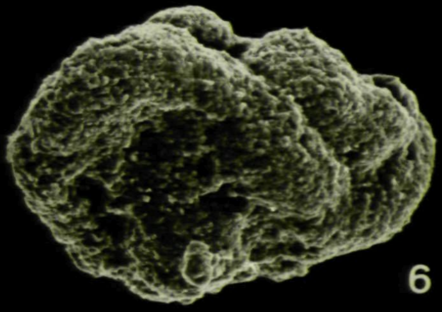
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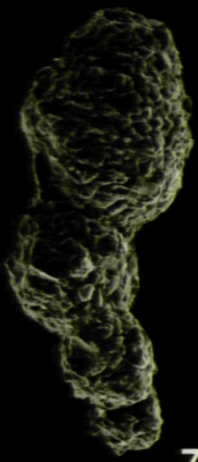
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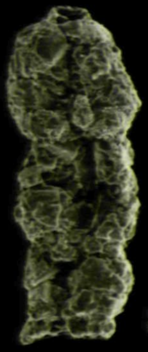
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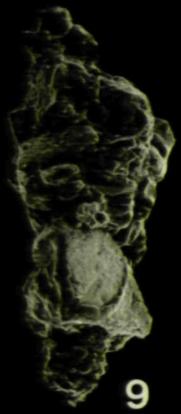
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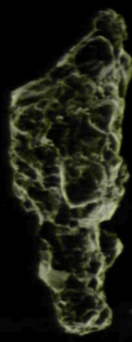
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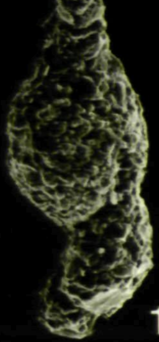
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Plate 2.

Fig. 1. *Haplophragmoides* sp. cf. *H. excavatus* Cushman and Waters, x350, h = 250, w = 222, sample ES/30442.

Fig. 2. *Haplophragmoides häusleri* Lloyd, x500, h = 200µ, w = 154µ, sample HF/30.

Figs 3-4. *Haplophragmoides kingakensis* Tappan. **3.** Side view, x150, h = 480µ, w = 440µ, sample HF/32. **4.** Apertural view, x150, h = 600µ, w = 267µ, sample HF/34.

Fig. 5. *Haplophragmoides latidorsatum* (Bornemann) *sensu* Lloyd, x350, h = 233µ, w = 206µ, sample HF/20.

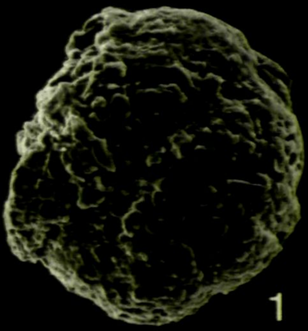
Fig. 6. *Haplophragmoides tryssa* Loeblich and Tappan, x200, h = 276µ, w = 248µ, sample ES/30446.

Figs 7-9. *Haplophragmoides* sp. 1. **7.** x350, h = 233µ, w = 200µ, sample HH/221. **8.** x350, h = 200µ, w = 167µ, sample HF/36. **9.** x350, h = 222µ, w = 206µ, sample HH/221.

Figs 10-11. *Haplophragmoides* sp. 2. **10.** x750, h = 108µ, w = 93µ, sample HH/175. **11.** x750, h = 113µ, w =85µ, sample HH/175.

Fig. 12. *Haplophragmoides* sp. 3, x500, h = 219µ, w = 173µ, sample ES/30424.

Plate 2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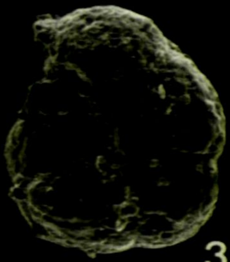
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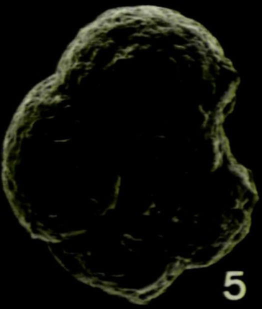
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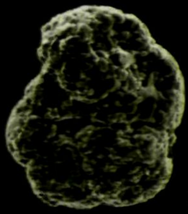
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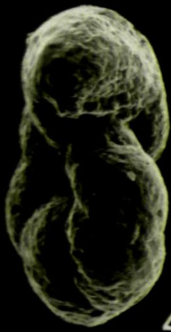
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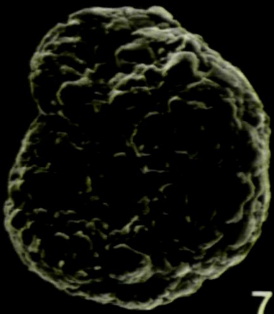
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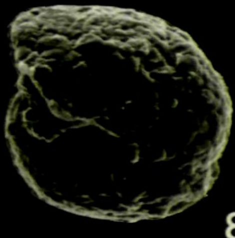
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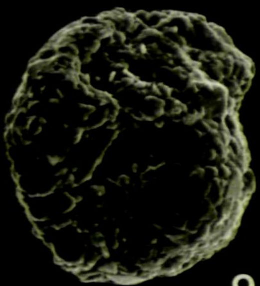
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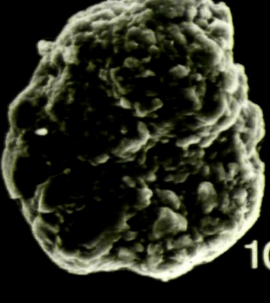
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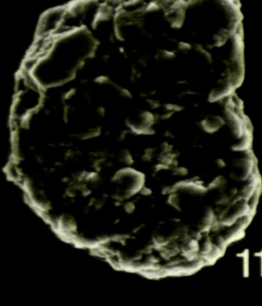
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Plate 3.

Figs 1-2. *Ammobaculites agglutinans* (d'Orbigny). **1.** Front view, x200, h = 629μ, w = 229μ, sample HF/32. **2.** Side view, x200, h = 514μ, w = 286μ, sample HF/32.

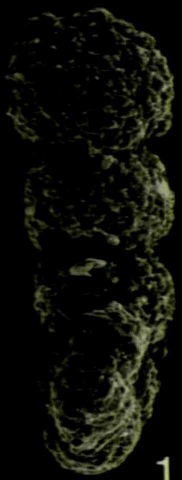
Figs 3-4. *Ammobaculites agglutinans* (d'Orbigny) form B. **3.** Side view, x200, h = 381μ, w = 181μ, sample HH/211. **4.** Front view, x200, h = 381μ, w = 114μ, sample HH/211.

Figs 5-7. *Ammobaculites barrowensis* Tappan. **5.** X200, h = 362μ, w = 286μ, sample HF/36. **6.** x200, h = 333μ, w = 305μ, sample HF/36. **7.** x200,h = 390μ, w = 295μ, sample HF/36.

Figs 8-11. *Ammobaculites canui* (Cushman). **8.** Close coiled form, side view, x 100, h = 720μ, w = 620μ, sample HH/173. **9.** Close-coiled form, apertural view, x100, h = 680μ, w = 360μ, sample HH/173. **10.** Uncoiled form, side view, x100, h = 800μ, w = 700μ, sample HF/46. **11.** Uncoiled form side view, x 200, h = 552μ, w = 362μ, sample ES/30444.

Figs 12-14. *Ammobaculites coprolithiformis* (Schwager). **12.** Fine-grained form, side view, x35, h = 3000μ, w = 1556μ, sample HH/185. **13.** Fine-grained form, front view, x50, h = 2308μ, w = 1038μ, sample HH/185. **14.** Fine-grained form, side view, x75, h = 1525μ, w = 800μ, sample HH/185.

Plate 3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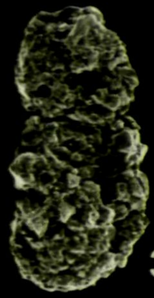
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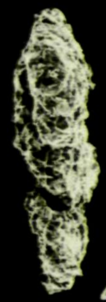
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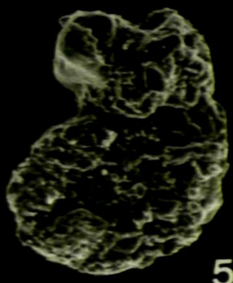
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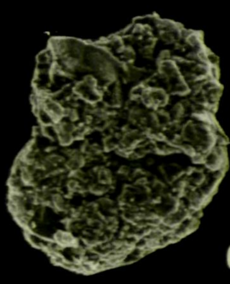
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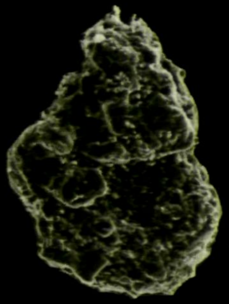
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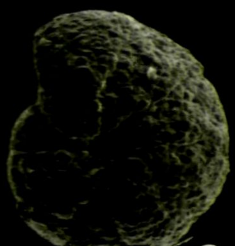
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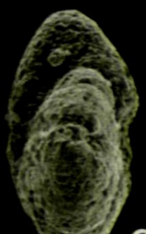
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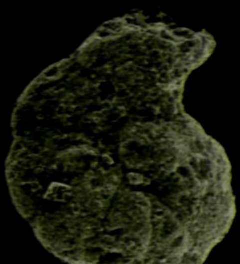
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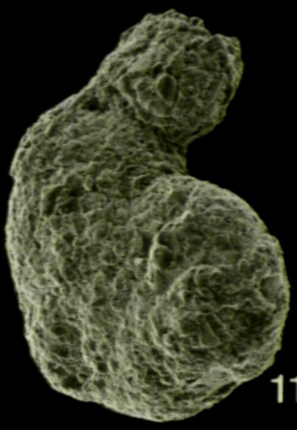
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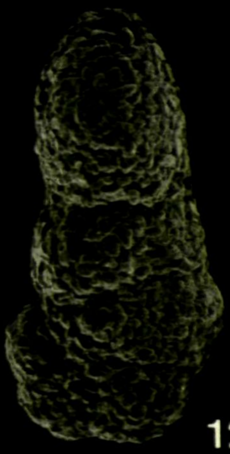
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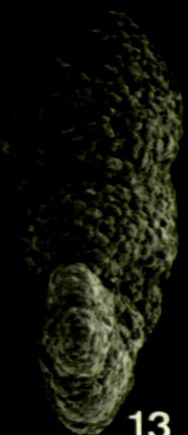
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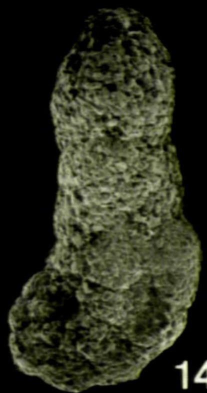
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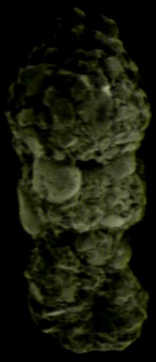
Plate 4.

Figs 1-11. *Ammobaculites coprolithiformis* (Schwager). **1-2.** Coarse-grained form. **1.** x35, h = 2722µ, w = 1111µ, sample ES/30442. **2.** Detail of aperture, x100, scale-bar = 100µ. **3-4.** Juvenile form. **3.** Side view, x 100, h = 980µ, w = 740µ, sample HH/189. **4.** Apertural view, x100, h = 1000µ, w = 680µ, sample HH/189. **5.** Coarse grained form, note very large grain in final chamber, x35, h = 2944µ, w = 1222µ, sample ES/30442. **6.** Coarse grained form with large ooids, x35, h = 2611µ, w = 1111µ, sample HF/52. **7-11.** Coarse –grained forms. **7.** X35, h = 2611µ, w = 778µ, sample ES/30442. **8.** x35, h = 3000µ, w = 889µ, sample HF/52. **9.** x35, h = 2611µ, w = 778µ, sample ES/30442. **10.** x50, h = 2500µ, w = 692µ, sample ES/30442. **11.** x50, h = 2462µ, w = 692µ, sample ES/30442.

Plate 4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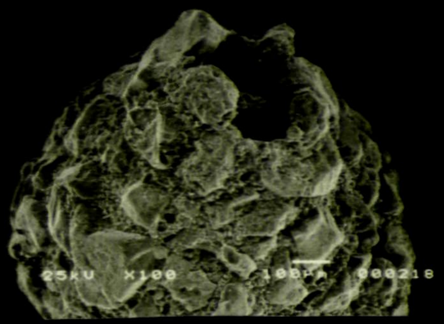

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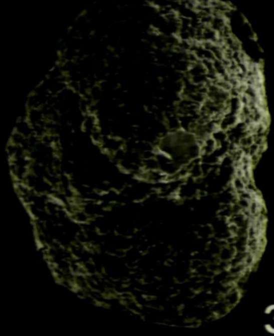
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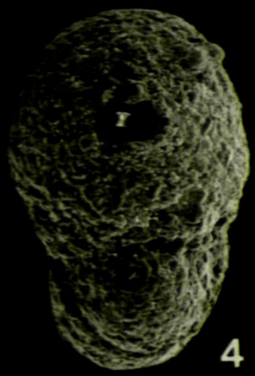
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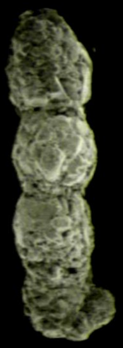
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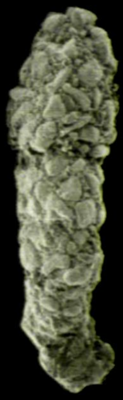
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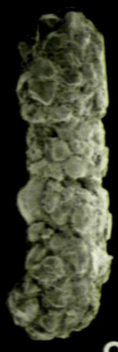
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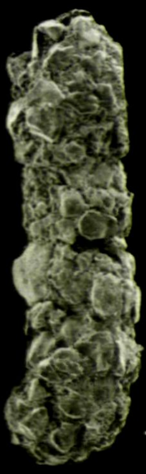
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Plate 5.

Figs 1-2. *Ammobaculites deceptorius* (Häusler). **1.** x200, h = 495µ, w = 33µ, sample HH/213. **2.** x200, h = 371µ, w = 114µ, sample HH/213.

Fig. 3. *Ammobaculites fontinensis* (Terquem), x200, h = 371µ, w = 267µ, sample HF/50.

Fig. 4. *Ammobaculites fisheri* Crespin, x100, h = 1140µ, w = 360µ, sample HH/221.

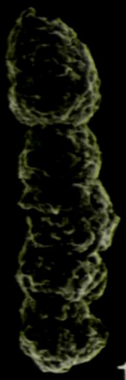
Figs 5-8. 093, *Ammobaculites godmani* (Barnard). **5.** x200, h = 381µ, w = 162µ, sample HH/219. **6.** x350, h = 306µ, w = 161µ, sample HH/211. **7.** x350, h = 306µ, w = 89µ, sample HH/211. **8.** x350, h = 300µ, w = 133µ, sample HH/211.

Fig. 9. *Ammobaculites vetusta* (Terquem and Berthelin), x350, h = 272µ, w= 78µ, sample HH/197.

Fig. 10. *Ammobaculites irregulariformis* Bartenstein and Brand, x200, h = 352µ, w = 248µ, sample HH/215.

Fig. 11. *Ammobaculites* sp. cf. *Ammobaculites* sp. 2 Bartenstein and Brand, x 350, h = 311µ, w = 178µ, sample HH/213.

Plate 5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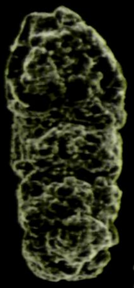
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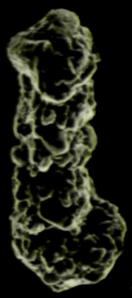
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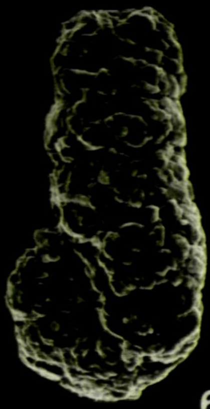
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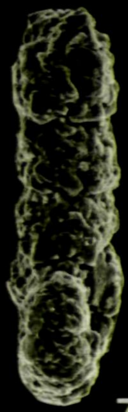
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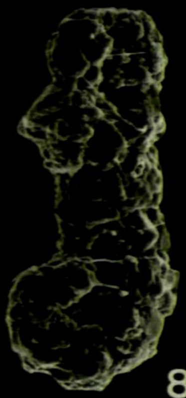
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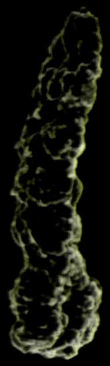
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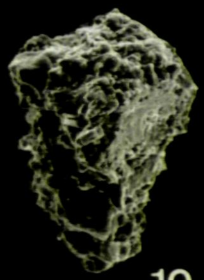
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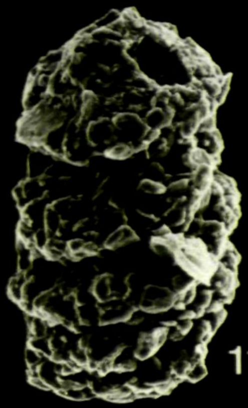
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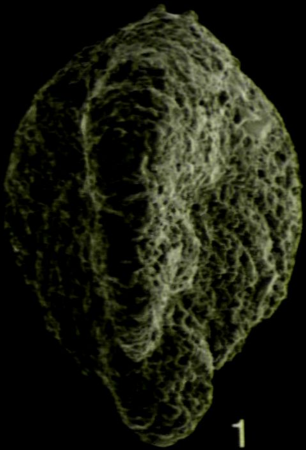
Plate 6.

Figs 1-9. *Triplasia* sp. 1. **1-4.** Large squat forms. **1.** x100, h = 1240μ, w = 840μ, sample HH/209. **2.** x75, h = 1550μ, w = 925μ, sample HH/211. **3.** x75, h = 1475μ, w = 750μ, sample HH/209. **4.** x75, h = 1200μ, w = 925μ, sample HH/209. **5-6.** Elongate forms. **5.** x100, h = 1160μ, w = 460μ, sample HH/209. **6.** x75, h = 1325μ, w = 475μ, sample HH/211. **7.** Intermediate form with triradiate structure poorly developed, x100, h = 920μ, w = 560μ, sample HH/209. **8.** *Flabellammina*-like flat form, broken specimen, (note attached specimen of *Nubeculinella bigoti*), x75, h = 1375μ, w = 575μ, sample HH/209. **9.** Quadrate form, x100, w = 1040μ, sample HH/211.

Plate 6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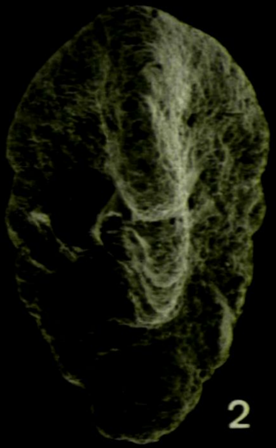
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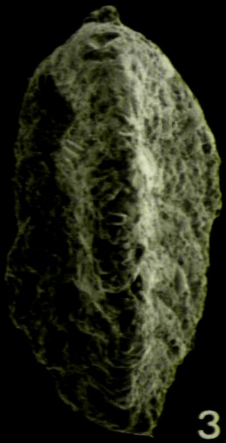
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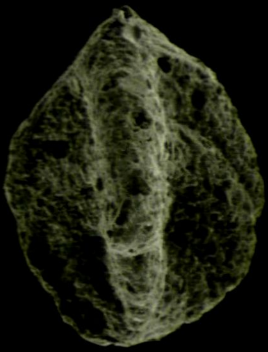
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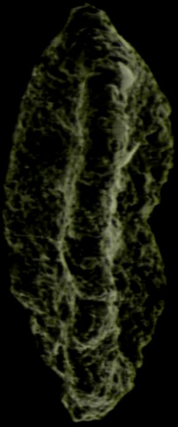
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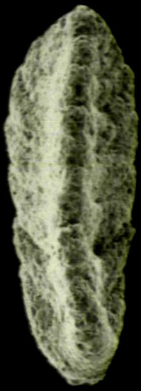
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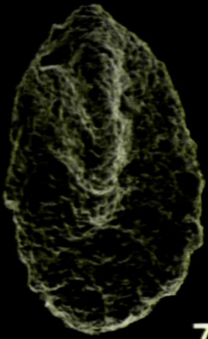
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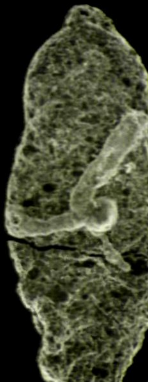
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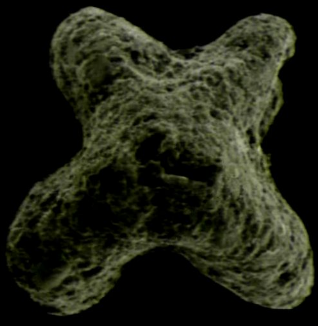
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Plate 7.

Fig. 1. *Suboidellina* sp., x200, h = 486, w = 229, sample HH/213.

Fig. 2. *Placopsilina* sp. cf. *P. cenomana* d'Orbigny, x150, h = 733, w = 227, sample HH/213.

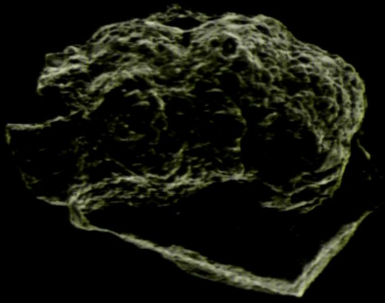
Fig. 3. *Spiroplectammina biformis* (Parker and Jones), x200, h = 486, w = 200, sample HH/209.

Fig. 4. *Spiroplectammina* sp. aff. *S. suprajurassica* Kosyreva, x750, h = 168, w = 73, sample HH/211.

Figs 5-7. *Trochammina canningensis* Tappan. **5.** Ventral view, x 350, d = 222, sample HH/171. **6.** Dorsal view, x 350, d = 261, sample HH/171. **7.** Dorsal view, x350, d = 206, sample HH/171.

Figs 8-11. *Trochammina globigeriniformis* (Parker and Jones). **8.** Low spired form, side view, x 350, h = 178, w = 272, sample HH/171. **9.** High spired form, x 350, h = 222, w = 233, sample HH/171. **10.** Ventral view, x 350, d = 217, sample ES/30446. **11.** Dorsal view, x 350, d = 239, sample ES/30448.

Plate 7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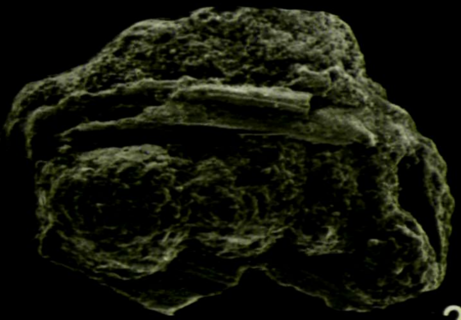
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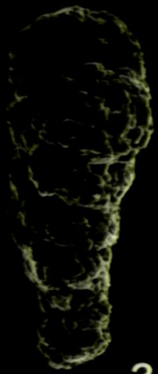
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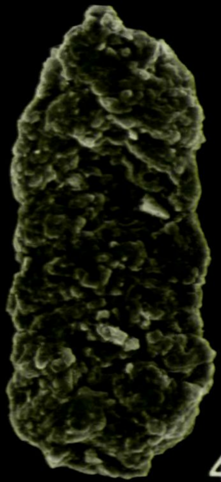
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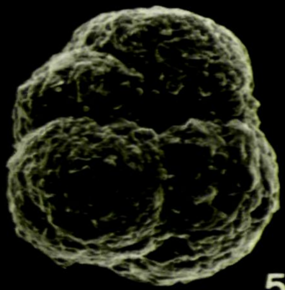
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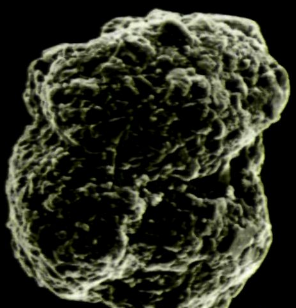
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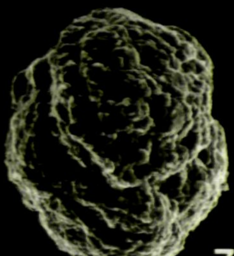
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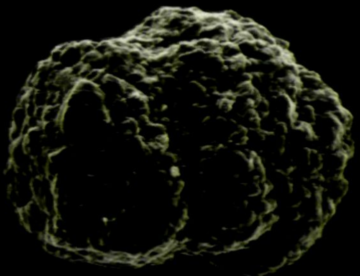
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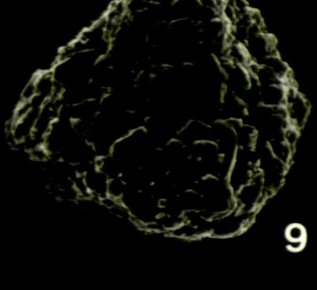
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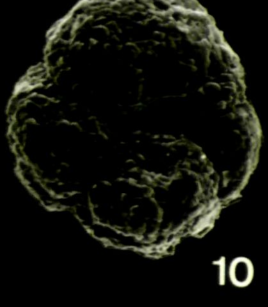
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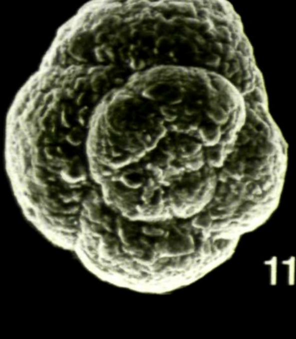
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Plate 8.

Figs 1-2. *Trochammina* sp. cf. *T. inflata* (Montagu). **1.** Dorsal view, x 350, d = 328μ, sample HH/223. **2.** Ventral view, x200, d = 400μ, sample HH/211.

Figs 3-4. *Trochammina kosyrevae* Levina. **3.** Ventral view, x200, d = 419μ, sample HH/215. **4.** Dorsal view, x 350, d = 250μ, sample HH/225.

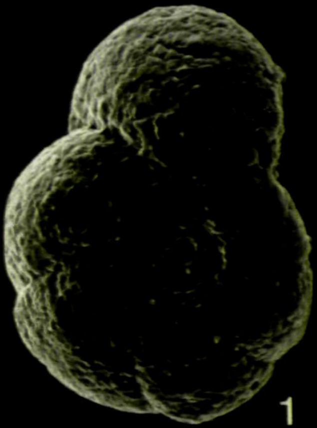
Fig. 5. *Trochammina* sp. cf. *T. omskensis* Kosyreva, dorsal view, x200, d = 381μ, sample HH/225.

Fig. 6. *Trochammina* sp. cf. *T. qinquilocularis* Dain, dorsal view, x200, d = 324μ, sample HH/195.

Figs 7-8. *Trochammina* sp. cf. *T. rosaceaformis* Romanova. **7.** Dorsal view, x200, d = 267μ, sample HH/217. **8.** Dorsal view, x500, d = 173μ, sample HF/52.

Figs 9-12. *Trochammina* sp. 2. **9.** Dorsal view, specimen with compressed final chambers, x500 d = 162μ, sample HH/225. **10.** Side View, x350, h = 206μ, w = 194μ, sample HH/225. **11.** Side view, x350, h = 183μ, w= 156μ, sample HH/225. **12.** Side view, specimen with compressed final chambers, x500, h = 165μ, w = 154μ, sample HH/225.

Plate 8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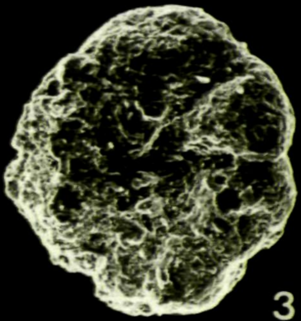
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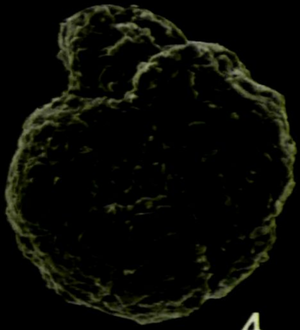
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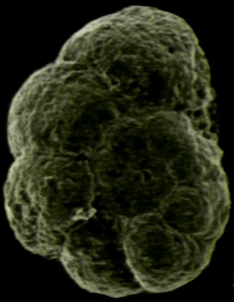
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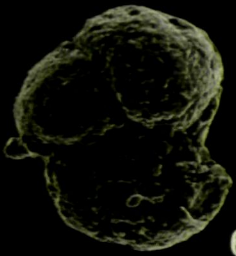
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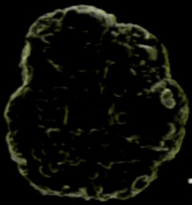
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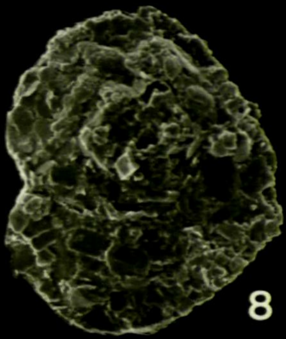
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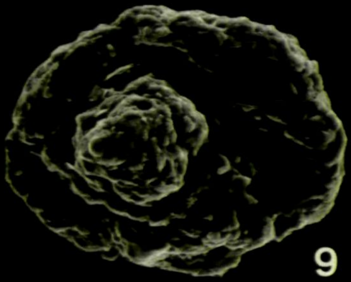
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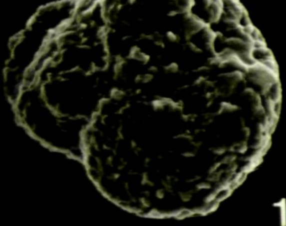
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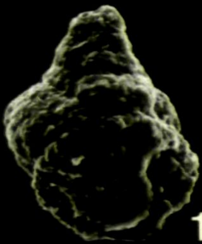
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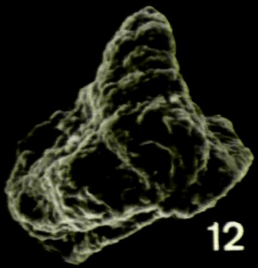
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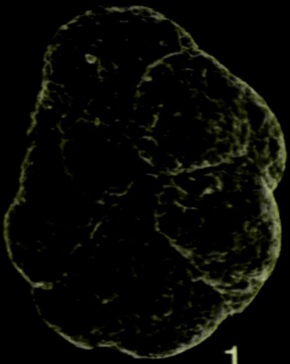
Plate 9.

Figs 1-9. *Trochammina squamata* Parker and Jones. **1.** Dorsal view, compressed form, x150, d = 667μ, sample HH/211. **2.** Dorsal view, compressed form, x150, d = 613μ, sample HH/213. **3.** Dorsal view, uncompressed form, x150, d = 507μ, sample HH/213. **4.** Ventral view, compressed form, x150, d = 600μ, sample HH/211. **5.** Side view, specimen compressed within the plane of coiling, x200, h = 514μ, w = 286μ, sample HH/213. **6.** Side view, compressed within the pane of coiling, x200, h = 438μ, w = 238μ, sample HH/213. **7-8.** Sample HH/213. **7.** Ventral view, x100, d = 620μ. **8.** Detail of aperture, x500, scale-bar = 50μ. **9.** Side view, compressed within the plane of coiling, x200, h = 571μ, w = 352μ, sample HH/213.

Fig. 10. *Trochammina* sp. 1, Ventral view, x100, d = 740μ, HH/217.

Fig. 11. *Trochammina* sp. cf. *T. taboryensis* Levina, dorsal view, x350, d = 339μ, sample HH/203.

Plate 9



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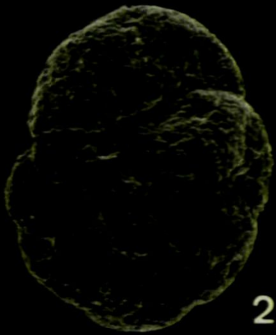

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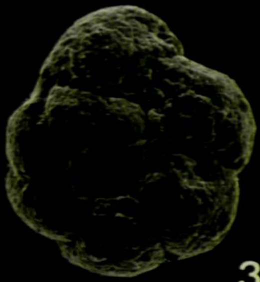

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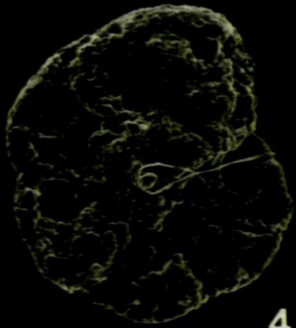

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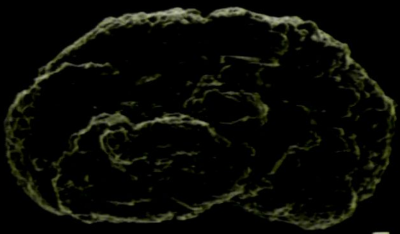

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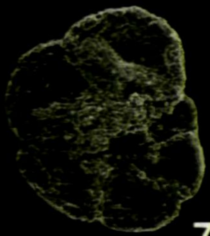

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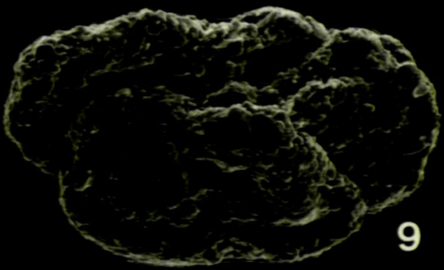

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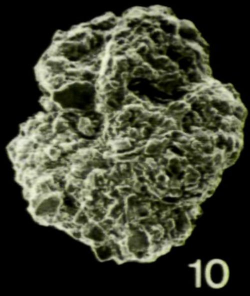

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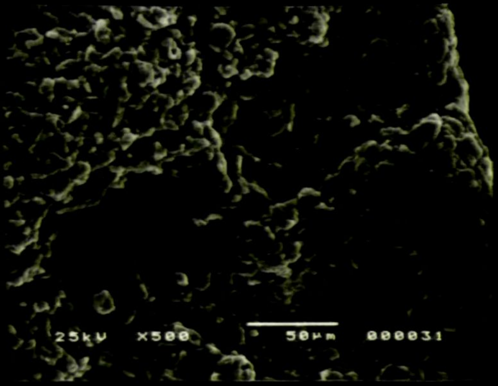

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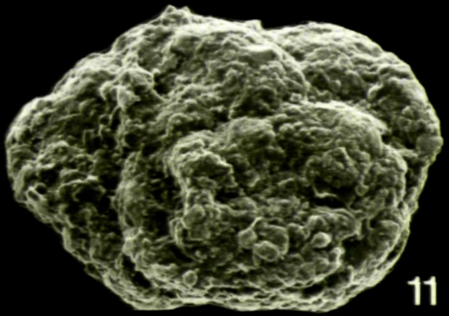

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Plate 10.

Figs 1-2. *Verneuilinoides tryphera* Loeblich and Tappan. **1.** Side view, x750, h = 168μ, w = 95μ, sample HH/225. **2.** Side view, x500, h = 177μ, w = 85μ, sample HH/225.

Figs 3-4. *Verneuilinoides* sp. 1. **3.** Side view, x350, h = 194μ, w = 122μ, sample HH/225. **4.** Side view, x350, h = 183μ, w = 128μ, sample HH/225.

Figs 5-6. *Eggerella? meentzeni* (Klinger) *sensu* Lloyd. **5.** Side view, x500, h = 150μ, w = 123μ, sample HH/225. **6.** Apertural view, x500, w = 123μ, sample HH/225.

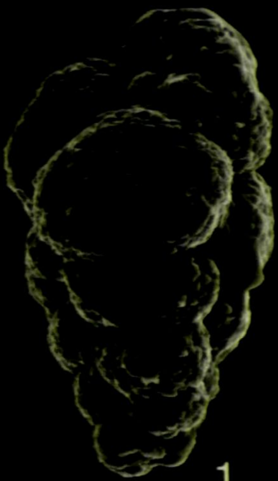
Fig. 7. *Gaudryina sherlocki* (Bettenstaedt), side view, x750, h = 160μ, w = 73μ, sample HH/225.

Fig. 8. *Textularia dumortieri* (Schwager), side view, x350, h = 339μ, w = 211μ, sample HF/44.

Figs 9-10. *Bigenerina clavellata* Loeblich and Tappan. **9.** Side view, x150, h = 787μ, w = 187μ, sample HF/44. **10.** Side view, x200, h = 562μ, w = 152μ, sample HF/44.

Figs 11-13. *Textularia pugiunculus* (Schwager). **11.** Side view, x200, h = 476μ, w = 162μ, sample HF/36. **12.** Side view, x200, h = 419μ, w = 143μ, HF/36. **13.** Side view, x200, h = 448μ, w = 143μ, HF/36.

Plate 10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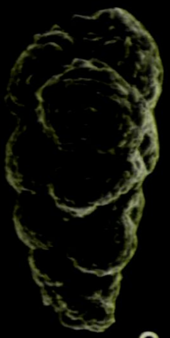
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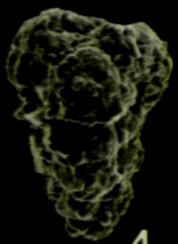
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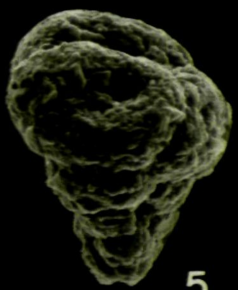
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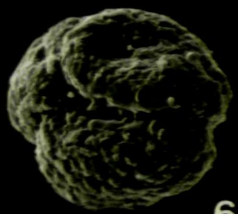
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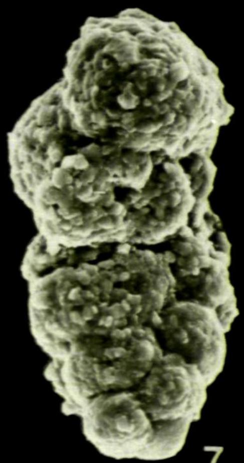
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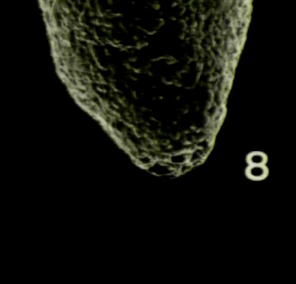
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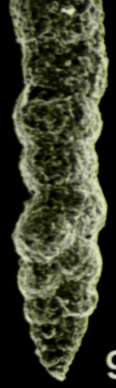
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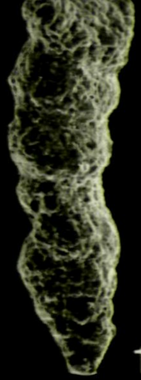
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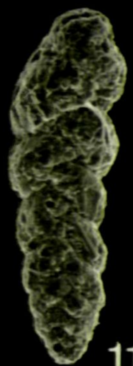
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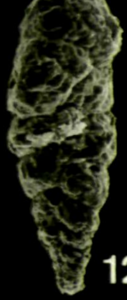
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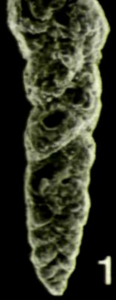
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Plate 11.

Fig. 1. *Textularia pugiunculus* (Schwager), side view, x350, h = 267µ, w = 178µ, sample HF/36.

Figs 2-3. *Textularia jurassica* (Gümbel). **2.** Side view, x 100, h = 514µ, w = 190µ, sample HH/209. **3.** Side view, x200, h = 486µ, w = 190µ, sample HH/209.

Fig. 4. *Textularia* sp. 1, side view, x150, h = 787µ, w = 373µ, sample HH/221.

Fig. 5. *Textularia* sp. 2, side view, x350, h = 283µ, w = 167µ, sample HH/169.

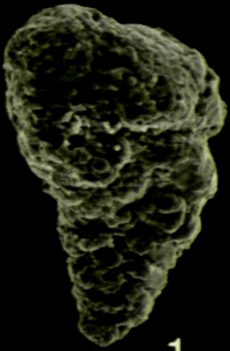
Figs 6-11. *Trocholina nodulosa* Seibold and Seibold. **6.** Ventral view, x350, d = 200µ, sample HF/48. **7.** Ventral view, x200, d = 305µ, sample HF/46. **8.** Ventral view, x200, d = 276µ, sample ES/30416. **9.** Ventral view, x200, d = 286µ, sample HF/46. **10.** Dorsal view, x200. d = 267µ, sample HF/46. **11.** Dorsal view, x200, d = 286µ, sample HF/46.

Fig. 12. *Spirillina andrea* Bielecka, ventral view, x750, d = 117µ, sample HH/219.

Fig. 13. ?*Trocholina* sp., ventral view, x200, d = 295µ, sample ES/30436.

Fig. 14. *Cornuspira* sp 1, ventral view, x200, d = 381µ, sample HH/225.

Plate 11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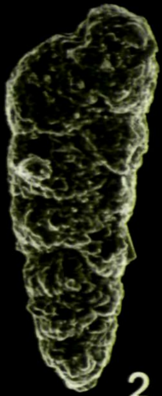
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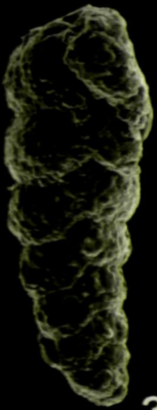
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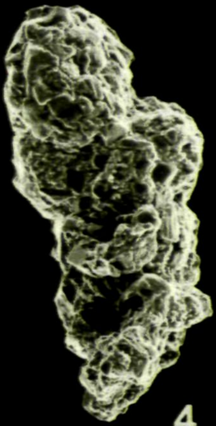
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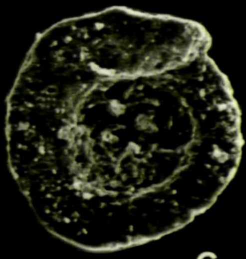
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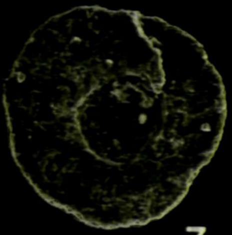
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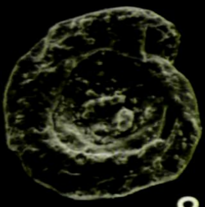
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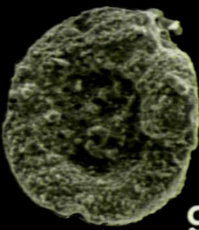
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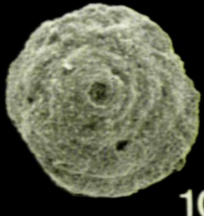
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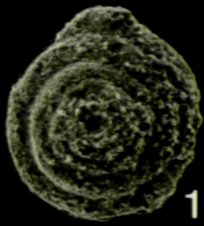
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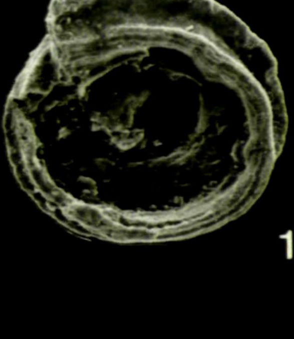
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Plate 12.

Figs 1-2. *Spirillina infima* (Strickland) *emend.* Barnard. **1.** Side view, x350, d = 228μ, sample ES/30416. **2.** Side view, x200, d = 257μ, sample ES/30416.

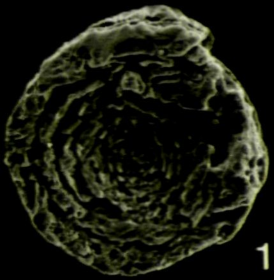
Figs 3-4. *Spirillina tenuissima* Gümbel. **3.** Side view, x 350, d = 228μ, sample ES/30420. **4.** Side view, x 200, d = 276μ, sampl ES/30420.

Fig. 5. *Cornuspira* sp. 2, side view, x200, d = 267μ, sampl HF/56.

Figs 6-7. *Nubeculinella bigoti* Cushman. **6.** Attached to shell fragment, x200, left chamber, h = 210μ, w = 105μ, sample HH/213. **7.** Attached to ostracod valve, x150, ostracod size, l = 827μ, h = 453μ, sample HH/213.

Figs 8-12. *Nubeculinella tibia* var. *bulbifera* (Paalzow). **8.** x150, h = 880μ, w = 227μ, sample HH/209. **9.** x150, h = 987μ, w = 173μ, sample HH/209. **10.** x100, h = 1020μ, w = 300μ, sample HH/209. **11.** x150, h = 760μ, w = 200μ, sample HH/209. **12.** x100, h = 1280μ, w = 180μ, sample HH/209.

Plate 12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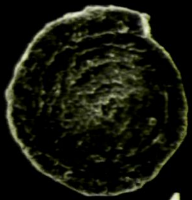
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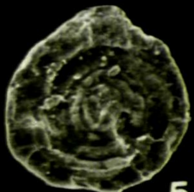
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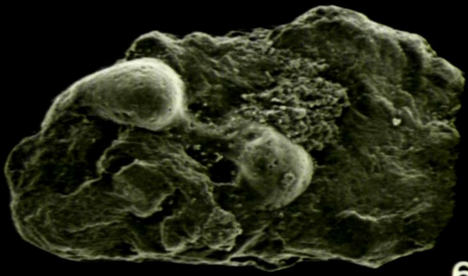
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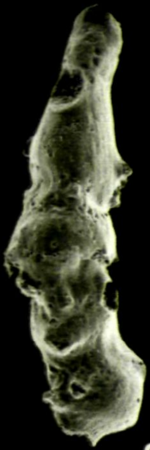
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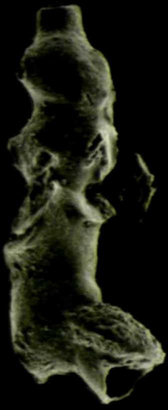
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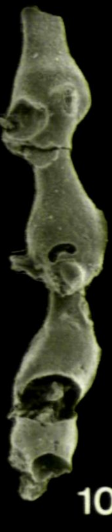
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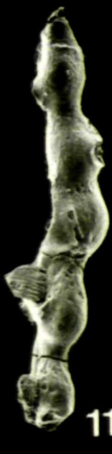
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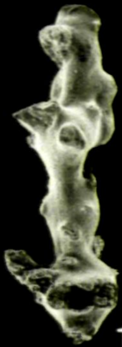
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Plate 13.

Fig. 1. *Ophthalmidium compressum* Barnard, Cordey and Shipp, side view, x500, h = 196, w = 119, sample HH/223.

Figs 2-4. *Ophthalmidium strumosum* (Gümbel). **2.** Side view, x200, h = 486, w = 248, sample ES/30442. **3.** Side view, x200, h = 486, w = 229, sample ES/30442. **4.** Side view, x200, h = 467, w = 267, sample ES/30442.

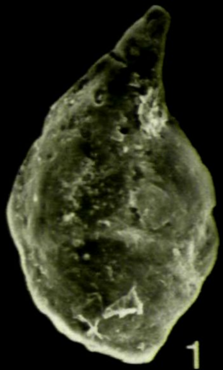
Fig. 5. *Spiroloculina variabilis* Barnard, Cordey and Shipp, x500, h = 204, w = 100, sample HH/195.

Fig. 6. *Massilina* sp. cf. *M. dorsetensis* Cifelli, side view, x500, h = 177, w = 96, sample HH/211.

Figs 7-10. *Quinquiloculina horelli* Barnard, Cordey and Shipp. **7.** Side view, x350, h = 294, w = 122, sample ES/30450. **8-9.** Sample ES/30450. **8.** Side view, x350, h = 306, w = 139. **9.** Detail of aperture, x1,500, scale bar = 10μ. **10.** Side view, x500, h = 242, w = 85, sample ES/30450.

Fig. 11. *Quinquiloculina* sp.1, side view, x350, h = 294, w = 72, sample HF/52.

Plate 13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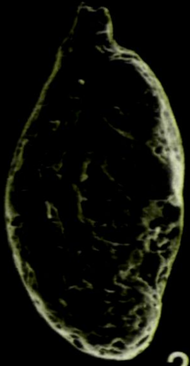
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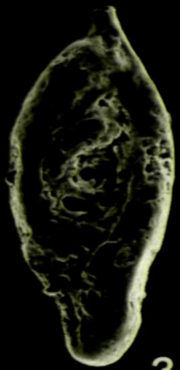
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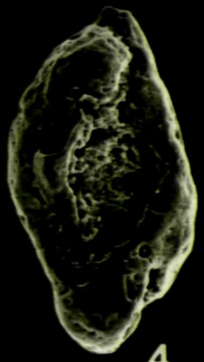
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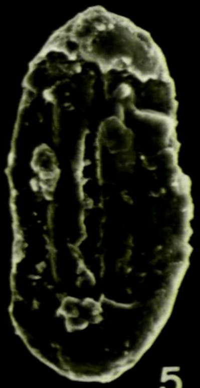
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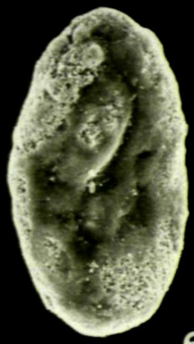
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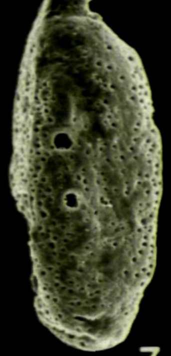
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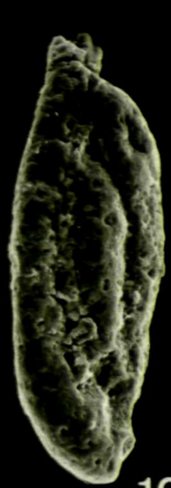
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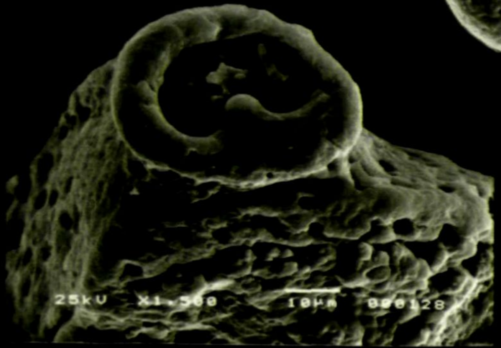

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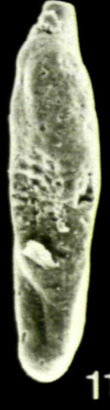
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Plate 14.

Fig. 1. *Falsopalmula* sp. cf. *F. deslongchampsis* (Terquem), side view, x350, h = 333μ, w = 217μ, sample HH/213.

Figs 2-3. *Falsopalmula* sp. cf. *F. primordialis* (Terquem), sample ES/30434. 2. Side view, x150, h = 467μ, w = 229μ. 3. Side view, x150, h = 760μ, w = 307μ.

Fig. 4-5. *Dentalina bicornis* Terquem. **4.** Broken specimen, x200, h = 619μ, w = 190μ, sample HH/203. **5.** Side view, x200, h = 533μ, w = 152μ, sample ES/30450.

Fig. 6. *Dentalina* sp. cf. *D. debilis* (Berthelin), broken specimen, x200, h = 638μ, w = 114μ, sample ES/30452.

Fig. 7. *Dentalina* sp. aff. *D. communis* d'Orbigny *sensu* Cordey, x200, h = 486μ, w = 114μ, sample HF/52.

Figs 8-9. *Dentalina gümbeli* Schwager, sample HF/40. **8.** Side view, x100, h = 1180μ, w = 200μ. **9.** Detail of aperture, x750, w = 114μ.

Fig. 10. *Dentalina marsupifera* Schwager, side view, x350, h = 344μ, w = 83μ, HF/28.

Fig. 11. *Dentalina torta* Terquem, side view,x100, h = 1220μ, w = 160μ, sample HF/32.

Fig. 12. *Dentalina varians* Terquem, broken specimen, x350, h = 306μ, w = 67μ, HH/209.

Plate 14


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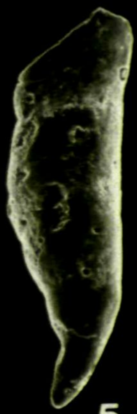
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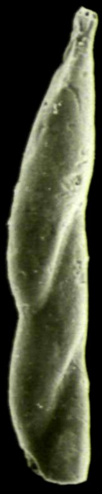
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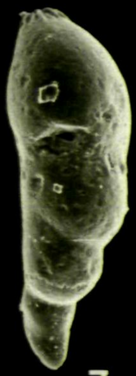
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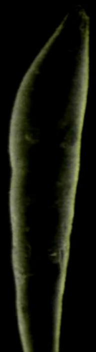
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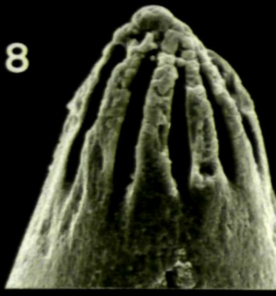
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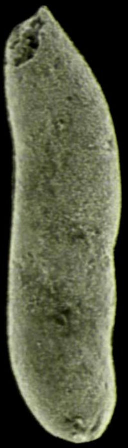
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Plate 15.

Fig. 1. *Dentalina vetusta* d'Orbigny, broken specimen, x100, h = 940μ, w = 120μ, sample HF/52.

Fig. 2. *Dentalina* sp. 1, x500, h = 235μ, w = 42μ, sample HH/187.

Fig. 3. *Nodosaria balteata* Loeblich and Tappan, broken specimen, x350, h = 317μ, w = 89μ, sample ES/30430.

Fig. 4. *Nodosaria corallina* Gümbel, x100, h = 960μ, w = 280μ, sample ES/30444.

Figs 6-7. *Nodosaria opalini* Bartenstein, sample HH/213. **6.** x350, h = 328μ, w = 72μ. **7.** x350, h = 261μ, w = 67μ.

Fig. 8. *Nodosaria* sp. cf. *N. rudis* d'Orbigny, broken specimen, x200, h = 543μ, w = 210μ, sample HF/16.

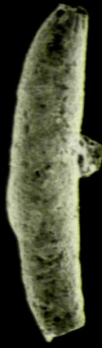
Fig. 9. *Nodosaria simplex* (Terquem), broken specimen, x350, h = 278μ, w = 72μ, sample HH/205.

Fig. 10. *Nodosaria* sp. cf. *N. metensis* (Terquem) *sensu* Gordon, broken specimen, x200, h = 524μ, w = 124μ, sample HH/181.

Fig. 11. *Pseudonodosaria vulgata* (Bornemann), x500, h = 158μ, w = 96μ, sample HH/209.

Figs 12-13. *Pseudonodosaria radiata* (Barnard), sample HH/217. **12.** x200, h = 486μ, w = 295μ. **13.** Broken specimen showing spiral ribbing, x200 h = 543μ, w = 362μ.

Plate 15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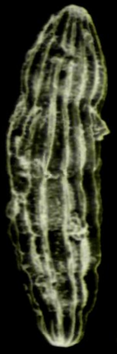
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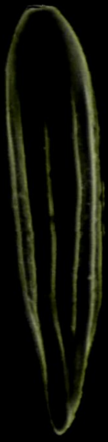
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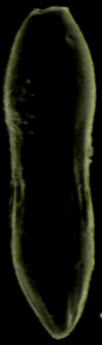
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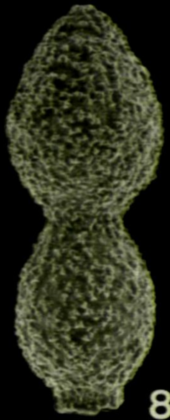
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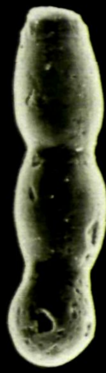
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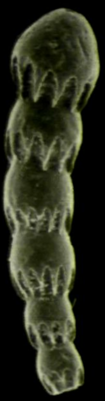
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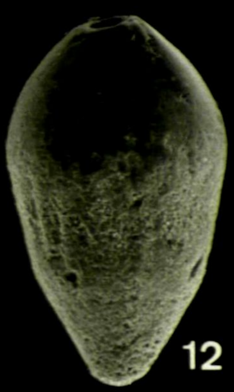
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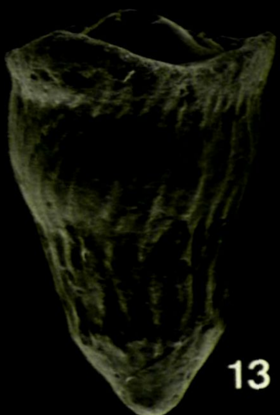
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Plate 16.

Figs 1-3. *Lingulina cernua* (Berthelin), sample HH/215. **1.** x500, h = 242μ, w = 69μ. **2.** x500, h = 242μ, w = 81μ. **3.** x500, h = 242μ, w = 92.

Figs 4, 8. *Lingulina nodosaria* (Terquem), sample HH/195. **4.** x350, h = 344μ, w = 78μ. **8.** x100, h = 410μ, w = 86μ.

Fig. 5. *Lingulina laevissima* (Terquem), broken specimen, x200, h = 619μ, w = 124μ, sample HH/211.

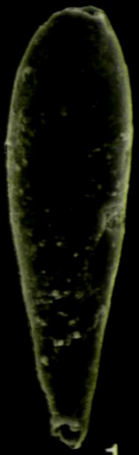
Fig. 6. *Lingulina pupa* (Terquem), x200, h = 410μ, w = 133μ, sample HH/211.

Figs 7, 9. *Frondicularia franconica* Gümbel, sample ES/30452. **7.** x200, h = 619μ, w = 248μ. **9.** x100, h = 1040μ, w = 280μ.

Fig. 10. *Frondicularia* sp. cf. *F. lignaria* Terquem, x500, h = 235μ, w = 131μ, sample HH/177.

Figs 11-12. *Tristix triangularis* Barnard. **11.** Microspheric form, x150, h = 573μ, w = 200μ, sample ES/30452. **12.** Megalospheric form, x150, h = 520μ, w = 187μ, sample ES/30454.

Plate 16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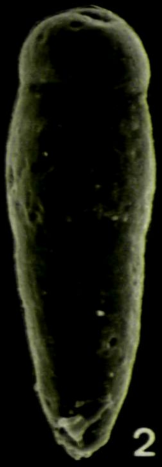
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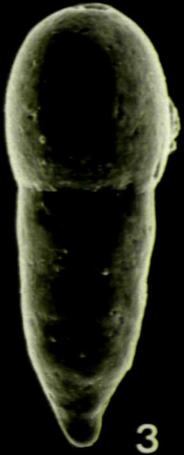
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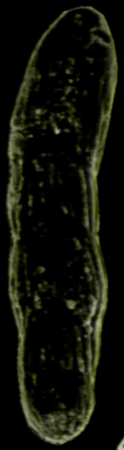
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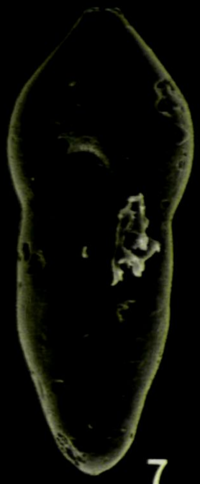
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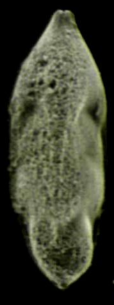
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Plate 17.

Figs 1-2. *Lenticulina brevispira* (Wisniowski), sample HH/221. **1.** Side view, x200, h = 381μ, w = 219μ. **2.** Apertural view, x350, h = 278μ, w = 128.

Figs 3-5. *Lenticulina ectypa* (Loeblich andTappan). **3-4.** x200, sample HH/203. **3.** Side view, h = 333μ, w = 210μ. **4.** Apertural view, w = 124μ. **5.** Side view, x200, h = 410μ, w = 219μ, sample HH/203

Figs 6-8. *Lenticulina major* (Bornemann). **6.** Side view, x100, h = 1160μ, w = 420μ, sample HH/217. **7.** Rear view, x150, h = 840μ, w = 187μ, sample HH/223. **8.** Side view, x 150, h = 867μ, w = 440μ, sample HH217.

Figs 9-10. *Lenticulina münsteri* Roemer. **9.** Side view, x100, h = 900μ, w = 720μ, sample HH/197. **10.** Side view, x100, h = 780μ, w = 600μ, sample HH/197.

Fig. 11. *Lenticulina* sp. cf. *L. polonica* var. *glabra* (Wisniowski) *sensu* Cordey, side view, x200, h = 343μ, w = 333μ, sample HH/211.

Fig. 12. *Lenticulina polygona* (Paalzow), side view, x100, h = 860μ, w = 660μ, sample HH/223.

Fig. 13. *Lenticulina protracta* (Bornemann), close-coiled form, x200, h = 400μ, w = 286μ, sample HH/217.

Plate 17


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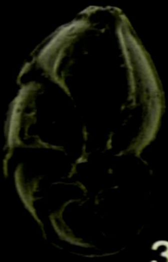
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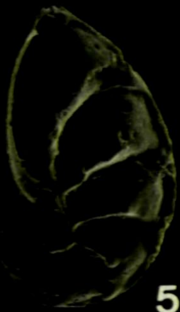
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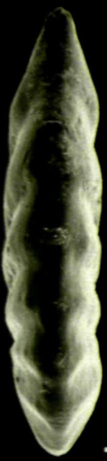
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Plate 18.

Figs 1-2. *Lenticulina protracta* (Bornemann). **1.** Uncoiled form, x200, h = 638μ, w = 219μ, sample HH/199. **2.** Uncoiled form, x200, h = 590μ, w = 286μ, sample HH/199.

Figs 3-4. *Lenticulina quenstedti* (Gümbel). **3.** Side view, x150, h = 547μ, w = 400μ, sample HH/179. **4.** Apertural view, x200, h = 390μ, w = 181μ, sample HH/183.

Figs 5-6. *Lenticulina tricarinella* (Reuss). **5.** Side view, x200, h = 371μ, w = 257μ, sample HF/44. **6.** Apertural view, x200, h = 429μ, w = 171μ, sample HF/44.

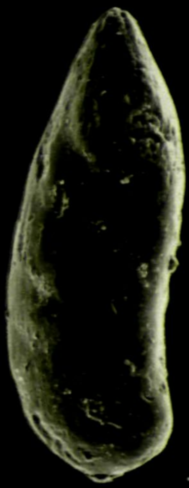
Figs 7-8. *Lenticulina subalata* (Reuss). **7.** Side view, x150, h = 693μ, w = 413μ, sample HF/18. **8.** Rear view, x100, h = 960μ, w = 600μ, sample HF/18.

Figs 9-10. *Lenticulina varians* (Bornemann) form B, Lutze. **9.** Side view, x 350, h = 350μ, w = 217μ, sample H/223 **10.** Side view, x350, h = 322μ, w = 217μ, sample HH/223.

Fig. 11. *Lenticulina* sp. 1, side view, x200, h = 343μ, w = 286μ, sample HH/211.

Fig. 12. *Marginulina undulata* Terquem, side view, x200, h = 514μ, w = 248μ, sample ES/30436.

Plate 18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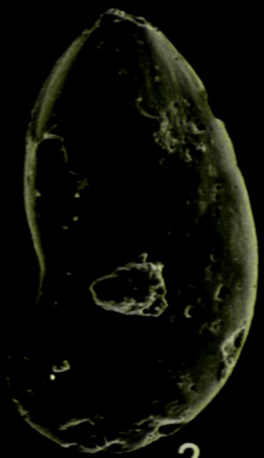
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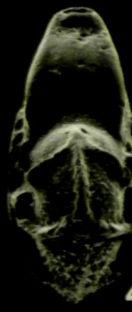
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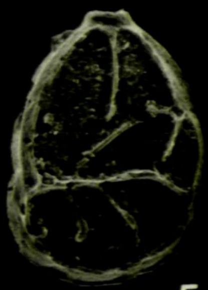
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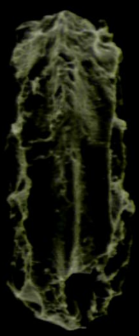
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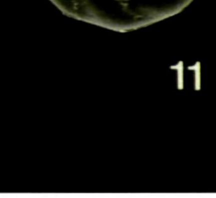
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Plate 19.

Figs 1-2. *Marginulina batrakiensis* (Myatluik). **1.** Side view, x200, h = 524μ, w = 190μ, sample HF/41. **2.** Apertural view, x150, h = 720μ, w = 187μ, sample HF/41.

Figs 3-5. *Citharina serratocostata* (Gümbel). **3.** x150, h = 880μ, w = 280μ, sample HH/221. **4.** x100, h = 940μ, w = 300μ, sample HH/221. **5.** x75, h = 1600μ, w = 571μ, sample ES/30452.

Figs 6-7. *Citharina flabelloides* (Terquem). **6.** x75, h = 1714μ, w = 571μ, sample HH/199. **7.** x75, h = 1425μ, w = 450μ, sample HH/199.

Figs 8-9. *Citharina heteropleura* (Terquem). **8.** x75, h = 1425μ, w = 400μ, sample ES/30454. **9.** x100, h = 1300μ, w = 420μ, sample ES/30454.

Fig. 10. *Citharina lepida* (Schwager), x100, h = 1240μ, w = 560μ, sample ES/30452.

Figs 11-13. *Citharina tenuicostata* Lutze. **11.** x150, h = 733μ, w = 333μ, sample HH/203. **12.** x200, h = 581μ, w = 219μ, sample HH/203. **13.** x150, h = 787μ, w = 387μ, sample ES/30444.

Plate 19


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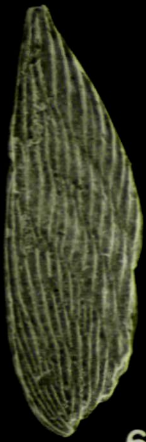
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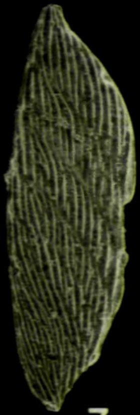
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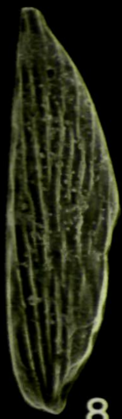
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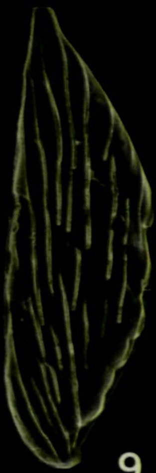
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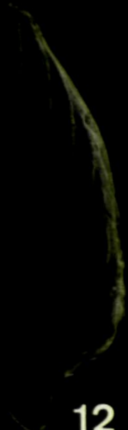
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Plate 20.

Figs 1-4. *Citharinella exarata* Loeblich and Tappan. **1.** x150, h = 853μ,w = 347μ, sample HH/201. **2.** x100, h = 980μ, w = 400μ, sample ES/30434. **3.** x200, h = 495μ,w = 229μ, sample HH/201. **4.** Specimen with frondicularid initial chamber arrangement, x150, h = 800μ,w = 333μ, sample ES/30434.

Fig. 5. *Planularia angustissima* (Wisniowski), x200, h = 381μ,w = 86μ, sample HH/223.

Figs 6-8. *Planularia bieriana* (Gümbel). **6.** End view, x150, h = 667μ,w = 80μ, sample HF/44. **7.** Side view, specimen with fine arcuate striae, x200, h = 600μ,w = 200μ, sample HH/203. 5. **8.** Side view, x150, h = 520μ,w = 227μ, sample HF/44.

Fig. 9. *Planularia eugenii* (Terquem), x150, h = 707,w = 427, sample ES/30454.

Figs 10-11. *Planularia listi* (Bornemann). **10.** x100, h = 1140μ, w = 400μ, sample HF/28. **11.** x200, h = 581μ, w = 190μ, sample HF/30.

Figs 12-14. *Planularia suturalis* (Terquem). **12.** Side view, x200, h = 505μ,w = 229μ, sample HH/215. **13.** Apertural view, x200,h = 524μ,w = 95μ, sample HH/215. **14.** Side view, x200, h = 562μ,w = 248μ, sample HH/215.

Plate 20


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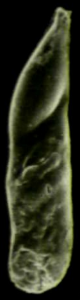
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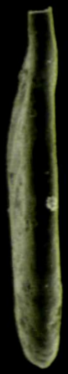
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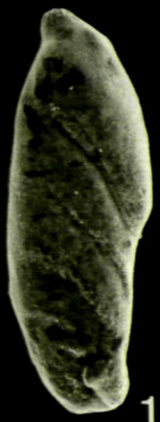
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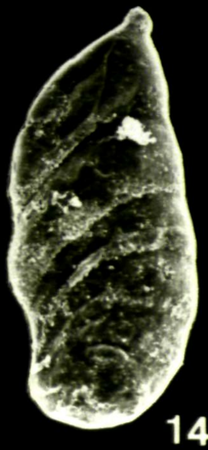
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Plate 21.

Figs 1-4. *Vaginulina anomala* Blake. **1.** x100,h = 1340μ, w = 300μ, sample HF/50. **2.** Broken specimens, x200, h = 495μ, w = 114μ, sample ES/30444. **3.** x200, h = 467μ, w = 181μ, sample ES/30426. **4.** x200, h = 686μ, w = 181μ, sample ES/30444.

Figs 5-6. *Vaginulina barnardi* Gordon. **5.** x150, h = 720μ, w = 253μ, sample HF/48. **6.** x150, h = 707μ,w = 320μ, sample HF/48.

Figs 7-9. *Vaginulina contracta* (Terquem), **7.** x350, h = 306μ,w = 78μ, sample HH/223. **8.** x350, h = 283μ,w = 100μ, sample HH/223. **9.** x350, h = 367μ,w = 128μ, sample HF/52.

Fig. 10. *Vaginulina jurassica* (Gümbel), broken specimen, x200, h = 543μ,w = 152μ, sample HF/40.

Fig. 11. *Vaginulina* sp. 1 x100, h = 1320μ,w = 280μ, sample HF/28.

Plate 21


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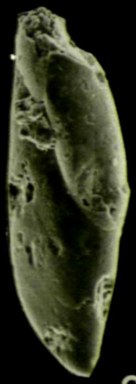
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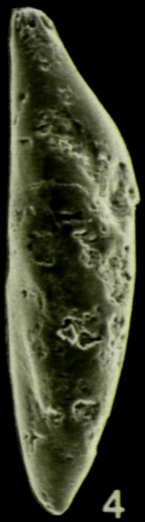
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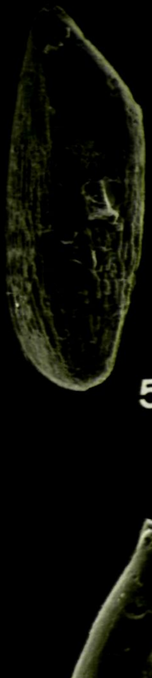
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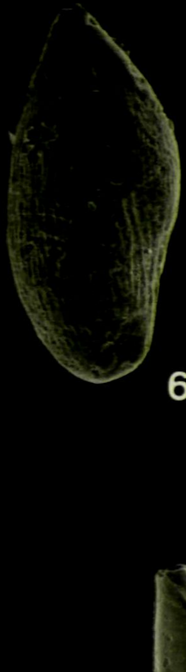
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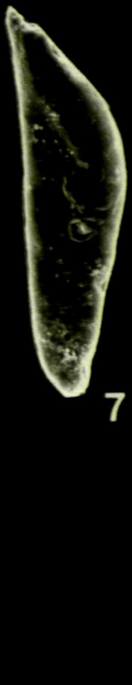
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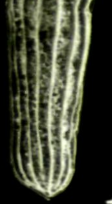
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Plate 22.

Fig. 1. *Lagena globosa* (Montagu), x500, h = 162μ, w = 127μ, sample ES/30454.

Fig. 2. *Lagena* sp. 1, x500, h = 208μ, w = 127μ, sample HH/199.

Fig. 3. *Lagena* sp. cf. *Lagena* sp. 3 Bartenstein and Brand, x500, d = 158μ, sample HH/197.

Fig. 4. *Eoguttulina oolithica* (Terquem), x350, h = 356μ, w = 178μ, sample HH/223.

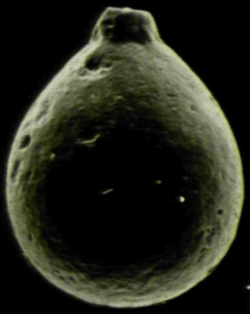
Figs 5-6. *Eoguttulina oolithica* (Terqquem) form A. **5.** x500, h = 238μ, w = 135μ, sample HH/197. **6.** x500, h = 219μ, w = 150μ, sample HH/197.

Fig. 7. *Eoguttulina inovroclaviensis* (Bielecka and Pozaryski), damaged specimen, x200, h = 390μ, w = 143μ, sample ES/30436.

Fig. 8. *Eoguttulina liassica* (Strickland), x200, h = 448μ, w =210μ, sample HF/50.

Figs 9-10. *Ramulina spandeli* Paalzow. **9.** Two chambers, x150, h = 773μ, w =267μ, sample HF/34. **10.** Single chamber, x200, h = 419μ, w =267μ, sample ES/30450.

Plate 22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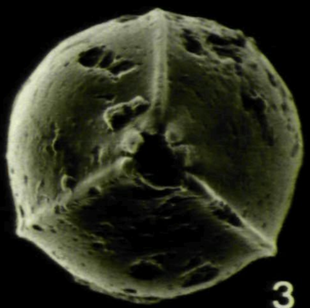
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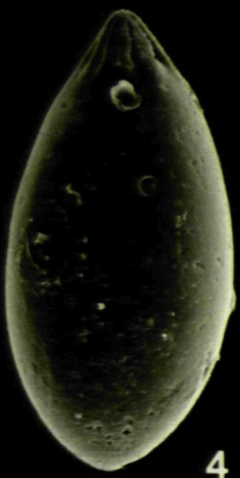
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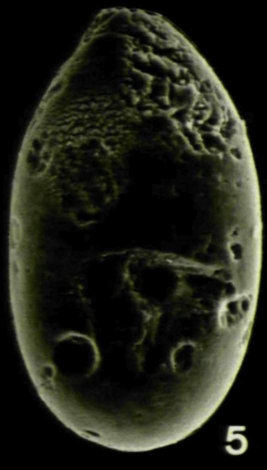
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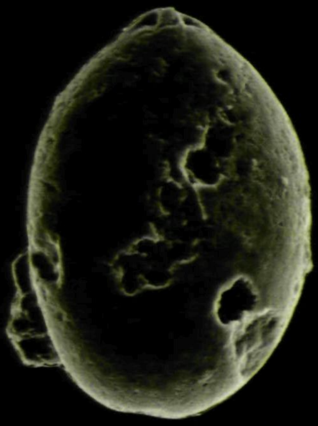
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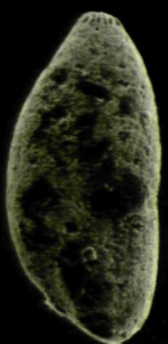
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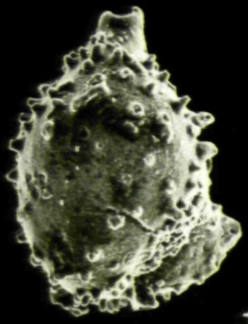
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Plate 23.

Figs 1-3. *Reinholdella lutzei* Barnard, Cordey and Shipp. **1.** Dorsal view, x200, d = 381µ, sample HF/24. **2.** Ventral view, x200, d = 333, sample HF/24. **3.** Ventral view, x200, d = 286µ, 24/150µ, x200.

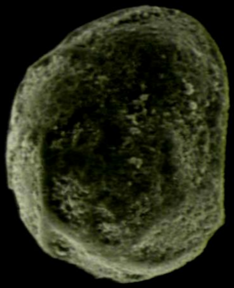
Fig. 4. *Reinholdella* sp. 1, dorsal view, x200, d =295µ, sample HH/211.

Fig. 5-6, 9. *Epistomina mosquensis* Uhlig. **5.** Dorsal view, x100, d = 820µ, sample HH/219. **6.** Ventral side, x100, d = 920µ, sample HH/219. **9.** Ventral side, showing "horse-shoe" depression, x150, d = 547µ, sample HH/219.

Fig. 7-8. *Epistomina mosquensis* Uhlig form A. **7.** Dorsal view, x 150, d = 547µ, sample HH/221. **8.** Dorsal view, x150, d = 520µ, sample HH/221.

Figs 10-11. *Epistomina parastelligera* (Hofker). **10.** Dorsal view, x200, d = 371µ, sample HH/189. **11.** Dorsal view, x150, d = 440µ, sample HH/189.

Plate 23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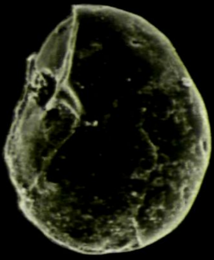
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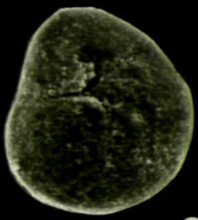
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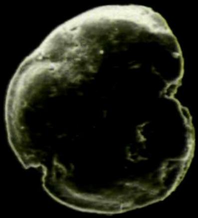
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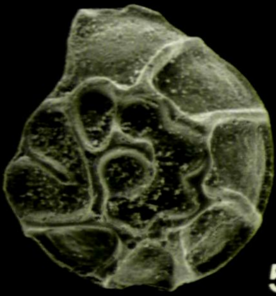
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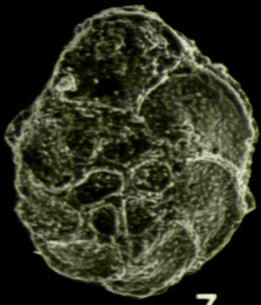
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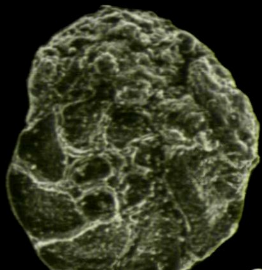
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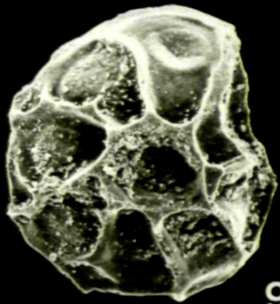
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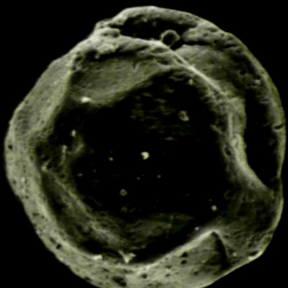
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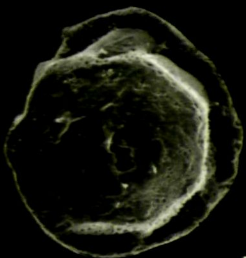
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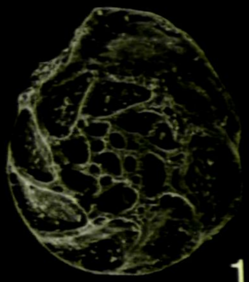
Plate 24.

Figs 1-2. *Epistomina stellicostata* Bielecka and Pozaryski. **1.** Dorsal view, x150, d = 507µ, sample HH/189. **2.** Ventral view, x200, d = 419µ, sample HH/189.

Figs 3-5. *Epistomina tenuicostata* Bartenstein and Brand. **3.** Dorsal view, x 150, d = 640µ, sample HH/181. **4.** Dorsal view, x200, d = 486µ, sample HH/181. **5.** Ventral view, x200, d = 400µ, sample HH/181.

Figs 6-7. *Paalzowella feifeli* (Paalzow). **6.** Ventral view, x350, d = 217µ, sample HH/185. **7.** Side view, x500, h = 73µ, w = 192µ, sample HH/185.

Plate 24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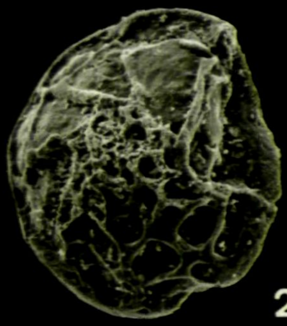
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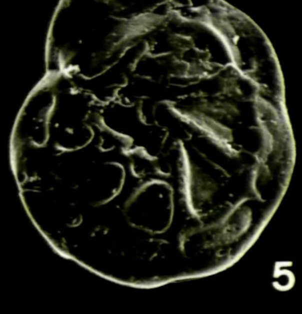
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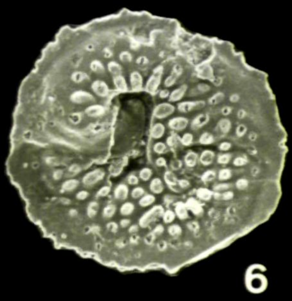
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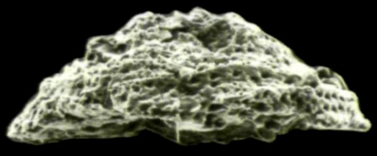
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Plate 25.

A-E. *Rhabdotites dorsetensis* Hodson, Harris and Lawson, *emend.* Hampton. **A.** Elongate form with pustules, x150, sample ES/30447. **B.** x150, sample ES/30447. **C.** Curved, elongate form, x150, sample ES/30477. **D.** Short, squat form, with pustules, x200, sample 30450. **E.** Bifurcated form, x200, ES/3047.

F-G. *Eocaudina*-type plates. **F.** x200, sample ES/30434. **G.** x200, ES/30419.

H. *Achistrum* cf. *issleri* (Croneis), side view showing spear, x100, sample ES/30447.

I-J. *Achistrum monochordata* Hodson, Harris and Lawson. **I.** Eye with broken crossbar, spear missing, x200, sample ES/30419. **J.** Eye with single crossbar, spear missing, x200, sample ES/30454.

K. *Achistrum gamma* Hodson, Harris and Lawson, eye with bifurcated crossbar, spear missing, x150, sample ES/30454.

L. *?Anduncrum* sp. x200, eye with adherent material, sample ES/30447.

M. *Achistrum bichordata* Fletcher, eye with two crossbars and adherent material, x200, sample ES/30447.

N-O. *Priscopedatus* spp. **N.** Top view, x350, sample ES/30450. **O.** top view, x350, sample ES/30450.

P-R. *Theelia convexa* (Whidborne). **P.** Rear view, x500, sample ES/30453. **Q-R.** Sample ES/30450. **Q.** Front view, x350. **R.** Close up of rim, showing dentition, x2000.

S. *Synaptites* sp. x200, sample ES/30450.

T-U. *Frizzellus*-type elements. **T.** x200, sample ES/30434. **U.** x200, sample ES/30447.


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Appendices.

Appendix 1.

Descriptive sedimentary log of the East Stour Borehole [ST 8013 2297] drilled by the BGS in 1988.

Appendix 2.

Abundance data and % abundance data for the Hartmoor Hill, Bowden Farm and Hallett's Farm Boreholes.

Appendix 1.

Descriptive sedimentary log for the BGS East Stour Borehole.

	Thickness (m)	Depth (m)
T. clavellata Beds		
No core to 3.5m, only 0.14m of core recovered between 3.5 and 4.2m (probably from 4.06 to 4.2). Gamma-ray log a clay unit between 3 and 4m	c4.06	4.06
Oolite, fine- to medium-grained, sparry, yellow-buff (orange-stained on joint surfaces); some coarse shell fragments in basal 0.07m	0.14	4.20
Oolite, fine-grained in a micritic matrix, shelly, bluish grey	0.22	4.42
Oolite, fine- to coarse-grained in a clay matrix, medium grey, orange-stained.	0.06	4.48
Oolite, clayey, fine-grained, dark grey, but orange-stained on bedding surfaces; ?ammonite fragment at 4.5m, shell fragments	0.12	4.60
Oolite, shelly, fine-grained, micritic, orange-stained	0.35	4.95
Clay, very oolitic (fine-grained), grey, but irregularly orange-stained	0.05	5.00
Todber Freestone		
Oolite, yellowish brown, fine- to medium-grained, crumbly in places, otherwise moderately cemented	1.60	6.60
Oolite, fine- to medium-grained, grey, a few muddy streaks, wisps and ?clasts, grey, hard	0.15	6.75
Oolite, yellowish-brown, crumbly	0.10	6.85
Oolite, fine- to medium-grained, a few clay streaks and wisps, grey, hard	0.35	7.20

Oolite, yellowish brown, moderate to poorly cemented, scattered shell fragments in basal 0.3m	0.50	7.70
Oolite, pale to medium grey, fine- to medium-grained in a micritic matrix	0.15	7.85
Oolite pale to medium grey, oolitic, dark grey (?chamosite), fine- to medium-grained in a sparry matrix; clay coatings on some bedding surfaces	0.15	8.00
Oolite, medium grey, with scattered dark grey (?chamosite) ooliths, clayey, with dark grey clay wisps and thin beds (up to 5mm thick); 1 fish tooth or scale at 8.1m	0.10	8.10
Oolite, fine- to medium-grained, ooliths set in a sparry matrix	0.05	8.15
Oolite, medium-grained, ooliths dark grey (?chamosite) patchily irregularly weathered to an orange powder, set in a sparry matrix, shelly	0.27	8.42
Oolite, medium-grained, with dark (?chamosite) ooliths set in a micritic matrix; clay wisps and thin beds up to 5mm thick	0.13	8.55
Mudstone, silty with some fine-grained sand, dark grey, passing over 2cm into a clayey fine-grained sand, and then down into a fine-grained sandy clay	0.10	8.65
Mudstone, fine-grained sandy, scattered ooliths, dark grey	0.07	8.72
Oolite, ?chamositic in a micritic matrix, pale to medium grey; scattered shells	0.53	9.25
Newton Clay Mudstone, sandy, very fine-grained, medium grey, laminated with dark grey fine-grained clayey sand; small lignite fragments, calcareous	0.10	9.35

Micrite, very clayey, pale to medium grey, scattered shells in basal 5cm	0.40	9.75
Micrite, shelly, pale to medium grey	0.15	9.90
Oolite, micritic, shelly, medium-grained ?chamosite ooliths; small clay clasts, medium to dark grey	0.45	10.35
Micrite; scattered small shells	0.30	10.65
Micrite, very hard, pale to medium grey, with dark grey wisps and lamination	0.10	10.75
Mudstone, weakly calcareous, a few scattered shell fragments	0.15	10.90
Micritic very fine-grained oolite, hard, a few scattered shells	0.10	11.00
Mudstone, calcareous, pale to medium grey, silty and fine-grained sandy	0.04	11.04
As above, but calcareously cemented, ?clasts or burrows (horizontal) 1cm x 5cm, at 11.1m; clasts up to 3cm across at 11.2m; scattered shells; below 11.2m heavily bioturbated, a few lignite fragments	0.40	11.44
As above, but only weakly cemented	0.12	11.58
As above, but well cemented	0.12	11.70
As above, but less well cemented, streaked with dark lignitic beds; scattered shell fragments	0.22	11.92
Cementstone, pale grey with clasts of medium grey mudstone, scattered shell fragments	0.26	12.18
Mudstone, silty and fine-grained sandy, pale to medium grey, scattered shells; small lignite fragments; bioturbated 12.5 to 12.6m	0.42	12.60
Cementstone	0.14	12.74
Mudstone, fine-grained sandy, medium grey, lignitic, strongly bioturbated with horizontal burrows up to 7mm wide x 2cm long infilled with pale grey		

mudstone; scattered shell fragments, a few scattered dark ooliths; below 12.9m, large (up to 1cm) horizontal burrow-fills of oolitic, shelly ?sandy mudstone in a pale grey mudstone, below 13m, clasts of mudstone in an oolitic shelly matrix; entire shells of small *Ostrea*; below 13.08m, 1cm-diameter inclined burrows lined with dark grey mudstone passing inwards into lighter grey mudstone, cutting oolitic shelly and oolite-free mudstone; below 13.25m, clasts of pale grey mudstone in shelly mudstone	0.66	13.40
Mudstone, medium grey, 4-6mm thick, laminated with fine-grained buff sand (1-2mm thick); sandstone 13.50-13.52m; fine-grained sand 13.56-13.58m, mudstone dominant, but beds of fine-grained sand up to 8mm thick, and burrowfills and wisps up to 5mm thick common; from 13.76 to 13.90m fine-grained sand dominant; below 13.9m, fine-grained ooliths appear and become common to 14m (set in a sandy matrix), in beds up to 3cm thick	0.60	14.00
Mudstone, pale grey, laminated in thin beds with fine-grained buff sand	0.08	14.08
Sandstone, oolitic, fine-grained	0.02	14.10
Sand, fine-grained, laminated with 1 to 4mm thick medium grey mudstone beds	0.18	14.28
Sandstone, fine-grained, oolitic	0.02	14.30
Sand, clayey, laminated with medium grey mudstone; burrowed	0.20	14.50
Sand, very fine-grained, buff	0.10	14.60
Sand, fine-grained, laminated with medium grey clay; sand dominant	0.10	14.70
Clay, sandy, fine-grained with impersistent fine-grained sand lenses up to 4mm thick; irregular pods of sand up to 10mm thick; sand laminae become less common down to 15.5m	0.80	15.50

laminae on bedding planes	0.35	15.85
Mudstone, fine-grained sandy, a few scattered dark ooliths, especially in burrow fills which are up to 1cm across; scattered shells	0.15	16.00
Mudstone, blocky, pale grey with a few sand laminae, and burrowfills of fine-grained sandy mudstone with a few scattered dark ooliths and shell fragments in upper 20cm; crushed echinoid at 16.30m	0.60	16.60
Mudstone, medium grey, fine-grained sandy with thin laminae of fine-grained sand containing scattered dark ooliths	0.20	16.80
Mudstone, pale grey, sand free, a few scattered lignite fragments; darker grey in basal 20cm	0.60	17.40
Mudstone, pale grey, a few sand laminae with scattered dark ooliths and shell fragments; sand laminae and ooliths disappear below 17.9m	0.90	18.30
Mudstone, sand free, medium grey, interburrowed with light grey mudstone; large bivalve 18.65m; becomes slightly sandy at 18.7m; at 18.75m bedding surfaces of fine-grained sand with scattered lignite and small dark ooliths	0.50	18.80
Mudstone, medium grey, fine-grained sandy with scattered dark ooliths; clasts of pale grey mudstone up to 4cm x 1cm; scattered dark pisoliths up to 8mm, shell fragments at 18.95, 1905 and 19.07m, laminae consist of dark ooliths, scattered shell fragments and a little quartz. At 19m, clasts of dark grey mudstone, up to 6mm x 1cm in medium grey mudstone, becomes an interburrowed light and dark grey mudstone downwards; scattered shells	0.35	19.15
Mudstone, very sandy fine-grained, pale grey, scattered shells	0.20	19.35
Mudstone, medium grey, interburrowed with pale grey, fine-grained sandy clay	0.05	19.40

Mudstone, sandy, bivalves at 19.5 and 19.55m	0.20	19.60
Mudstone, medium grey, interburrowed with fine-grained clayey buff sand; burrows up to 8mm across, horizontal (19.65m); passes down into	0.05	19.65
Mudstone, fine-grained sandy, medium, becoming darker grey downwards, scattered small (1mm) lignite fragments; small bivalves at 19.75 and 19.99m; lignite fragment 6cm by 1cm at 19.99m)	0.35	20.00
Mudstone, medium grey interburrowed with fine-grained buff sand; passes down into	0.20	20.20
Mudstone, very sandy, fine-grained, pale grey, some burrowing	0.27	20.47
Mudstone, medium grey, a little fine-grained sand on bedding surfaces	0.06	20.53
Mudstone, medium grey, interburrowed with buff fine-grained sand; shelly layer at 20.7m; passes down into	0.32	20.85
Mudstone, very sandy, fine-grained, pale to medium grey; scattered bivalves, small gastropods; shelly layer at 21.0m; large bivalves at 21.2m; below 21.2m becomes darker grey, shelly, blocky (?clay clasts); ooliths at 21.28m; very oolitic below 21.3m; pisoliths appear at 21.3m and become commoner downwards	0.64	21.49
Sturminster Pisolite Limestone, oolitic, pisolitic, shelly in a micritic matrix; irregular piped top down to 7cm	0.15	21.64
Cucklington Oolite Limestone, oolitic, shelly, micritic matrix, very occasional pisoliths; angular mudstone clasts 3 x 1cm scattered throughout; ooliths fine- to coarse-grained, poorly sorted; passes into a sparry matrix below 21.8m; large (1cm diameter x 12cm long) inclined clay-filled burrows 22 to 22.12m	0.48	22.12

Oolite, fine- to coarse-grained in a micritic matrix, mudstone partings, and clasts up to 2 x 2cm	0.08	22.20
Mudstone, very oolitic	0.10	22.30
Oolite, medium-grained, fairly well sorted in a sparry matrix; mudstone partings and clasts (2.5 x 1cm) and burrows (7mm wide x 6cm long), shelly	0.80	23.10
Mudstone, very oolitic, with clasts of medium grey mudstone 5cm x 1.5cm, shelly	0.14	23.24
Oolite, fine- to medium-grained in a sparry matrix to 23.35m, in a micritic matrix below; shelly partings, and clasts of mudstone; very occasional pisoliths	0.76	24.02
Oolite, medium-grained in a sparry matrix, shelly (including small gastropods), clay partings; becomes micritic below 24.04m	0.18	24.20
Oolite, medium-grained, hard in a sparry matrix	0.10	24.30
Oolite, micritic	0.10	24.40
Oolite, medium-grained in a sparry matrix, mudstone partings and clasts (1 x 2cm)	0.10	24.50
Oolite, micritic, mudstone clasts ?and burrows 6cm x 1cm, shelly	0.10	24.60
Oolite, fine- to medium-grained in a sparry matrix; lignite 1.5cm x 4cm at 24.68m	0.10	24.70
Oolite, fine- to mediuum-grained in a micritic matrix, shelly, mudstone partings, and clasts (1x2cm)	0.11	24.81
Core loss	0.05	24.86
Mudstone, oolitic	0.04	24.90
Oolite, micritic, with partings of oolitic mudstone	0.05	24.95

Oolite, sparry, with partings of oolitic mudstone and micrite, shelly	0.30	25.25
Mudstone, very oolitic, shelly with clasts of mudstone	0.05	25.30
Oolite, sparry	0.10	25.40
Mudstone, oolitic, shelly	0.05	25.45
Oolite, sparry with a few dark (?chamosite) ooliths, shelly	0.05	25.50
Woodrow Clay Mudstone, slightly sandy, scattered dark (?chamosite) ooliths down to 26m (much less common below), extremely shelly (including ammonite at 26.35m); very little sand at 26.1m	1.40	26.90
Mudstone, sandy, medium grey with clasts (7cm x 1cm) of pale grey mudstone; with dark (?chamosite) ooliths	0.44	27.34
Micrite, shelly, clasts of medium grey mudstone, 4cm 1cm; small scattered ooliths	0.46	27.80
Mudstone, very shelly (fragmental), sparsely oolitic with clasts of pale and medium grey mudstone; a little fine-grained sand; becomes more oolitic below 28.1m	0.40	28.20
Hazelbury Bryan Formation Mudstone, very sandy (39.1%) fine-grained, a few scattered shells; horizontal burrowfills up to 1cm diam. by 7cm across infilled with medium- and fine-grained ooliths in a clayey matrix; below 28.3m passes down into a very clayey fine-grained sand	0.50	28.70
?Core loss	0.90	29.60
Mudstone, fine-grained, sandy, weakly calcareous, bioturbated, clasts of medium grey mudstone at 29.8m; burrows up to 1cm diameter x 5cm long together with *Chondrites* type	0.90	30.50

Mudstone, fine-grained, sandy (13%), very common clasts (33.7%) up to 3cm x 8cm of medium grey silty mudstone; weakly calcareously cemented; a few scattered shells; below 31m intensely burrowed, together with common mudstone clasts; *Trigonia* at 31.82m; ?*Gervillia* at 31.84m; large bivalve at 31.94m; shelly concentrate, including *Trigonia* at 32m	1.50	32.00
Sand, fine-grained, buff, intensely burrowed with clasts of medium grey mudstone 6cm x 1cm	0.10	32.10
Sand, very fine-grained, calcareously cemented 32.32-32.62m; common irregular clasts of medium grey mudstone up to 1cm by 3cm at 32.64 and 32.70m; small (up to 1cm) clasts of medium grey mudstone below 33.60m, and thin clay laminae	2.05	34.15
Sandstone, fine-grained, calcareously cemented, strongly burrowed and bioturbated	0.10	34.25
Sand, very fine-grained, buff; scattered wispy partings of mudstone, and mudstone clasts up to 1.5 x 1cm	0.25	34.50
Sandstone, calcareously cemented, intensely burrowed, common clay clasts	0.25	34.75
Sand, very fine-grained, as above	0.20	34.95
Sandstone, as above	0.15	35.10
Sand, as above, weakly cemented, mudstone clasts 6 x 3cm in basal 10 cm; irregular contact with bed below	1.17	36.27
Sand, very fine-grained, clayey, laminated with very fine-grained sand 36.27 to 36.30m; below 36.3m, burrowed and bioturbated; clay laminae at 36.4m; scattered bivalves; clay clasts up to 1cm long; becomes more clayey below 36.55m, large articulated bivalves at 36.8 and		

36.9m; lignite fragments at 36.85m; angular mudstone clasts 2cm x 2cm at 36.93m	0.68	36.95
?Core loss	0.20	37.15
Mudstone, very sandy (27.4%) very fine-grained, bioturbated and burrowed, burrows mostly horizontal, but some vertical, clasts of medium grey mudstone 2cm x 1cm; scattered small lignite fragments	0.33	37.48
Mudstone, sandy very fine-grained, very bioturbated and burrowed, mostly horizontal burrows, but some vertical up to 1cm diameter; much disseminated lignite at base	0.32	37.80
Mudstone, sandy, very fine-grained, highly lignitic, laminated; burrowfills 2 to 3cm in diameter, mostly horizontal; some interburrowing, with fine-grained pale sand infilling burrows in dark grey lignitic sandy clay; large (8-9mm) burrows infilled with lignitic sand; scattered clasts of lignitic sand	0.20	38.00
Mudstone, very sandy (24.4%) very fine-grained, strongly bioturbated and burrowed (small 2 to 3mm), burrows, horizontal filled with pale grey sand stand out in sharp contrast from lignitic clayey sand matrix; clasts of pale and medium grey mudstone, becoming much darker at 38.3m with disseminated lignite; sharp base	0.42	38.42
Mudstone, very fine-grained, sandy (21.78%) medium grey, angular clasts of mudstone up to 3cm across, others elongate 1cm x 7cm; burrows mostly 2 to 3mm diameter, horizontal, filled with pale grey fine-grained sand; finely disseminated lignite; a few scattered shells; gradual change at about 38.8m into	0.38	38.80
Mudstone, sandy, bioturbated; sand-free mudstone interbeds at 39.1m; horizontal burrow fills 1cm x 3cm infilled with shelly oolitic sand;		

shelly sand coatings to some bedding surfaces; clasts of medium grey mudstone up to 3cm x 1.5cm	0.60	39.40
Mudstone, sandy, oolitic, shelly, bioturbated and burrowed; common mudstone clasts 5cm x 3cm. Burrows with infills of pale grey mudstone in medium grey oolitic mudstone	0.47	39.87
Micrite, shelly, oolitic with common mudstone partings; large burrowfill, sub-horizontal, 1 x 4cm at 40.05m; scattered mudstone clasts up to 3cm across; lignite fragment 1cm x 4cm at 40.25m	0.75	40.62
Mudstone, oolitic, sandy, pale grey; scattered shell fragments (including *Pecten)*	0.18	40.80
Sandstone, weakly cemented, very fine-grained, very clayey, burrowed (horizontal up to 1cm diameter), clay clasts up to 1cm across; scattered shell fragments (including common *Pecten)*, becoming very shelly below 41m; scattered lignite fragments below 40.95m, scattered ooliths below 41.1m	0.45	41.25
Micrite, oolitic (in top 10cm), sandy, shelly with common clay clasts up to 2cm across	0.37	41.62
Mudstone, sandy, very shelly (to 41.77m); slickensiding 41.65-42m; common clay clasts, and small (up to 3mm) burrows	0.38	42.00
Sand, medium-grained, to at least 42.5m; fine-grained below 42.8m, shelly, clayey, bioturbated; scattered clay clasts below 42.6m	1.23	43.23
Core loss	0.32	43.55
Sand, fine-grained	0.40	43.95
Sandstone, fine- to medium-grained, calcareously cemented, bioturbated, burrowed (including vertical burrowed bivalve); large bivalve at 44.37m; burrowed into bed beneath	0.44	44.39

Sand, pale grey, fine-grained and clayey, medium grey; scattered shells, a few clay laminae and clasts up to 2cm across; intensely burrowed - mostly horizontal; weakly calcareously cemented	0.41	44.80
Mudstone, fine-grained very sandy, pale grey, intensely burrowed, burrows horizontal up to 1cm diameter - into pale grey silty to fine-grained sandy mudstone; clasts of fine-grained sandy and silty mudstone up to 2.5cm across; articulated bivalve at 45.1m; shell fragments 45.5 to 45.6m; *Trigonia* at 45.83m; weakly calcareously cemented	1.03	45.83
Sand, fine-grained, medium grey, clayey; common clasts of pale grey mudstone; scattered bivalves; at 46m interburrowed medium to dark grey lignitic clayey sand and pale buff fine-grained sand	0.19	46.02
Sandstone, pale grey, fine-grained, hard, piped top	0.02	46.04
Sandstone, clayey, intensely burrowed, clay clasts and partings	0.22	46.26
Mudstone, pale grey with bedding surfaces coated, and burrows filled, with fine- to medium grey quartz sand	0.12	46.38
Sand, medium-grained, clayey with burrows 1cm x 7cm and clasts of pale grey mudstone	0.10	46.48
Sandstone, fine- to medium-grained burrowed, scattered clay clasts; scattered ooliths	0.27	46.75
Sandstone, very clayey, fine- to medium-grained, poorly sorted, calcareously cemented clasts of silty mudstone up to 2cm x 6cm; burrowed and bioturbated; some burrows up to 12mm wide - both inclined and vertical-filled with very fine-grained clayey sand; scattered lignite fragments up to 2cm across; scattered shells below 47.8m	2.05	48.80

Mudstone, very sandy to clayey fine-grained sand, shelly (including *Trigonia*); common mudstone clasts	0.50	49.30
Mudstone, silty with a little fine-grained sand; horizontal burrows 15mm diam. x 7+cm long in top 2cm; at 49.6m horizontal burrows 4mm x 7+cm; below 49.9m some fine-grained sand partings; sand free 51.0 to 51.5m; scattered bivalves from 50.8m; slickensiding at 57.0, 51.35 and 51.6m; fragmentary shell plasters on some bedding surfaces below 51.5m; small gastropods 51.52; 51.65m; ammonite at 51.72m	2.70	52.00
Mudstone, very sandy, fine-grained, shelly, 2-3mm diam horizontal burrows; bioturbated; mudstone clasts up to 3cm x 1cm	0.70	52.70
Mudstone, sandy, fine-grained	0.20	52.90
Core loss	0.50	53.40
Mudstone, fine-grained sandy partings, burrows 5mm diam., others 12mm x 7cm, horizontal (at 53.6m)	0.30	53.70
Mudstone, very fine-grained, sandy; mudstone clasts up to 6cm x 1cm; horizontal burrows up to 5mm diam.	0.31	54.01
Mudstone, sandy, very fine-grained, strongly burrowed with pale grey, silty, very fine-grained sand fills in dark (?lignitic) fine-grained sand (to 54.1m); passes down into pale grey, fine-grained sandy mudstone with medium grey burrow fills; small bivalves; ammonite at 54.55m, mudstone clasts up 3cm x 2cm	0.64	54.65
Mudstone pale grey, fine-grained sand partings; scattered bivalves	0.35	55.00
Mudstone, medium grey with 1-2mm diam. burrows infilled with pale grey mudstone; scattered bivalves;		

some bedding surfaces coated with fine-grained sand; burrow fills 15mm diam. below 55.2m	0.95	55.95
Sandstone, very fine-grained, lignitic, finely laminated	0.05	56.00
Mudstone, very sandy (15%) very fine-grained, shelly; common clay clasts	0.66	56.66
Mudstone dark grey with small (1-2m) diam. burrows filled with medium grey, fine-grained sandy clay; at 56.76m clasts (up to 2cm) of medium grey mudstone in pale grey sandy mudstone, passing over 1cm into dark grey sandy mudstone with burrows 8mm x 7cm infilled with pale grey sandy mudstone; at 56.85m, pale grey sandy mudstone with burrows and clasts of medium grey mudstone; scattered shells; ammonites at 56.94; 57.04 and 57.1m; shelly concentrate at 57.15m; scattered lignite	0.49	57.15
Mudstone, pale grey with dark coated listric surfaces	0.10	57.25
Mudstone, silty with some fine-grained sand; scattered nacreous shell fragments 57.30 to 57.37m; interbedded dark grey and medium grey silty mudstone	0.30	57.55
Mudstone, very fine-grained, sandy (22.4%) clasts of pale grey mudstone up to 2cm x 4cm; scattered shell fragments; ammonite 57.6m	0.10	57.65

Appendix 2.

Abundance data for the Hartmoor Hill, Bowden Farm and Hallet's Farm Boreholes.

Sample	Ammobaculites agglutinans	Ammobaculites agglutinans form B	Ammobaculites barrowensis	Ammobaculites canui	Ammobaculites coprolithiformis	Ammobaculites deceptorius	Ammobaculites fisheri	Ammobaculites fontinensis	Ammobaculites godmani	Ammobaculites irregulariformis	Ammobaculites sp. cf. A. sp. B&B	Ammobaculites vetusta	Ammovertella liassica	Bigenerina clavellata	Citharina flabelloides	Citharina heteropleura	Citharina lepida	Citharina serratocostata	Citharina tenuicostata	Citharinella exarata	Cornuspira sp. 2	Cornuspira sp. A sensu Lloyd	Dentalina bicornis	Dentalina guembeli	Dentalina sp. (Barnard)	Dentalina torta	Dentalina varians	Dentalina vetusta	Eggerella meentzeni	Eoguttulina anglica	Eoguttulina liassica	Eoguttulina oolithica	Eoguttulina oolithica form A	Epistomina mosquensis	Epistomina mosquensis form A	Epistomina parastelligera	Epistomina spp. indet.	Epistomina stellicostata	Epistomina tenuicostata	Falsopalmula cf. deslongchampsi	Frondicularia franconica	Frondicularia lignaria	Gaudryina sherlocki	Glomospira irregularis	Haplophragmoides haeusleri	Haplophragmoides kingakensis	Haplophragmoides latidorsatum	Haplophragmoides sp. 1
169	37			0	80	7		1	19								2	1		1				2							4		1	0		94			131		8				1			
171	10			69	61	9		3	21								1	1			2						1		2		5	17		0							5							
173				256	468			1	52									1	4		1			1		1		1			2	1	1	0					15		5		1					
175	6			0	0			1	61															1				1			3	3	4	0				1	20		8							
177	2			2	522			1	1							2		1						3							2	1	1	0		17		36	579		3	1						
179	2		1	0	437				16						2			2						1								3		0		78		119	377		2							
181	54		1	1	255																			2										0		466		60	253		1							
183	8			13	536				9								1										1						1	0		374		209	48		2							
185	1		1	0	608												2							4				1			3	5	1	0		71		385			2							
187			1	1	482				16																5		1						3	0		265		368										
189	1		11	4	321				47																				1		1			0		340		230	6									
191	8			1	8	1			35			1																				2		0		321			272		1							12
193			2	0	0				2									6						8			2					2	2	0					494		3							4
195	13		2	0	241	12												1	7	3	1			3				2				2	5	0					62		14							14
197	17		2	0	346	31			26						1			5	1					6				3			1		5	0		8			83		14							2
199	26	4	10	0	541	15		1	3						2		2		11	8				3				1			1	1	3	0					196		13							
201	5		11	4	601	48		1	4	4		1			4				9	14				5			2	4			4	3	2	0			1		224		5							
203	2			0	89	2			4										6				1	3				1			1		3	0					500		8							
205	1			0	15				10																									0		538			40									1
207	3			0	115	3			11																						2	1		0		209	1		259		3							1
209	73		21	0	180	50		1	27					2			1	3			2			1			5		2	1	2	5		0	1		4		195								1	1
211	133	31	11	0	158	61			11	10		5		3										1			1				2			7		2		2	53									
213	127	1	6	0	48	49		10	14	6	1		1							5				1							2	1		4	1	6		4	4	1	1						19	
215	118	2	8	0	338	42			35	4										3							6				3	2		222		17			6		5							4
217	43		4	0	234			1	21						1			2		2														146	2	89		1			2							6
219	11			0	3	3		1	29									4			3								2		1			430	6	268					1							
221	45		4	0	45		1		58					4				5													4	4		341	6	56					1							12
223	20		2	0	15			4	29	2								1											2		2	13		61		213					1							1
225	12			0	154			1	15									5			1	1							2		9	1		164	1	133							4	1		3		2

Hartmoor Hill Abundance Data

Sample	Haplophragmoides sp. 2	Haplophragmoides tryssa	Haplophragmoides/Trochammina sp. indet.	Lagena globosa	Lagena sp. 1	Lagena sp. 3	Lagenammina difflugiformis	Lenticulina brevispira	Lenticulina ectypa	Lenticulina major	Lenticulina muensteri	Lenticulina polonica glabra	Lenticulina polygona	Lenticulina protracta	Lenticulina quenstedti	Lenticulina sp. (juvenile)	Lenticulina sp. 1	Lenticulina subalata	Lenticulina varians	Lingulina cernua	Lingulina laevissima	Lingulina nodosaria	Lingulina pupiformis	Lingulina spp. indet.	Marginulina batrakiensis	Massalina dorsetensis	Nodosaria corallina	Nodosaria metensis	Nodosaria opalini	Nodosaria simplex	Ophthalmidium compressum	Ophthalmidium strumosum	Paalzowella feifeli	Placopsilina sp.	Planularia angustissima	Planularia bieriana	Planularia suturalis	Pseudonodosaria radiata	Pseudonodosaria vulgata	Quinquiloculina horelli	Ramulina spandeli	Reinholdella sp. 1	Reophax helvetica	Reophax multilocularis	Reophax spp. indet.	Reophax sterkii	Reophax variabilis	Spirillina andrea	Spirillina infima
169	1						1	1			273			11							1											1											2			4			3
171	7						42				145			1	3					8									1				1							13			2						8
173											204				5					1		2					1		1	1							1			107									18
175	107						1				194			2						1		1					1																		4				
177	4										104		1	3								1						1	1						3	1				16					2				
179				1	1					1	126			5	33												1	1	2							2				48									4
181											16				4					1								1																	1				
183					1					3	56				27													1																					
185	1						1		4		35			1	11					1								1					3			4				58									2
187										2	33			1	8					5									2											17									
189	1										66				11																														4				
191							4			4	41			4	1																				1														1
193								1		4	244			9	10												5	2					1							6						17			
195										16	572			12	6					1		3					5		5							3				3						1			7
197	24		3			1	1		3	14	473			1	5					3							7									1					1			1		3			
199	23			2	2		1		2	30	255			11	2				3	3																1				1						3			
201	3								3	17	180			6	3					2				1	1		2			1					2								4			4			
203	2								27	7	200			5					2																	1													
205				1				2			32																		1	1																			
207	14			2			1			4	258			3											1				1																				
209	40		2				5	9	4	11	45				3					1	1	1							1										2				9			17			3
211	68	1		1			2	15	1	4	52	2		3	4		1				1		1						1													1	20	6					
213	115		5	2			4	19	1	9	17					2				5														3			1						25			14			
215	121		3				3	33		34	83			9		7		1	6	18									3								2						6	2		9			
217	86		3	3				1		42	72			5		3			8						1						13							4					10						
219	35		5				1	61		10	39					3													1		1																	1	4
221	10		6	1			1	33		11	53			7		17			13						1	1			1		1												5			3			2
223	52		4							38	126		1	17	1	4		2	19					1	1				2		1				2								5	1					10
225	20		27	2			4		1	21	69			10		12			12						3						2												16	1	1	2	3		2

Hartmoor Hill Abundance Data

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Sample	225	223	221	219	217	215	213	211	209	207	205	203	201	199	197	195	193	191	189	187	185	183	181	179	177	175	173	171	169
Spirillina tenuissima													1			3				1							11	15	
Spiroloculina variabilis																1													
Spiroplectammina biformis		1	1					1	1							1					2								
Spiroplectammina sp. 1								1																					
Spiroplectammina suprajurassica			1																										
Subbdelloidina sp.			3			3	9																						
Textularia jurassica			1						19			1			5	2										19		3	
Textularia sp. 1			1																										
Textularia sp. 2																													1
Triplasia sp. 1	0	0	0	0	0	0	0	156	82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tristix triangularis				1		1			1				2	2	1							1						1	
Trochammina canningensis															1					1								6	
Trochammina globigeriniformis	7		1		9								1	1									5		5	13	8	370	49
Trochammina inflata		1	2		1	1		3	1		1																		
Trochammina kosyrevae	1	1	1			2																							
Trochammina minutissima			1		1																								
Trochammina omskensis	1																												
Trochammina quinquilocularis																1													
Trochammina rosaceaformis					1																								
Trochammina sp. 1					3																								
Trochammina sp. 2	30	17	12	11	12	6	23	40	10				1					1											
Trochammina squamata	37	71	58	4	32	74	127	267	96	1		2	12	12	41	12	12	5		2	1			1		1	13	9	28
Trochammina toboryensis												3																	
Trocholina nodulosa													1			1												3	
Vaginulina anomala									1				1	1	1	1							1					1	
Vaginulina barnardi																												1	
Vaginulina contracta	2	2		1								1	3															3	
Vaginulina jurassica		1				3																							
Verneuilinoides sp. 1	20	3	1	2				1	12		1				1														
Verneuilinoides tryphera	53	37	32	54	10	5	11	5	28	2				4	1		1			1									

Sample	Ammobaculites agglutinans	Ammobaculites agglutinans form B	Ammobaculites barrowensis	Ammobaculites canui	Ammobaculites coprolithiformis	Ammobaculites deceptorius	Ammobaculites fisheri	Ammobaculites fontinensis	Ammobaculites godmani	Ammobaculites irregulariformis	Ammobaculites sp. cf. A. sp. B&B	Ammobaculites vetusta	Ammovertella liassica	Bigenerina clavellata	Citharina flabelloides	Citharina heteropleura	Citharina lepida	Citharina serratocostata	Citharina tenuicostata	Citharinella exarata	Cornuspira sp. 2	Cornuspira sp. A sensu Lloyd	Dentalina bicornis	Dentalina guembeli	Dentalina sp. (Barnard)	Dentalina torta	Dentalina varians	Dentalina vetusta	Eggerella meentzeni	Eoguttulina anglica	Eoguttulina liassica	Eoguttulina oolithica	Eoguttulina oolithica form A	Epistomina mosquensis
169	4.84	0	0	0	10.5	0.92	0	0.13	2.48	0	0	0	0	0	0	0	0.26	0.13	0	0.13	0	0	0	0.26	0	0	0	0	0	0	0.52	0	0.13	0
171	1.18	0	0	8.12	7.18	1.06	0	0.35	2.47	0	0	0	0	0	0	0	0.12	0.12	0	0	0.24	0	0	0	0	0	0.12	0	0.24	0	0.59	2	0	0
173	0	0	0	21.6	39.5	0	0	0.08	4.39	0	0	0	0	0	0	0	0	0.08	0.34	0	0.08	0	0	0.08	0	0.08	0	0.08	0	0	0.17	0.08	0.08	0
175	1.32	0	0	0	0	0	0	0.22	13.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.22	0	0	0	0.22	0	0	0.66	0.66	0.88	0
177	0.15	0	0	0.15	39.7	0	0	0.08	0.08	0	0	0	0	0	0	0.15	0	0.08	0	0	0	0	0	0.23	0	0	0	0	0	0	0.15	0.08	0.08	0
179	0.16	0	0.08	0	34.5	0	0	0	1.26	0	0	0	0	0	0.16	0	0	0.16	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0.24	0	0
181	4.81	0	0.09	0.09	22.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18	0	0	0	0	0	0	0	0	0	0
183	0.62	0	0	1.01	41.5	0	0	0	0.7	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0.08	0
185	0.08	0	0.08	0	50.3	0	0	0	0	0	0	0	0	0	0	0	0.17	0	0	0	0	0	0	0.33	0	0	0	0.08	0	0	0.25	0.41	0.08	0
187	0	0	0.08	0.08	39.7	0	0	0	1.32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.41	0	0.08	0	0	0	0	0	0.25	0
189	0.1	0	1.05	0.38	30.7	0	0	0	4.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0.1	0	0	0
191	1.1	0	0	0.14	1.1	0.14	0	0	4.83	0	0	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.28	0	0
193	0	0	0.24	0	0	0	0	0	0.24	0	0	0	0	0	0	0	0	0.72	0	0	0	0	0	0.96	0	0	0.24	0	0	0	0	0.24	0.24	0
195	1.25	0	0.19	0	23.2	1.16	0	0	0	0	0	0	0	0	0	0	0	0.1	0.67	0.29	0.1	0	0	0.29	0	0	0	0.19	0	0	0	0.19	0.48	0
197	1.49	0	0.17	0	30.3	2.71	0	0	2.27	0	0	0	0	0	0.09	0	0	0.44	0.09	0	0	0	0	0.52	0	0	0	0.26	0	0	0.09	0	0.44	0
199	2.17	0.33	0.83	0	45.1	1.25	0	0.08	0.25	0	0	0	0	0	0.17	0	0.17	0	0.92	0.67	0	0	0	0.25	0	0	0	0.08	0	0	0.08	0.08	0.25	0
201	0.41	0	0.91	0.33	49.8	3.98	0	0.08	0.33	0.33	0	0.08	0	0	0.33	0	0	0	0.75	1.16	0	0	0	0.41	0	0	0.17	0.33	0	0	0.33	0.25	0.17	0
203	0.23	0	0	0	10.2	0.23	0	0	0.46	0	0	0	0	0	0	0	0	0	0.69	0	0	0	0.11	0.34	0	0	0	0.11	0	0	0.11	0	0.34	0
205	0.16	0	0	0	2.33	0	0	0	1.55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
207	0.34	0	0	0	12.8	0.34	0	0	1.23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.22	0.11	0	0
209	7.43	0	2.14	0	18.3	5.09	0	0.1	2.75	0	0	0	0	0.2	0	0	0.1	0.31	0	0	0.2	0	0	0.1	0	0	0.51	0	0.2	0.1	0.2	0.51	0	0
211	11.6	2.7	0.96	0	13.8	5.31	0	0	0.96	0.87	0	0.44	0	0.26	0	0	0	0	0	0	0	0	0	0.09	0	0	0.09	0	0	0	0.17	0	0	0.61
213	18	0.14	0.85	0	6.82	6.96	0	1.42	1.99	0.85	0.14	0	0.14	0	0	0	0	0	0	0.71	0	0	0	0.14	0	0	0	0	0	0	0.28	0.14	0	0.57
215	9.44	0.16	0.64	0	27	3.36	0	0	2.8	0.32	0	0	0	0	0	0	0	0	0	0.24	0	0	0	0	0	0	0.48	0	0	0	0.24	0.16	0	17.8
217	4.92	0	0.46	0	26.8	0	0	0.11	2.4	0	0	0	0	0	0.11	0	0	0.23	0	0.23	0	0	0	0	0	0	0	0	0	0	0	0	0	16.7
219	1.1	0	0	0	0.3	0.3	0	0.1	2.91	0	0	0	0	0	0	0	0	0.4	0	0	0.3	0	0	0	0	0	0	0	0.2	0	0.1	0	0	43.2
221	5.19	0	0.46	0	5.19	0	0.12	0	6.69	0	0	0	0	0.46	0	0	0	0.58	0	0	0	0	0	0	0	0	0	0	0	0	0.46	0.46	0	39.3
223	2.54	0	0.25	0	1.91	0	0	0.51	3.68	0.25	0	0	0	0	0	0	0	0.13	0	0	0	0	0	0	0	0	0	0	0.25	0	0.25	1.65	0	7.75
225	1.38	0	0	0	17.7	0	0	0.12	1.73	0	0	0	0	0	0	0	0	0.58	0	0	0.12	0.12	0	0	0	0	0	0	0.23	0	1.04	0.12	0	18.9

Hartmoor Hill % Abundance Data

Sample	Epistomina mosquensis form A	Epistomina parastelligera	Epistomina spp. indet.	Epistomina stellicostata	Epistomina tenuicostata	Falsopalmula cf. deslongchampsi	Frondicularia franconica	Frondicularia lignaria	Gaudryina sherlocki	Glomospira irregularis	Haplophragmoides haeusleri	Haplophragmoides kingakensis	Haplophragmoides latidorsatum	Haplophragmoides sp. 1	Haplophragmoides sp. 2	Haplophragmoides tryssa	Haplophragmoides/Trochammina sp. indet.	Lagena globosa	Lagena sp. 1	Lagena sp. 3	Lagenammina difflugiformis	Lenticulina brevispira	Lenticulina ectypa	Lenticulina major	Lenticulina muensteri	Lenticulina polonica glabra	Lenticulina polygona	Lenticulina protracta	Lenticulina quenstedti	Lenticulina sp. (juvenile)	Lenticulina sp. 1	Lenticulina subalata	Lenticulina varians	Lingulina cernua
169	0	12.3	0	0	17.1	0	1.05	0	0	0	0.13	0	0	0	0.13	0	0	0	0	0	0.13	0.13	0	0	35.7	0	0	1.44	0	0	0	0	0	0
171	0	0	0	0	0	0	0.59	0	0	0	0	0	0	0	0.82	0	0	0	0	0	4.94	0	0	0	17.1	0	0	0.12	0.35	0	0	0	0	0.94
173	0	0	0	0	1.27	0	0.42	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17.2	0	0	0	0.42	0	0	0	0	0.08
175	0	0	0	0.22	4.42	0	1.77	0	0	0	0	0	0	0	23.6	0	0	0	0	0	0.22	0	0	0	42.8	0	0	0.44	0	0	0	0	0	0.22
177	0	1.29	0	2.74	44	0	0.23	0.08	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	7.9	0	0.08	0.23	0	0	0	0	0	0
179	0	6.16	0	9.4	29.8	0	0.16	0	0	0	0	0	0	0	0	0	0	0.08	0.08	0	0	0	0	0.08	9.95	0	0	0.39	2.61	0	0	0	0	0
181	0	41.5	0	5.35	22.5	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.43	0	0	0	0.36	0	0	0	0	0.09
183	0	29	0	16.2	3.72	0	0.15	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0.23	4.34	0	0	0	2.09	0	0	0	0	0
185	0	5.87	0	31.8	0	0	0.17	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0.08	0	0.33	0	2.89	0	0	0.08	0.91	0	0	0	0	0.08
187	0	21.8	0	30.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	2.72	0	0	0.08	0.66	0	0	0	0	0.41
189	0	32.6	0	22	0.57	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	6.32	0	0	0	1.05	0	0	0	0	0
191	0	44.3	0	0	37.6	0	0.14	0	0	0	0	0	0	1.66	0	0	0	0	0	0	0.55	0	0	0.55	5.66	0	0	0.55	0.14	0	0	0	0	0
193	0	0	0	0	59	0	0.36	0	0	0	0	0	0	0.48	0	0	0	0	0	0	0	0.12	0	0.48	29.2	0	0	1.08	1.19	0	0	0	0	0
195	0	0	0	0	5.97	0	1.35	0	0	0	0	0	0	1.35	0	0	0	0	0	0	0	0	0	1.54	55.1	0	0	1.16	0.58	0	0	0	0	0.1
197	0	0.7	0	0	7.26	0	1.22	0	0	0	0	0	0	0.17	2.1	0	0.26	0	0	0.09	0.09	0	0.26	1.22	41.4	0	0	0.09	0.44	0	0	0	0	0.26
199	0	0	0	0	16.3	0	1.08	0	0	0	0	0	0	0	1.92	0	0	0.17	0.17	0	0.08	0	0.17	2.5	21.3	0	0	0.92	0.17	0	0	0	0.25	0.25
201	0	0	0.08	0	18.6	0	0.41	0	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0.25	1.41	14.9	0	0	0.5	0.25	0	0	0	0	0.17
203	0	0	0	0	57.4	0	0.92	0	0	0	0	0	0	0	0.23	0	0	0	0	0	0	0	3.1	0.8	23	0	0	0.57	0	0	0	0	0.23	0
205	0	83.5	0	0	6.21	0	0	0	0	0	0	0	0	0.16	0	0	0	0.16	0	0	0	0.31	0	0	4.97	0	0	0	0	0	0	0	0	0
207	0	23.4	0.11	0	28.9	0	0.34	0	0	0	0	0	0	0.11	1.56	0	0	0.22	0	0	0.11	0	0	0.45	28.8	0	0	0.34	0	0	0	0	0	0
209	0.1	0	0.41	0	19.8	0	0	0	0	0	0	0	0.1	0.1	4.07	0	0.2	0	0	0	0.51	0.92	0.41	1.12	4.58	0	0	0	0.31	0	0	0	0	0.1
211	0	0.17	0	0.17	4.61	0	0	0	0	0	0	0	0	0	5.92	0.09	0	0.09	0	0	0.17	1.31	0.09	0.35	4.53	0.17	0	0.26	0.35	0	0.09	0	0	0
213	0.14	0.85	0	0.57	0.57	0.14	0.14	0	0	0	0	0	2.7	0	16.3	0	0.71	0.28	0	0	0.57	2.7	0.14	1.28	2.41	0	0	0	0	0.28	0	0	0	0.71
215	0	1.36	0	0	0.48	0	0.4	0	0	0	0	0	0	0.32	9.68	0	0.24	0	0	0	0.24	2.64	0	2.72	6.64	0	0	0.72	0	0.56	0	0.08	0.48	1.44
217	0.23	10.2	0	0.11	0	0	0.23	0	0	0	0	0	0	0.69	9.84	0	0.34	0.34	0	0	0	0.11	0	4.81	8.24	0	0	0.57	0	0.34	0	0	0.92	0
219	0.6	26.9	0	0	0	0	0.1	0	0	0	0	0	0	0	3.51	0	0.5	0	0	0	0.1	6.12	0	1	3.92	0	0	0	0	0.3	0	0	0	0
221	0.69	6.46	0	0	0	0	0.12	0	0	0	0	0	0	1.38	1.15	0	0.69	0.12	0	0	0.12	3.81	0	1.27	6.11	0	0	0.81	0	1.96	0	0	1.5	0
223	0	27.1	0	0	0	0	0.13	0	0	0	0	0	0	0.13	6.61	0	0.51	0	0	0	0	0	0	4.83	16	0	0.13	2.16	0.13	0.51	0	0.25	2.41	0
225	0.12	15.3	0	0	0	0	0	0	0.46	0.12	0	0.35	0	0.23	2.3	0	3.11	0.23	0	0	0.46	0	0.12	2.42	7.95	0	0	1.15	0	1.38	0	0	1.38	0

Hartmoor Hill % Abundance Data

Sample	Lingulina laevissima	Lingulina nodosaria	Lingulina pupiformis	Lingulina spp. indet.	Marginulina batrakiensis	Massalina dorsetensis	Nodosaria corallina	Nodosaria metensis	Nodosaria opalini	Nodosaria simplex	Ophthalmidium compressum	Ophthalmidium strumosum	Paalzowella feifeli	Placopsilina sp.	Planularia angustissima	Planularia bieriana	Planularia suturalis	Pseudonodosaria radiata	Pseudonodosaria vulgata	Quinquiloculina horelli	Ramulina spandeli	Reinholdella sp. 1	Reophax helvetica	Reophax multilocularis	Reophax spp. indet.	Reophax sterkii	Reophax variabilis	Spirillina andrea	Spirillina infima	Spirillina tenuissima	Spiroloculina variabilis	Spiroplectammina biformis	Spiroplectammina sp. 1	Spiroplectammina suprajurassica
169	0.13	0	0	0	0	0	0	0	0	0	0	0.13	0	0	0	0	0	0	0	0	0	0	0.26	0	0	0.52	0	0	0.39	0	0	0	0	0
171	0	0	0	0	0	0	0	0	0.12	0	0	0	0.12	0	0	0	0	0	0	1.53	0	0	0.24	0	0	0	0	0	0.94	1.76	0	0	0	0
173	0	0.17	0	0	0	0	0.08	0	0.08	0.08	0	0	0	0	0	0	0.08	0	0	9.04	0	0	0	0	0	0	0	0	1.52	0.93	0	0	0	0
175	0	0.22	0	0	0	0	0.22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.88	0	0	0	0	0	0	0	0	0
177	0	0.08	0	0	0	0	0	0.08	0.08	0	0	0	0	0	0.23	0.08	0	0	0	1.22	0	0	0	0	0.15	0	0	0	0	0	0	0	0	0
179	0	0	0	0	0	0	0.08	0.08	0.16	0	0	0	0	0	0	0.16	0	0	0	3.79	0	0	0	0	0	0	0	0	0.32	0	0	0	0	0
181	0	0	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0
183	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0	0.08	0	0	0	0	0.25	0	0	0.33	0	0	0	4.8	0	0	0	0	0	0	0	0	0.17	0	0	0.17	0	0
187	0	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0	0	0	0	1.4	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0
189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.38	0	0	0	0	0	0	0	0	0
191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0	0	0	0	0
193	0	0	0	0	0	0	0.6	0.24	0	0	0	0	0.12	0	0	0	0	0	0	0.72	0	0	0	0	0	2.03	0	0	0	0	0	0	0	0
195	0	0.29	0	0	0	0	0.48	0	0.48	0	0	0	0	0	0	0.29	0	0	0	0.29	0	0	0	0	0	0.1	0	0	0.67	0.29	0.1	0.1	0	0
197	0	0	0	0	0	0	0.61	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0.09	0	0	0.09	0	0.26	0	0	0	0	0	0	0	0
199	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0.08	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0
201	0	0	0	0.08	0.08	0	0.17	0	0	0.08	0	0	0	0	0.17	0	0	0	0	0	0	0	0.33	0	0	0.33	0	0	0	0.08	0	0	0	0
203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0.16	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0.11	0	0	0	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
209	0.1	0.1	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0.2	0	0	0	0.92	0	0	1.73	0	0	0.31	0	0	0.1	0	0
211	0.09	0	0.09	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0.09	1.74	0.52	0	0	0	0	0	0	0	0.09	0.09	0
213	0	0	0	0	0	0	0	0	0	0	0	0	0	0.43	0	0	0.14	0	0	0	0	0	3.55	0	0	1.99	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0	0.24	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0.48	0.16	0	0.72	0	0	0	0	0	0	0	0
217	0	0	0	0	0.11	0	0	0	0	0	1.49	0	0	0	0	0	0	0.46	0	0	0	0	1.14	0	0	0	0	0	0	0	0	0	0	0
219	0	0	0	0	0	0	0	0	0.1	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.4	0	0	0	0	0
221	0	0	0	0	0.12	0.12	0	0	0.12	0	0.12	0	0	0	0	0	0	0	0	0	0	0	0.58	0	0	0.35	0	0	0.23	0	0	0.12	0	0.12
223	0	0	0	0.13	0.13	0	0	0	0.25	0	0.13	0	0	0	0.25	0	0	0	0	0	0	0	0.64	0.13	0	0	0	0	1.27	0	0	0.13	0	0
225	0	0	0	0	0.35	0	0	0	0	0	0.23	0	0	0	0	0	0	0	0	0	0	0	1.84	0.12	0.12	0.23	0.35	0	0.23	0	0	0	0	0

Hartmoor Hill % Abundance Data

Sample	Subbdelloidina sp.	Textularia jurassica	Textularia sp. 1	Textularia sp. 2	Triplasia sp. 1	Tristix triangularis	Trochammina canningensis	Trochammina globigeriniformis	Trochammina inflata	Trochammina kosyrevae	Trochammina minutissima	Trochammina omskensis	Trochammina quinquilocularis	Trochammina rosaceaformis	Trochammina sp. 1	Trochammina sp. 2	Trochammina squamata	Trochammina toboryensis	Trocholina nodulosa	Vaginulina anomala	Vaginulina barnardi	Vaginulina contracta	Vaginulina jurassica	Verneuilinoides sp. 1	Verneuilinoides tryphera
169	0	0	0	0.13	0	0	0	6.41	0	0	0	0	0	0	0	0	3.66	0	0	0	0	0	0	0	0
171	0	0.35	0	0	0	0.12	0.71	43.5	0	0	0	0	0	0	0	0	1.06	0	0.35	0.12	0.12	0.35	0	0	0
173	0	0	0	0	0	0	0	0.68	0	0	0	0	0	0	0	0	1.1	0	0	0	0	0	0	0	0
175	0	4.19	0	0	0	0	0	2.87	0	0	0	0	0	0	0	0	0.22	0	0	0	0	0	0	0	0
177	0	0	0	0	0	0	0	0.38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
179	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0
181	0	0	0	0	0	0	0	0.45	0	0	0	0	0	0	0	0	0	0	0	0.09	0	0	0	0	0
183	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0
187	0	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0	0.08
189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	0.69	0	0	0	0	0	0	0	0
193	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.43	0	0	0	0	0	0	0	0.12
195	0	0.19	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	1.16	0	0.1	0.1	0	0	0	0	0
197	0	0.44	0	0	0	0.09	0.09	0	0	0	0	0	0	0	0	0	3.59	0	0	0.09	0	0	0	0.09	0.09
199	0	0	0	0	0	0.17	0	0.08	0	0	0	0	0	0	0	0	1	0	0	0.08	0	0	0	0	0.33
201	0	0	0	0	0	0.17	0	0.08	0	0	0	0	0	0	0	0.08	0.99	0	0.08	0.08	0	0.25	0	0	0
203	0	0.11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.23	0.34	0	0	0	0.11	0	0	0
205	0	0	0	0	0	0	0	0	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0
207	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11	0	0	0	0	0	0	0	0.22
209	0	1.93	0	0	8.34	0.1	0	0	0.1	0	0	0	0	0	0	1.02	9.77	0	0	0.1	0	0	0	1.22	2.85
211	0	0	0	0	13.6	0	0	0	0.26	0	0	0	0	0	0	3.48	23.2	0	0	0	0	0	0	0.09	0.44
213	1.28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.27	18	0	0	0	0	0	0	0	1.56
215	0.24	0	0	0	0	0.08	0	0	0.08	0.16	0	0	0	0	0	0.48	5.92	0	0	0	0	0	0.24	0	0.4
217	0	0	0	0	0	0	0	1.03	0.11	0	0.11	0	0	0.11	0.34	1.37	3.66	0	0	0	0	0	0	0	1.14
219	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0	1.1	0.4	0	0	0	0	0.1	0	0.2	5.42
221	0.35	0.12	0.12	0	0	0	0	0.12	0.23	0.12	0.12	0	0	0	0	1.38	6.69	0	0	0	0	0	0	0.12	3.69
223	0	0	0	0	0	0	0	0	0.13	0.13	0	0	0	0	0	2.16	9.02	0	0	0	0	0.25	0.13	0.38	4.7
225	0	0	0	0	0	0	0	0.81	0	0.12	0	0.12	0	0	0	3.46	4.26	0	0	0	0	0.23	0	2.3	6.11

Hartmoor Hill % Abundance Data

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Bowden Farm Borehole Abundance Data

Sample	144	140	136	132	128	124	120	116	112	108	104	96	92	88	84	80	76	72
Ammobaculites agglutinans	11	7	8		15	1	3	16	3	67	14	3	10	15		10	1	
Ammobaculites agglutinans form B										4								
Ammobaculites barrowensis					1			4		10	1	3	4					
Ammobaculites canui	1	6	4	8	2	1	146	6	145	26	1		9					
Ammobaculites coprolithiformis	323	622	501	562	466	428	134	21	153	34	67	6	372	383	131	60	73	0
Ammobaculites deceptorius					1			2	1	1								
Ammobaculites fontinensis								5										
Ammobaculites godmani	9	1	19	8	63	2	8	64	4	41	24	15	16	75	1	3		6
Ammobaculites sp. cf. A. sp. B&B											1							
Bigenerina clavellata											5							
Citharina heteropleura						3	8	2		1								
Citharina lepida							2	1		4		1				4	5	
Citharina serratocostata							3			2		1	4	1		4		
Citharina tenuicostata							4	1		4			3	2			3	
Citharinella exarata										2			7					
Ammobaculites irregulariformis									1									
Ammobaculites vetusta													1					
Cornuspira sp. 2									2									
Dentalina guembeli	2	1		1			1	2		1	3		8	1				
Dentalina sp. (Barnard)											1							
Dentalina varians													1					
Eggerella meentzeni	1										1							
Eoguttulina liassica	1	1		1			1	1	1			1		1				
Eoguttulina oolithica	1			1	1		3	1	1			2		2				
Epistomina mosquensis	14		1															
Epistomina mosquensis form A	1																	
Eoguttulina oolithica form A							1								1			
Epistomina parastelligera	613	145	287	152	199	163	142		439	71	325	166						140
Epistomina spp. indet.																2		
Epistomina stellicostata	3	288	385	429	119	270	184	165										
Epistomina tenuicostata	92	103			124	166	152	224		142	244	300	10					222
Frondicularia franconica	1		2		1		1	3	3	4		2	5		1		1	
Gaudryina sherlocki											1							
Haplophragmoides sp. 1	3									3	5			1				
Haplophragmoides sp. 2	13	2	1		32			35	5	14	7			4	2	6	2	6
Haplophragmoides tryssa							1			1			1					
Lagena globosa														3		1		
Lagena sp. 1								1										
Lagenammina difflugiformis								5		3	15	1		71	23	2		
Lenticulina ectypa		1				2		2		1		2	6					
Lenticulina major						1						4						

Sample	Lenticulina muensteri	Lenticulina protracta	Lenticulina quenstedti	Lenticulina varians	Lingulina cernua	Nodosaria corallina	Nodosaria metensis	Nodosaria opalini	Ophthalmidium compressum	Ophthalmidium strumosum	Planularia listi	Reinholdella lutzei	Lenticulina subalata	Planularia eugenii	Reophax helvetica	Reophax sterkii	Reophax variabilis	Paalzowella feifeli	Quinquiloculina horelli	Spirillina infima	Spirillina tenuissima	Textularia dumortieri	Textularia jurassica	Textularia sp. 1	Textularia sp. 2	Tristix triangularis	Trochammina canningensis	Trochammina globigeriniformis	Trochammina omskensis	Trochammina inflata	Trochammina quinquilocularis	Trochammina sp. 2	Trochammina squamata	Trocholina nodulosa	Vaginulina anomala	Vaginulina barnardi	Vaginulina jurassica	Verneuilinoides sp. 1
72	85																				17																	
76	178	1								1											7												2					
80	159	1											9		2								7										10			1		
84	45	2																		1	4		6			2			2									
88	178				1			2												8	6		56			1							58					
92	458	3						5		195										1			1			1		1				1	7			5		
96	96	11										5				6	1			1					1		1	11					2					
104	3	7			1			2		3	1				1	10			70	11	1		18			1	3	15		1			14	1	1			2
108	256	6	2		1	1	1								1				14							1		2					28	1				
112	143	4			6	1	1	2	2	4				1					2	1	1	1	1							4							2	
116	128	10	4		4			2								1			1		1		10			1							35				1	
120	131	23	3	2	2				2										4	1	2					2							1					
124	86	1	17										2					1	28							1												
128	10	1	9		3			1											2					1						1	1		12					
132	1	1	2										1						39		1												4					
136	6	2	4																2														1					
140	12		5																35																			
144	77	2	2																																			

Bowden Farm Borehole Abundance Data

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Sample	Ammobaculites agglutinans	Ammobaculites agglutinans form B	Ammobaculites barrowensis	Ammobaculites canui	Ammobaculites coprolithiformis	Ammobaculites deceptorius	Ammobaculites fontinensis	Ammobaculites godmani	Ammobaculites sp. cf. A. sp. B&B	Bigenerina clavellata	Citharina heteropleura	Citharina lepida	Citharina serratocostata	Citharina tenuicostata	Citharinella exarata	Ammobaculites irregulariformis	Ammobaculites vetusta	Cornuspira sp. 2	Dentalina guembeli	Dentalina sp. (Barnard)	Dentalina varians	Eggerella meentzeni	Eoguttulina liassica	Eoguttulina oolithica	Epistomina mosquensis	Epistomina mosquensis form A	Eoguttulina oolithica form A
72	0	0	0	0	0	0	0	1.261	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0.365	0	0	0	26.64	0	0	0	0	0	0	1.825	0	1.095	0	0	0	0	0	0	0	0	0	0	0	0	0
80	3.559	0	0	0	21.35	0	0	1.068	0	0	0	1.423	1.423	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	59.28	0	0	0.452	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.452
88	1.726	0	0	0	44.07	0	0	8.631	0	0	0	0	0.115	0.23	0	0	0	0	0.115	0	0	0	0.115	0.23	0	0	0
92	0.881	0	0.352	0.793	32.78	0	0	1.41	0	0	0	0	0.352	0.264	0.617	0	0.088	0	0.705	0	0.088	0	0	0	0	0	0
96	0.467	0	0.467	0	0.935	0	0	2.336	0	0	0	0.156	0.156	0	0	0	0	0	0	0	0	0	0.156	0.312	0	0	0
104	1.589	0	0.114	0.114	7.605	0	0	2.724	0.114	0.568	0	0	0	0	0	0	0	0	0.341	0.114	0	0.114	0	0	0	0	0
108	8.933	0.533	1.333	3.467	4.533	0.133	0	5.467	0	0	0.133	0.533	0.267	0.533	0.267	0	0	0	0.133	0	0	0	0	0	0	0	0
112	0.321	0	0	15.52	16.38	0.107	0	0.428	0	0	0	0	0	0	0	0.107	0	0.214	0	0	0	0	0.107	0.107	0	0	0
116	2.108	0	0.527	0.791	2.767	0.264	0.659	8.432	0	0	0.264	0.132	0	0.132	0	0	0	0	0.264	0	0	0	0.132	0.132	0	0	0
120	0.31	0	0	15.1	13.86	0	0	0.827	0	0	0.827	0.207	0.31	0.414	0	0	0	0	0.103	0	0	0	0.103	0.31	0	0	0.103
124	0.085	0	0	0.085	36.49	0	0	0.171	0	0	0.256	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
128	1.408	0	0.094	0.188	43.76	0.094	0	5.915	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.094	0	0	0
132	0	0	0	0.661	46.41	0	0	0.661	0	0	0	0	0	0	0	0	0	0	0.083	0	0	0	0.083	0.083	0	0	0
136	0.654	0	0	0.327	40.96	0	0	1.554	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.082	0	0
140	0.57	0	0	0.488	50.61	0	0	0.081	0	0	0	0	0	0	0	0	0	0	0.081	0	0	0	0.081	0	0	0	0
144	0.94	0	0	0.085	27.61	0	0	0.769	0	0	0	0	0	0	0	0	0	0	0.171	0	0	0.085	0.085	0.085	1.197	0.085	0

Bowden Farm Borehole % Abundance Data

Sample	Epistomina parastelligera	Epistomina spp. indet.	Epistomina stellicostata	Epistomina tenuicostata	Frondicularia franconica	Gaudryina sheriocki	Haplophragmoides sp. 1	Haplophragmoides sp. 2	Haplophragmoides tryssa	Lagena globosa	Lagena sp. 1	Lagenammina difflugiformis	Lenticulina ectypa	Lenticulina major	Lenticulina muensteri	Lenticulina protracta	Lenticulina quenstedti	Lenticulina varians	Lingulina cernua	Nodosaria corallina	Nodosaria metensis	Nodosaria opalini	Ophthalmidium compressum	Ophthalmidium strumosum	Planularia listi	Reinholdella lutzei	Lenticulina subalata
72	29.41	0	0	46.64	0	0	0	1.261	0	0	0	0	0	0	17.86	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0.365	0	0	0.73	0	0	0	0	0	0	64.96	0.365	0	0	0	0	0	0	0	0.365	0	0	0
80	0	0.712	0	0	0	0	0	2.135	0	0.356	0	0.712	0	0	56.58	0.356	0	0	0	0	0	0	0	0	0	0	3.203
84	0	0	0	0	0.452	0	0	0.905	0	0	0	10.41	0	0	20.36	0.905	0	0	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0.115	0.46	0	0.345	0	8.17	0	0	20.48	0	0	0	0.115	0	0	0.23	0	0	0	0	0
92	0	0	0	0.881	0.441	0	0	0	0.088	0	0	0	0.529	0	40.35	0.264	0	0	0	0	0	0.441	0	17.18	0	0	0
96	25.86	0	0	46.73	0.312	0	0	0	0	0	0	0.156	0.312	0.623	14.95	1.713	0	0	0	0	0	0	0	0	0	0.779	0
104	36.89	0	0	27.7	0	0.114	0.568	0.795	0	0	0	1.703	0	0	0.341	0.795	0	0	0.114	0	0	0.227	0	0.341	0.114	0	0
108	9.467	0	0	18.93	0.533	0	0.4	1.867	0.133	0	0	0.4	0.133	0	34.13	0.8	0.267	0	0.133	0.133	0.133	0	0	0	0	0	0
112	47	0	0	0	0.321	0	0	0.535	0	0	0	0	0	0	15.31	0.428	0	0	0.642	0.107	0.107	0.214	0.214	0.428	0	0	0
116	0	0	21.74	29.51	0.395	0	0	4.611	0	0	0.132	0.659	0.264	0	16.86	1.318	0.527	0	0.527	0	0	0.264	0	0	0	0	0
120	14.68	0	19.03	15.72	0.103	0	0	0	0.103	0	0	0	0	0	13.55	2.378	0.31	0.207	0.207	0	0	0	0.207	0	0	0	0
124	13.9	0	23.02	14.15	0	0	0	0	0	0	0	0	0.171	0.085	7.332	0.085	1.449	0	0	0	0	0	0	0	0	0	0.171
128	18.69	0	11.17	11.64	0.094	0	0	3.005	0	0	0	0	0	0	0.939	0.094	0.845	0	0.282	0	0	0.094	0	0	0	0	0
132	12.55	0	35.43	0	0	0	0	0	0	0	0	0	0	0	0.083	0.083	0.165	0	0	0	0	0	0	0	0	0	0.083
136	23.47	0	31.48	0	0.164	0	0	0.082	0	0	0	0	0	0	0.491	0.164	0.327	0	0	0	0	0	0	0	0	0	0
140	11.8	0	23.43	8.381	0	0	0	0.163	0	0	0	0	0.081	0	0.976	0	0.407	0	0	0	0	0	0	0	0	0	0
144	52.39	0	0.256	7.863	0.085	0	0.256	1.111	0	0	0	0	0	0	6.581	0.171	0.171	0	0	0	0	0	0	0	0	0	0

Bowden Farm Borehole % Abundance Data

Sample	Planularia eugenii	Reophax helvetica	Reophax sterkii	Reophax variabilis	Paalzowella feifeli	Quinquiloculina horelli	Spirillina infima	Spirillina tenuissima	Textularia dumortieri	Textularia jurassica	Textularia sp. 1	Textularia sp. 2	Tristix triangularis	Trochammina canningensis	Trochammina globigeriniformis	Trochammina omskensis	Trochammina inflata	Trochammina quinquilocularis	Trochammina sp. 2	Trochammina squamata	Trocholina nodulosa	Vaginulina anomala	Vaginulina barnardi	Vaginulina jurassica	Verneuilinoides sp. 1
72	0	0	0	0	0	0	0	3.571	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
76	0	0	0	0	0	0	0	2.555	0	0	0	0	0	0	0	0	0	0	0	0.73	0	0	0	0	0
80	0	0.712	0	0	0	0	0	0	0	2.491	0	0	0	0	0	0	0	0	0	3.559	0	0	0.356	0	0
84	0	0	0	0	0	0	0.452	1.81	0	2.715	0	0	0.905	0	0	0.905	0	0	0	0	0	0	0	0	0
88	0	0	0	0	0	0	0.921	0.69	0	6.444	0	0	0.115	0	0	0	0	0	0	6.674	0	0	0	0	0
92	0	0	0	0	0	0	0.088	0	0	0.088	0	0	0.088	0	0.088	0	0	0	0.088	0.617	0	0	0.441	0	0
96	0	0	0.935	0.156	0	0	0.156	0	0	0	0	0.156	0	0.156	1.713	0	0	0	0	0.312	0	0	0	0	0
104	0	0.114	1.135	0	0	7.946	1.249	0.114	0	2.043	0	0	0.114	0.341	1.703	0	0.114	0	0	1.589	0.114	0.114	0	0	0.227
108	0	0.133	0	0	0	1.867	0	0	0	0	0	0	0.133	0	0.267	0	0	0	0	3.733	0.133	0	0	0	0
112	0.107	0	0	0	0	0.214	0.107	0.107	0.107	0.107	0	0	0	0	0	0	0.428	0	0	0	0	0	0	0.214	0
116	0	0	0.132	0	0	0.132	0	0.132	0	1.318	0	0	0.132	0	0	0	0	0	0	4.611	0	0	0	0.132	0
120	0	0	0	0	0	0.414	0.103	0.207	0	0	0	0	0.207	0	0	0	0	0	0	0.103	0	0	0	0	0
124	0	0	0	0	0.085	2.387	0	0	0	0	0	0	0.085	0	0	0	0	0	0	0	0	0	0	0	0
128	0	0	0	0	0	0.188	0	0	0	0	0.094	0	0	0	0	0	0.094	0.094	0	1.127	0	0	0	0	0
132	0	0	0	0	0	3.22	0	0.083	0	0	0	0	0	0	0	0	0	0	0	0.33	0	0	0	0	0
136	0	0	0	0	0	0.164	0	0	0	0	0	0	0	0	0	0	0	0	0	0.082	0	0	0	0	0
140	0	0	0	0	0	2.848	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bowden Farm Borehole % Abundance Data

Sample	Ammobaculites agglutinans	Ammobaculites barrowensis	Ammobaculites canui	Ammobaculites coprolithiformis	Ammobaculites deceptorius	Ammobaculites fontinensis	Ammobaculites godmani	Bigenerina clavellata	Citharina flabelloides	Citharina heteropleura	Citharina lepida	Citharina serratocostata	Citharina tenuicostata	Citharinella exarata	Cornuspira sp. 2	Dentalina bicornis	Dentalina debilis	Dentalina guembeli	Dentalina torta	Dentalina varians	Dentalina vetusta	Eggerella meentzeni	Eoguttulina inovroclaviensis	Eoguttulina liassica	Eoguttulina oolithica	Eoguttulina oolithica form A	Epistomina parastelligera	Epistomina spp. indet.	Epistomina stellicostata	Epistomina tenuicostata	Falsopalmula cf. primordialis	Frondicularia franconica	Haplophragmoides excavatus	Haplophragmoides latidorsatum	Haplophragmoides sp. 1	Haplophragmoides sp. 3	Haplophragmoides tryssa	Haplophragmoides/Trochammina sp. indet.
30416			5	1						1		1																										
30418			49	100								17						2						5														
30420	1		16	131								21						2		1				9		1												
30422			0	0								0																										
30424	17		0	4	1		186					0												1						2						1		
30426			0	619								22				1				2				2	4			3				2			4			
30428	2		0	335								5	1					1										3			1							
30430			0	80			21			1		12		1	2										2	2	3	19		4		2						9
30432	17		0	158			9			2		0	2	1	1						1					3		80										
30434			1	118		4	7		2			5		19	2												157	1		3	7							
30436	12		2	332		6	64					1						2	3				1	5			276			18		1			6			
30438			0	169			51	1				0												1	1		440			1					20		2	
30440	11	2	0	538			81		3	8		0	1		2										2		1			1		1			2		2	111
30442	2		1	298					1			5	11	2							2					2		40				1	1					
30444	2		334	161			3	1	3		1	0	7					1			6					1			1			4		13				
30446	25	17	24	154	3	1	4					0										7															2	
30448	31		68	91	1		138			1	3	0	1	1	1			1				3		1			4			10		3			5			
30450	1		187	516							3	0	3		1	1		2						1			1			2		9			10			
30452	1	4	8	72			11		2	2	6	1	1				1	5	1		1			1	1					112		15						
30454	156		15	57	7	1	68		1	4	2	0	3		4											4						13			1			

East Stour Borehole Abundance Data

Sample	Lagena globosa	Lagena sp. 3	Lagenammina difflugiformis	Lenticulina ectypa	Lenticulina major	*Lenticulina muensteri*	Lenticulina polygona	Lenticulina protracta	Lenticulina quenstedti	Lenticulina sp. (juvenile)	Lenticulina subalata	Lenticulina tricarinella	Lingulina cernua	Lingulina nodosaria	Marginulina undulata	Nodosaria baleata	Nodosaria corallina	Nodosaria opalini	Ophthalmidium strumosum	Paalzowella feifeli	Planularia bieriana	Planularia eugenii	Planularia suturalis	Quinquiloculina horelli	Ramulina spandeli	Reophax helvetica	Reophax spp. indet.	Reophax sterkii	Spirillina infima	*Spirillina tenuissima*	Spiroplectammina biformis	Textularia jurassica	Tristix triangularis	*Trochammina canningensis*	Trochammina globigeriniformis	Trochammina omskensis	Trochammina sp. 2	*Trochammina squamata*
30416						38		2																					48	446								
30418						270		3					4						1								1		108	312								
30420						294		7			2																		62	356								
30422						0																																
30424			1			3												1									13			31		15			34			2
30426						167		2												1				2					36	222		7			3			
30428						278		4																					43	196								
30430						520							3			1								1						255		2						3
30432						399		18	3										8				1							33								
30434						526		5	2															2					7	19		1			10			40
30436						359		1					3		1			3	18											3	2	5			15			2
30438						145				1			1					1											2				1		12			
30440				2		137							1														1	3	4	11		1			3			58
30442						434		6				5							335										8	2			1					
30444				1		91		4									1		1			2	1							37		1			1			
30446			33			26																							1					3	370			5
30448			9			303		3	8									2					2	11					1						64		12	35
30450	1			2		196		6					1	1			1		1					88	2	3			13	4			1		3			11
30452		1			4	530	1	42	4								3					7				1							5	1	13			5
30454	3		2			245		28					2						1		3	5		2		1		1	1		1	4	3	11	79	1		30

East Stour Borehole Abundance Data

East Stour Borehole Abundance Data

Sample	30416	30418	30420	30422	30424	30426	30428	30430	30432	30434	30436	30438	30440	30442	30444	30446	30448	30450	30452	30454
Trocholina nodulosa	77	88	48					6	2			2			19					
Trocholina sp.											15								12	
Vaginulina anomala	2	3				1		1	3						5					
Vaginulina barnardi	5	10	10			12		6	28	3	3			1	11		1			
Vaginulina contracta						2														
Vaginulina jurassica		1						1												
Verneuilinoides sp. 1																				1
Verneuilinoides tryphera					1								17							

Sample	Ammobaculites agglutinans	Ammobaculites barrowensis	Ammobaculites canui	Ammobaculites coprolithiformis	Ammobaculites deceptorius	Ammobaculites fontinensis	Ammobaculites godmani	Bigenerina clavellata	Citharina flabelloides	Citharina heteropleura	Citharina lepida	Citharina serratocostata	Citharina tenuicostata	Citharinella exarata	Cornuspira sp. 2	Dentalina bicornis	Dentalina debilis	Dentalina guembeli	Dentalina torta	Dentalina varians	Dentalina vetusta	Eggerella meentzeni	Eoguttulina inovroclaviensis	Eoguttulina liassica	Eoguttuiina oolithica	Eoguttulina oolithica form A
30416	0	0	0.799	0.16	0	0	0	0	0	0.16	0	0.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30418	0	0	5.031	10.27	0	0	0	0	0	0	0	1.745	0	0	0	0	0	0.205	0	0	0	0	0	0.513	0	0
30420	0.104	0	1.665	13.63	0	0	0	0	0	0	0	2.185	0	0	0	0	0	0.208	0	0.104	0	0	0	0.937	0	0.104
30422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30424	5.431	0	0	1.278	0.319	0	59.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.319	0	0
30426	0	0	0	55.57	0	0	0	0	0	0	0	1.975	0	0	0	0.09	0	0	0	0.18	0	0	0	0.18	0.359	0
30428	0.23	0	0	38.55	0	0	0	0	0	0	0	0.575	0.115	0	0	0	0	0.115	0	0	0	0	0	0	0	0
30430	0	0	0	8.359	0	0	2.194	0	0	0.104	0	1.254	0	0.104	0.209	0	0	0	0	0	0	0	0	0	0.209	0.209
30432	2.211	0	0	20.55	0	0	1.17	0	0	0.26	0	0	0.26	0.13	0.13	0	0	0	0	0	0.13	0	0	0	0	0.39
30434	0	0	0.106	12.54	0	0.425	0.744	0	0.213	0	0	0.531	0	2.019	0.213	0	0	0	0	0	0	0	0	0	0	0
30436	1.035	0	0.173	28.65	0	0.518	5.522	0	0	0	0	0.086	0	0	0	0	0	0.173	0.259	0	0	0	0.086	0.431	0	0
30438	0	0	0	19.86	0	0	5.993	0.118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.118	0.118	0
30440	1.096	0.199	0	53.59	0	0	8.068	0	0.299	0.797	0	0	0.1	0	0.199	0	0	0	0	0	0	0	0	0	0.199	0
30442	0.173	0	0.086	25.73	0	0	0	0	0.086	0	0	0.432	0.95	0.173	0	0	0	0	0	0	0.173	0	0	0	0	0.173
30444	0.281	0	46.84	22.58	0	0	0.421	0.14	0.421	0	0.14	0	0.982	0	0	0	0	0.14	0	0	0.842	0	0	0	0	0.14
30446	3.704	2.519	3.556	22.81	0.444	0.148	0.593	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.037	0	0	0	0
30448	3.808	0	8.354	11.18	0.123	0	16.95	0	0	0.123	0.369	0	0.123	0.123	0.123	0	0	0.123	0	0	0	0.369	0	0.123	0	0
30450	0.093	0	17.46	48.18	0	0	0	0	0	0	0.28	0	0.28	0	0.093	0.093	0	0.187	0	0	0	0	0	0.093	0	0
30452	0.114	0.458	0.915	8.238	0	0	1.259	0	0.229	0.229	0.686	0.114	0.114	0	0	0	0.114	0.572	0.114	0	0.114	0	0	0.114	0.114	0
30454	20.53	0	1.974	7.5	0.921	0.132	8.947	0	0.132	0.526	0.263	0	0.395	0	0.526	0	0	0	0	0	0	0	0	0	0	0.526

East Stour Borehole % Abundance Data

Sample	Epistomina parastelligera	Epistomina spp. indet.	Epistomina stellicostata	Epistomina tenuicostata	Falsopalmula cf. primordialis	Frondicularia franconica	Haplophragmoides excavatus	Haplophragmoides latidorsatum	Haplophragmoides sp. 1	Haplophragmoides sp. 3	Haplophragmoides tryssa	Haplophragmoides/Trochammina sp. indet.	Lagena globosa	Lagena sp. 3	Lagenammina difflugiformis	Lenticulina ectypa	Lenticulina major	Lenticulina muensteri	Lenticulina polygona	Lenticulina protracta	Lenticulina quenstedti	Lenticulina sp. (juvenile)	Lenticulina subalata	Lenticulina tricarinella	Lingulina cernua	Lingulina nodosaria
30416	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.07	0	0.319	0	0	0	0	0	0
30418	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27.72	0	0.308	0	0	0	0	0.411	0
30420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.59	0	0.728	0	0	0.208	0	0	0
30422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30424	0	0	0	0.639	0	0	0	0	0	0.319	0	0	0	0	0.319	0	0	0.958	0	0	0	0	0	0	0	0
30426	0	0.269	0	0	0	0.18	0	0	0.359	0	0	0	0	0	0	0	0	14.99	0	0.18	0	0	0	0	0	0
30428	0	0.345	0	0	0.115	0	0	0	0	0	0	0	0	0	0	0	0	31.99	0	0.46	0	0	0	0	0	0
30430	0.313	1.985	0	0.418	0	0.209	0	0	0	0	0	0.94	0	0	0	0	0	54.34	0	0	0	0	0	0	0.313	0
30432	0	10.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51.89	0	2.341	0.39	0	0	0	0	0
30434	16.68	0.106	0	0.319	0.744	0	0	0	0	0	0	0	0	0	0	0	0	55.9	0	0.531	0.213	0	0	0	0	0
30436	23.81	0	0	1.553	0	0.086	0	0	0.518	0	0	0	0	0	0	0	0	30.97	0	0.086	0	0	0	0	0.259	0
30438	51.7	0	0	0.118	0	0	0	0	2.35	0	0.235	0	0	0	0	0	0	17.04	0	0	0	0.118	0	0	0.118	0
30440	0.1	0	0	0.1	0	0.1	0	0	0.199	0	0.199	11.06	0	0	0	0.199	0	13.65	0	0	0	0	0	0	0.1	0
30442	0	3.454	0	0	0	0.086	0.086	0	0	0	0	0	0	0	0	0	0	37.48	0	0.518	0	0	0	0.432	0	0
30444	0	0	0.14	0	0	0.561	0	1.823	0	0	0	0	0	0	0	0.14	0	12.76	0	0.561	0	0	0	0	0	0
30446	0	0	0	0	0	0	0	0	0	0	0.296	0	0	0	4.889	0	0	3.852	0	0	0	0	0	0	0	0
30448	0.491	0	0	1.229	0	0.369	0	0	0.614	0	0	0	0	0	1.106	0	0	37.22	0	0.369	0.983	0	0	0	0	0
30450	0.093	0	0	0.187	0	0.84	0	0	0.934	0	0	0	0.093	0	0	0.187	0	18.3	0	0.56	0	0	0	0	0.093	0.093
30452	0	0	0	12.81	0	1.716	0	0	0	0	0	0	0	0.114	0	0	0.458	60.64	0.114	4.805	0.458	0	0	0	0	0
30454	0	0	0	0	0	1.711	0	0	0.132	0	0	0	0.395	0	0.263	0	0	32.24	0	3.684	0	0	0	0	0.263	0

East Stour Borehole % Abundance Data

Sample	Marginulina undulata	Nodosaria baleata	Nodosaria corallina	Nodosaria opalini	Ophthalmidium strumosum	Paalzowella feifeli	Planularia bieriana	Planularia eugenii	Planularia suturalis	Quinquiloculina horelli	Ramulina spandeli	Reophax helvetica	Reophax spp. indet.	Reophax sterkii	Spirillina infima	Spirillina tenuissima	Spiroplectammina biformis	Textularia jurassica	Tristix triangularis	Trochammina canningensis	Trochammina globigeriniformis	Trochammina omskensis	Trochammina sp. 2	Trochammina squamata	Trocholina nodulosa	Trocholina sp.
30416	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.668	71.25	0	0	0	0	0	0	0	0	12.3	0
30418	0	0	0	0	0.103	0	0	0	0	0	0	0	0.103	0	11.09	32.03	0	0	0	0	0	0	0	0	9.035	0
30420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.452	37.04	0	0	0	0	0	0	0	0	4.995	0
30422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30424	0	0	0	0.319	0	0	0	0	0	0	0	0	4.153	0	0	9.904	0	4.792	0	0	10.86	0	0	0.639	0	0
30426	0	0	0	0	0	0.09	0	0	0	0.18	0	0	0	0	3.232	19.93	0	0.628	0	0	0.269	0	0	0	0	0
30428	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.948	22.55	0	0	0	0	0	0	0	0	0	0
30430	0	0.104	0	0	0	0	0	0	0	0.104	0	0	0	0	0	26.65	0	0.209	0	0	0	0	0	0.313	0.627	0
30432	0	0	0	0	1.04	0	0	0	0.13	0	0	0	0	0	0	4.291	0	0	0	0	0	0	0	0	0.26	0
30434	0	0	0	0	0	0	0	0	0	0.213	0	0	0	0	0.744	2.019	0	0.106	0	0	1.063	0	0	4.251	0	0
30436	0.086	0	0	0.259	1.553	0	0	0	0	0	0	0	0	0	0	0.259	0.173	0.431	0	0	1.294	0	0	0.173	0	1.294
30438	0	0	0	0.118	0	0	0	0	0	0	0	0	0	0	0.235	0	0	0	0.118	0	1.41	0	0	0	0.235	0
30440	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.299	0.398	1.096	0	0.1	0	0	0.299	0	0	5.777	0	0
30442	0	0	0	0	28.93	0	0	0	0	0	0	0	0	0	0.691	0.173	0	0	0.086	0	0	0	0	0	0	0
30444	0	0	0.14	0	0.14	0	0	0.281	0.14	0	0	0	0	0	0	5.189	0	0.14	0	0	0.14	0	0	0	2.665	0
30446	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.148	0	0	0	0	0.444	54.81	0	0	0.741	0	0
30448	0	0	0	0.246	0	0	0	0	0.246	1.351	0	0	0	0	0.123	0	0	0	0	0	7.862	0	1.474	4.3	0	0
30450	0	0	0.093	0	0.093	0	0	0	0	8.217	0.187	0.28	0	0	1.214	0.373	0	0	0.093	0	0.28	0	0	1.027	0	0
30452	0	0	0.343	0	0	0	0	0.801	0	0	0	0.114	0	0	0	0	0	0	0.572	0.114	1.487	0	0	0.572	0	1.373
30454	0	0	0	0	0.132	0	0.395	0.658	0	0.263	0	0.132	0	0.132	0.132	0	0.132	0.526	0.395	1.447	10.39	0.132	0	3.947	0	0

East Stour Borehole % Abundance Data

Sample	Vaginulina anomala	Vaginulina barnardi	Vaginulina contracta	Vaginulina jurassica	Verneuilinoides sp. 1	Verneuilinoides tryphera
30416	0.319	0.799	0	0	0	0
30418	0.308	1.027	0	0.103	0	0
30420	0	1.041	0	0	0	0
30422	0	0	0	0	0	0
30424	0	0	0	0	0	0.319
30426	0.09	1.077	0.18	0	0	0
30428	0	0	0	0	0	0
30430	0.104	0.627	0	0.104	0	0
30432	0.39	3.641	0	0	0	0
30434	0	0.319	0	0	0	0
30436	0	0.259	0	0	0	0
30438	0	0	0	0	0	0
30440	0	0	0	0	0	1.693
30442	0	0.086	0	0	0	0
30444	0.701	1.543	0	0	0	0
30446	0	0	0	0	0	0
30448	0	0.123	0	0	0	0
30450	0	0	0	0	0	0
30452	0	0	0	0	0	0
30454	0	0	0	0	0.132	0

East Stour Borehole % Abundance Data

Sample	Ammobaculites agglutinans	Ammobaculites barrowensis	Ammobaculites canui	Ammobaculites coprolithiformis	Ammobaculites deceptorius	Ammobaculites fontinensis	Ammobaculites godmani	Ammobaculites irregulariformis	Ammobaculites vetusta	Bigenerina clavellata	Citharina flabelloides	Citharina heteropleura	Citharina lepida	Citharina serratocostata	Citharina tenuicostata	Citharinella exarata	Cornuspira sp. 2	Dentalina aff. communis	Dentalina guembeli	Dentalina marsupifera	Dentalina torta	Dentalina varians	Dentalina vetusta	Eoguttulina inovroclaviensis	Eoguttulina liassica	Eoguttulina oolithica	Eoguttulina oolithica form A	Epistomina parastelligera	Epistomina stellicostata	Epistomina tenuicostata	Frondicularia franconica	Frondicularia lignaria	Glomospira irregularis	Haplophragmoides excavatus	Haplophragmoides haeusleri	Haplophragmoides kingakensis	Haplophragmoides latidorsatum	Haplophragmoides sp. 1
10	5			1	15		4							0			5								3						1							29
12	105	12		0	6	4								0			3											23								4		1
14	45	1		0	16							1		0		2	37											1								2		32
16	3			0			1							0					4				1					239					1					3
18	67	1		0	53		1							0					1									23								30		36
20	11			0	2		13							0																							2	
22	12			2	6		6							1			1		1						1			469		22						2		5
24	3			0	2	3					2	1		15			1		1						5			389	6	4						2		63
26	1	2		0	4		2		1					0					3						3			396										25
28	39			0	55					1	4			1	3		3		2	5					7			293							1	1		108
30	32			0	4									4					5	1					4	5		343			1			1	64	3		46
32	185	1		0	2						1			3			4		2		7					3		96								44		62
34	87			0	2		1				9			4			6		10							2		173						1		16		116
36	62	30		1	1	1	2	4		4	2			8			1		1				2		1	3		56								2	43	25
38	8			0			2				1			5												2		333										1
40				1	8		2				2	4		8					1				1								2							
41	6			0	2	3	5				3	5		2	12				7	1		1	1															
44			10	6	1	8	8	1		11				14		5					1		3				3									4		
46	1		133	124								1		37									1		3		2					1				14		
48			19	274						1				52					1		1				1		2				1							2
50	4			0	1	12	14							5					10					1	15		2				4							
52	10		20	541		7	64						1	16	6			1	2				4		2	3	1				1							
54	2			188		1								0			1		2		1	1				1	1				3					1		
56	5			217			7		1					1			12								2		6				2					2		2
58	41			453		1	18							6			2		1							1	4											

Hallett's Farm Borehole Abundance Data

Sample	Haplophragmoides tryssa	Haplophragmoides/Trochammina sp. indet.	Lagena globosa	Lagena sp. 1	Lagenammina difflugiformis	Lenticulina muensteri	Lenticulina protracta	Lenticulina quenstedti	Lenticulina subalata	Lenticulina tricarinella	Lingulina cernua	Lingulina laevissima	Lingulina nodosaria	Marginulina batrakiensis	Nodosaria cf. rudis	Nodosaria corallina	Nodosaria metensis	Nodosaria opalini	Ophthalmidium compressum	Ophthalmidium strumosum	Textularia dumortieri	Paalzowella sp.	Planularia angustissima	Planularia bieriana	Planularia eugenii	Planularia listi	Planularia suturalis	Quinquiloculina horelli	Quinquiloculina sp.	Ramulina spandeli	Reinholdella lutzei	Reophax helvetica	Reophax spp. indet.	Reophax sterkii	Reophax variabilis	Spirillina infima	Spirillina tenuissima	Spiroloculina variabilis
10		62			70	0																										2	4					
12		45			68	0																							2			21		7				
14					29	234			2																	4							1					
16					2	255			1						2																							
18		200			16	109			34																					1			3						
20	2					0																																
22	2	38			2	158			9																	2				1		4						
24					8	180		2	6		3															5					70					1		
26					3	27		2			5															3					65	1						
28		4	4	1	23	62	10				10															4						11						1
30		3			27	20	5				1														1	2						11						
32	2				14	20					5																1					34			1			
34					51	42		1			1							1												8		18		52	11			
36					210	11	2				1												1			2				1		9		95				
38					1	104	1		7															39										1				
40		13			3	67	2										1																	1				
41					2	64	4		10					2										2										1				
44	1		1		5	492		1		5						2		1			2	1		28												9	12	
46						223	7				1									2		1					1									104	231	
48						214	4				3																	8						1		25	158	
50						178	22				8																10									25	248	
52	2	2			5	263	20													1								3	1							11	251	
54			8		6	260	8				6	3	1					1										4	1				1			22	210	
56		25			3	106	2				2								1														2			23	222	
58		46			10	491													1									1								15	72	

Hallett's Farm Borehole Abundance Data

Sample	Textularia jurassica	Textularia pugiunculus	Tristix triangularis	Trochammina canningensis	Trochammina globigeriniformis	Trochammina inflata	Trochammina omskensis	Trochammina rosaceaformis	Trochammina squamata	Trocholina nodulosa	Vaginulina anomala	Vaginulina barnardi	Vaginulina contracta	Vaginulina jurassica	Vaginulina sp. 1	Verneuilinoides tryphera
10					69				7							
12					11				20							
14		2			16				4							
16																
18		13			30				37							
20		2			12				569							
22		10													1	
24		36			24										8	
26		14			28				1							
28		1		12	12		1								2	
30		53														
32		57							102							
34		28							25							
36		183			14				20							
38					21	4			4							
40	4								18					4		
41	1				3											
44	4								14	2		27				
46	2									49		9	2			
48	11		1							3		60				
50	2				4	1			12	10	1	6		1		
52	3		2					2		14	2	22	1			2
54					3				11				1			
56					2				106				1			
58	30								34	5						

Hallett's Farm Borehole Abundance Data

Sample	Ammobaculites agglutinans	Ammobaculites barrowensis	Ammobaculites canui	Ammobaculites coprolithiformis	Ammobaculites deceptorius	Ammobaculites fontinensis	Ammobaculites godmani	Ammobaculites irregulariformis	Ammobaculites vetusta	Bigenerina clavellata	Citharina flabelloides	Citharina heteropleura	Citharina lepida	Citharina serratocostata	Citharina tenuicostata	Citharinella exarata	Cornuspira sp. 2	Dentalina aff. communis	Dentalina guembeli	Dentalina marsupifera	Dentalina torta	Dentalina varians	Dentalina vetusta	Eoguttulina inovroclaviensis	Eoguttulina liassica	Eoguttulina oolithica	Eoguttulina oolithica form A
10	1.8051	0	0	0.361	5.4152	0	1.444	0	0	0	0	0	0	0	0	0	1.8051	0	0	0	0	0	0	0	1.083	0	0
12	31.627	3.6145	0	0	1.8072	1.2048	0	0	0	0	0	0	0	0	0	0	0.9036	0	0	0	0	0	0	0	0	0	0
14	10.49	0.2331	0	0	3.7296	0	0	0	0	0	0	0.2331	0	0	0	0.4662	8.6247	0	0	0	0	0	0	0	0	0	0
16	0.5859	0	0	0	0	0	0.1953	0	0	0	0	0	0	0	0	0	0	0	0.7813	0	0	0	0.1953	0	0	0	0
18	10.229	0.1527	0	0	8.0916	0	0.1527	0	0	0	0	0	0	0	0	0	0	0	0.1527	0	0	0	0	0	0	0	0
20	1.7945	0	0	0	0.3263	0	2.1207	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	1.5894	0	0	0.2649	0.7947	0	0.7947	0	0	0	0	0	0	0.1325	0	0	0.1325	0	0.1325	0	0	0	0	0	0.1325	0	0
24	0.3571	0	0	0	0.2381	0.3571	0	0	0	0	0.2381	0.119	0	1.7857	0	0	0.119	0	0.119	0	0	0	0	0	0.5952	0	0
26	0.1706	0.3413	0	0	0.6826	0	0.3413	0	0.1706	0	0	0	0	0	0	0	0	0	0.5119	0	0	0	0	0	0.5119	0	0
28	5.7269	0	0	0	8.0764	0	0	0	0	0.1468	0.5874	0	0	0.1468	0.4405	0	0.4405	0	0.2937	0.7342	0	0	0	0	1.0279	0	0
30	5.0314	0	0	0	0.6289	0	0	0	0	0	0	0	0	0.6289	0	0	0	0	0.7862	0.1572	0	0	0	0	0.6289	0.7862	0
32	28.638	0.1548	0	0	0.3096	0	0	0	0	0	0.1548	0	0	0.4644	0	0	0.6192	0	0.3096	0	1.0836	0	0	0	0	0.4644	0
34	13.083	0	0	0	0.3008	0	0.1504	0	0	0	1.3534	0	0	0.6015	0	0	0.9023	0	1.5038	0	0	0	0	0	0	0.3008	0
36	7.7694	3.7594	0	0.1253	0.1253	0.1253	0.2506	0.5013	0	0.5013	0.2506	0	0	1.0025	0	0	0.1253	0	0.1253	0	0	0	0.2506	0	0.1253	0.3759	0
38	1.4981	0	0	0	0	0	0.3745	0	0	0	0.1873	0	0	0.9363	0	0	0	0	0	0	0	0	0	0	0	0.3745	0
40	0	0	0	0.7042	5.6338	0	1.4085	0	0	0	1.4085	2.8169	0	5.6338	0	0	0	0	0.7042	0	0	0	0.7042	0	0	0	0
41	4.3796	0	0	0	1.4599	2.1898	3.6496	0	0	0	2.1898	3.6496	0	1.4599	8.7591	0	0	0	5.1095	0.7299	0	0.7299	0.7299	0	0	0	0
44	0	0	1.4663	0.8798	0.1466	1.173	1.173	0.1466	0	1.6129	0	0	0	2.0528	0	0.7331	0	0	0	0	0.1466	0	0.4399	0	0	0	0.4399
46	0.1054	0	14.015	13.066	0	0	0	0	0	0	0	0.1054	0	3.8988	0	0	0	0	0	0	0	0	0.1054	0	0.3161	0	0.2107
48	0	0	2.2565	32.542	0	0	0	0	0	0.1188	0	0	0	6.1758	0	0	0	0	0.1188	0	0.1188	0	0	0	0.1188	0	0.2375
50	0.6711	0	0	0	0.1678	2.0134	2.349	0	0	0	0	0	0	0.8389	0	0	0	0	1.6779	0	0	0	0	0.1678	2.5168	0	0.3356
52	0.7776	0	1.5552	42.068	0	0.5443	4.9767	0	0	0	0	0	0.0778	1.2442	0.4666	0	0	0.0778	0.1555	0	0	0	0.311	0	0.1555	0.2333	0.0778
54	0.2674	0	0	25.134	0	0.1337	0	0	0	0	0	0	0	0	0	0	0.1337	0	0.2674	0	0.1337	0.1337	0	0	0	0.1337	0.1337
56	0.6649	0	0	28.856	0	0	0.9309	0	0.133	0	0	0	0	0.133	0	0	1.5957	0	0	0	0	0	0	0	0.266	0	0.7979
58	3.3279	0	0	36.769	0	0.0812	1.461	0	0	0	0	0	0	0.487	0	0	0.1623	0	0.0812	0	0	0	0	0	0	0.0812	0.3247

Hallett's Farm Borehole % Abundance Data

Sample	Epistomina parastelligera	Epistomina stellicostata	Epistomina tenuicostata	Frondicularia franconica	Frondicularia lignaria	Glomospira irregularis	Haplophragmoides excavatus	Haplophragmoides haeusleri	Haplophragmoides kingakensis	Haplophragmoides latidorsatum	Haplophragmoides sp. 1	Haplophragmoides tryssa	Haplophragmoides/Trochammina sp. i	Lagena globosa	Lagena sp. 1	Lagenammina difflugiformis	Lenticulina muensteri	Lenticulina protracta	Lenticulina quenstedti	Lenticulina subalata	Lenticulina tricarinella	Lingulina cernua	Lingulina laevissima	Lingulina nodosaria	Marginulina batrakiensis	Nodosaria cf. rudis	Nodosaria corallina
10	0	0	0	0.361	0	0	0	0	0	0	10.469	0	22.383	0	0	25.271	0	0	0	0	0	0	0	0	0	0	0
12	6.9277	0	0	0	0	0	0	0	1.2048	0	0.3012	0	13.554	0	0	20.482	0	0	0	0	0	0	0	0	0	0	0
14	0.2331	0	0	0	0	0	0	0	0.4662	0	7.4592	0	0	0	0	6.7599	54.545	0	0	0.4662	0	0	0	0	0	0	0
16	46.68	0	0	0	0	0.1953	0	0	0	0	0.5859	0	0	0	0	0.3906	49.805	0	0	0.1953	0	0	0	0	0	0.3906	0
18	3.5115	0	0	0	0	0	0	0	4.5802	0	5.4962	0	30.534	0	0	2.4427	16.641	0	0	5.1908	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0.3263	0	0.3263	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	62.119	0	2.9139	0	0	0	0	0	0.2649	0	0.6623	0.2649	5.0331	0	0	0.2649	20.927	0	0	1.1921	0	0	0	0	0	0	0
24	46.31	0.7143	0.4762	0	0	0	0	0	0.2381	0	7.5	0	0	0	0	0.9524	21.429	0	0.2381	0.7143	0	0.3571	0	0	0	0	0
26	67.577	0	0	0	0	0	0	0	0	0	4.2662	0	0	0	0	0.5119	4.6075	0	0.3413	0	0	0.8532	0	0	0	0	0
28	43.025	0	0	0	0	0	0	0.1468	0.1468	0	15.859	0	0.5874	0.5874	0.1468	3.3774	9.1043	1.4684	0	0	0	1.4684	0	0	0	0	0
30	53.931	0	0	0.1572	0	0	0.1572	10.063	0.4717	0	7.2327	0	0.4717	0	0	4.2453	3.1447	0.7862	0	0	0	0.1572	0	0	0	0	0
32	14.861	0	0	0	0	0	0	0	6.8111	0	9.5975	0.3096	0	0	0	2.1672	3.096	0	0	0	0	0.774	0	0	0	0	0
34	26.015	0	0	0	0	0	0.1504	0	2.406	0	17.444	0	0	0	0	7.6692	6.3158	0	0.1504	0	0	0.1504	0	0	0	0	0
36	7.0175	0	0	0	0	0	0	0	0.2506	5.3885	3.1328	0	0	0	0	26.316	1.3784	0.2506	0	0	0	0.1253	0	0	0	0	0
38	62.36	0	0	0	0	0	0	0	0	0	0.1873	0	0	0	0	0.1873	19.476	0.1873	0	1.3109	0	0	0	0	0	0	0
40	0	0	0	1.4085	0	0	0	0	0	0	0	0	9.1549	0	0	2.1127	47.183	1.4085	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.4599	46.715	2.9197	0	7.2993	0	0	0	0	1.4599	0	0
44	0	0	0	0	0	0	0	0	0.5865	0	0	0.1466	0	0.1466	0	0.7331	72.141	0	0.1466	0	0.7331	0	0	0	0	0	0.2933
46	0	0	0	0	0.1054	0	0	0	1.4752	0	0	0	0	0	0	0	23.498	0.7376	0	0	0	0.1054	0	0	0	0	0
48	0	0	0	0.1188	0	0	0	0	0	0	0.2375	0	0	0	0	0	25.416	0.4751	0	0	0	0.3563	0	0	0	0	0
50	0	0	0	0.6711	0	0	0	0	0	0	0	0	0	0	0	0	29.866	3.6913	0	0	0	1.3423	0	0	0	0	0
52	0	0	0	0.0778	0	0	0	0	0	0	0	0.1555	0.1555	0	0	0.3888	20.451	1.5552	0	0	0	0	0	0	0	0	0
54	0	0	0	0.4011	0	0	0	0	0.1337	0	0	0	0	1.0695	0	0.8021	34.759	1.0695	0	0	0	0.8021	0.4011	0.1337	0	0	0
56	0	0	0	0.266	0	0	0	0	0.266	0	0.266	0	3.3245	0	0	0.3989	14.096	0.266	0	0	0	0.266	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0	0	3.7338	0	0	0.8117	39.854	0	0	0	0	0	0	0	0	0	0

Hallett's Farm Borehole % Abundance Data

Sample	Nodosaria metensis	Nodosaria opalini	Ophthalmidium compressum	Ophthalmidium strumosum	Textularia dumortieri	Paalzowella sp.	Planularia angustissima	Planularia bieriana	Planularia eugenii	Planularia listi	Planularia suturalis	Quinquiloculina horelli	Quinquiloculina sp.	Ramulina spandeli	Reinholdella lutzei	Reophax helvetica	Reophax spp. indet.	Reophax sterkii	Reophax variabilis	Spirillina infima	Spirillina tenuissima	Spiroloculina variabilis	Textularia jurassica	Textularia pugiunculus	Tristix triangularis	Trochammina canningensis	Trochammina globigeriniformis
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.722	1.444	0	0	0	0	0	0	0	0	0	24.91
12	0	0	0	0	0	0	0	0	0	0	0	0	0.6024	0	0	6.3253	0	2.1084	0	0	0	0	0	0	0	0	3.3133
14	0	0	0	0	0	0	0	0	0	0.9324	0	0	0	0	0	0	0.2331	0	0	0	0	0	0	0.4662	0	0	3.7296
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1527	0	0.458	0	0	0	0	0	0	0	1.9847	0	0	4.5802
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3263	0	0	1.9576
22	0	0	0	0	0	0	0	0	0	0.2649	0	0	0	0.1325	0	0.5298	0	0	0	0	0	0	0	1.3245	0	0	0
24	0	0	0	0	0	0	0	0	0	0.5952	0	0	0	0	8.3333	0	0	0	0	0.119	0	0	0	4.2857	0	0	2.8571
26	0	0	0	0	0	0	0	0	0	0.5119	0	0	0	0	11.092	0.1706	0	0	0	0	0	0	0	2.3891	0	0	4.7782
28	0	0	0	0	0	0	0	0	0	0.5874	0	0	0	0	0	1.6153	0	0	0	0	0	0.1468	0	0.1468	0	1.7621	1.7621
30	0	0	0	0	0	0	0	0	0.1572	0.3145	0	0	0	0	0	1.7296	0	0	0	0	0	0	0	8.3333	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0.1548	0	0	0	0	5.2632	0	0	0.1548	0	0	0	0	8.8235	0	0	0
34	0	0.1504	0	0	0	0	0	0	0	0	0	0	0	1.203	0	2.7068	0	7.8195	1.6541	0	0	0	0	4.2105	0	0	0
36	0	0	0	0	0	0	0.1253	0	0	0.2506	0	0	0	0.1253	0	1.1278	0	11.905	0	0	0	0	0	22.932	0	0	1.7544
38	0	0	0	0	0	0	0	7.3034	0	0	0	0	0	0	0	0	0	0.1873	0	0	0	0	0	0	0	0	3.9326
40	0.7042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7042	0	0	0	0	2.8169	0	0	0	0
41	0	0	0	0	0	0	0	1.4599	0	0	0	0	0	0	0	0	0	0.7299	0	0	0	0	0.7299	0	0	0	2.1898
44	0	0.1466	0	0	0.2933	0.1466	0	4.1056	0	0	0	0	0	0	0	0	0	0	0	1.3196	1.7595	0	0.5865	0	0	0	0
46	0	0	0	0.2107	0	0.1054	0	0	0	0	0.1054	0	0	0	0	0	0	0	0	10.959	24.341	0	0.2107	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0.9501	0	0	0	0	0	0.1188	0	2.9691	18.765	0	1.3064	0	0.1188	0	0
50	0	0	0	0	0	0	0	0	0	0	1.6779	0	0	0	0	0	0	0	0	4.1946	41.611	0	0.3356	0	0	0	0.6711
52	0	0	0	0.0778	0	0	0	0	0	0	0	0.2333	0.0778	0	0	0	0	0	0	0.8554	19.518	0	0.2333	0	0.1555	0	0
54	0	0.1337	0	0	0	0	0	0	0	0	0	0.5348	0.1337	0	0	0	0.1337	0	0	2.9412	28.075	0	0	0	0	0	0.4011
56	0	0	0.133	0	0	0	0	0	0	0	0	0	0	0	0	0	0.266	0	0	3.0585	29.521	0	0	0	0	0	0.266
58	0	0	0.0812	0	0	0	0	0	0	0	0	0.0812	0	0	0	0	0	0	0	1.2175	5.8442	0	2.4351	0	0	0	0

Hallett's Farm Borehole % Abundance Data

Sample	Trochammina inflata	Trochammina omskensis	Trochammina rosaceaformis	Trochammina squamata	Trocholina nodulosa	Vaginulina anomala	Vaginulina barnardi	Vaginulina contracta	Vaginulina jurassica	Vaginulina sp. 1	Verneuilinoides tryphera
10	0	0	0	2.5271	0	0	0	0	0	0	0
12	0	0	0	6.0241	0	0	0	0	0	0	0
14	0	0	0	0.9324	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	5.6489	0	0	0	0	0	0	0
20	0	0	0	92.822	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0.1325	0
24	0	0	0	0	0	0	0	0	0	0.9524	0
26	0	0	0	0.1706	0	0	0	0	0	0	0
28	0	0.1468	0	0	0	0	0	0	0	0.2937	0
30	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	15.789	0	0	0	0	0	0	0
34	0	0	0	3.7594	0	0	0	0	0	0	0
36	0	0	0	2.5063	0	0	0	0	0	0	0
38	0.7491	0	0	0.7491	0	0	0	0	0	0	0
40	0	0	0	12.676	0	0	0	0	2.8169	0	0
41	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	2.0528	0.2933	0	3.9589	0	0	0	0
46	0	0	0	0	5.1633	0	0.9484	0.2107	0	0	0
48	0	0	0	0	0.3563	0	7.1259	0	0	0	0
50	0.1678	0	0	2.0134	1.6779	0.1678	1.0067	0	0.1678	0	0
52	0	0	0.1555	0	1.0886	0.1555	1.7107	0.0778	0	0	0.1555
54	0	0	0	1.4706	0	0	0	0.1337	0	0	0
56	0	0	0	14.096	0	0	0	0.133	0	0	0
58	0	0	0	2.7597	0.4058	0	0	0	0	0	0

Hallett's Farm Borehole % Abundance Data

Publications.

Read at the Annual Conference of the Usshers Society, 1992.

SOME HOLOTHURIAN SCLERITES FROM THE CORALLIAN GROUP OF NORTH DORSET

A. S. HENDERSON, A. D. TALWAR AND M. B. HART

Henderson, A. S., Talwar, A. D. and Hart, M. B. 1992. Some Holothurian sclerites from the Corallian Group of north Dorset. *Proceedings of the Ussher Society*, **8**, 11-14.

Borehole samples of Corallian sediments from East Stour, north Dorset were examined for their microfossil content. Although the main emphasis of the research was concerned with foraminifera, significant numbers of small calcareous platelets of holothuroid echinoderms or Sea Cucumbers were observed. These are known as sclerites and various forms are illustrated and described. They are the first to be recorded from the Corallian Group of this area.

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INTRODUCTION

The mid Upper Jurassic succession (Oxford Clay, Corallian and Kimmeridge Clay) is poorly exposed in north Dorset and south Somerset. The British Geological Survey has recently remapped this area and drilled three boreholes to augment the limited surface outcrops (Bristow, 1989, 1990; Freshney, 1990). One of these holes [ST 8013 2297], at East Stour, north Dorset penetrates most of the Corallian from the *Clavellata* Beds through to the Hazelbury Bryan Formation. Samples from this borehole have been examined for microfauna, as part of a long-term project. The primary aim of this research is to develop a viable biozonation of the Upper Jurassic succession for the Wessex Basin using microfossils, which when compared with the standard ammonite zonation, will be developed into a fully integrated stratigraphy.

The lithologies covered by the borehole, and the position of the samples with Holothurian sclerites, are shown in Figure 1.

Holothurian sclerites as a group have received little attention in this country. Published works include Hodson *et al.* (1956) who studied specimens from the Oxford Clay of the Dorset Coast; Hampton, (1957, 1958a, 1958b, 1959, 1960) on Upper Bathonian forms from the Dorset Coast; Fletcher (1962) described forms from the Ampthill Clay of Melton, near Hull, and Lord and Senior (1973) redescribed two holothurian species from the Middle Jurassic of South Dorset. Soodan and Whatley (1987, 1988) published a two-part paper titled "Fossil Holothuroidea from the Jurassic of Great Britain". Gilliland (1992) studied in detail the Holothurians from the Blue Lias of southern Britain.

Fossil holothurian sclerites are widely distributed in marine sedimentary strata of moderate to shallow depths, and are found most frequently in clays, marls, shales and sandy shales. They are less common in limestones and marly limestones, and are rare in sandstones. Palaeoenvironments range from tropical to subarctic marine; suggested bathymetry ranges from sublittoral to moderate depths. Although Recent holothurians are abundant and varied in deep seas, fossil sclerites are rare in deep-sea deposits due to dissolution after deposition.

The present study represents a preliminary account of Corallian holothurian sclerites from a continuous lithological succession.

The samples have been prepared using standard micropalaeontological processing techniques, which are not ideal for the preservation of holothurian sclerites. Inherently, they have a far more delicate structure than most foraminifera or ostracods, even the action of separating residues in standard nesting sieves can damage the more fragile specimens. The presence of matrix adhering to the specimens and or the growth of secondary calcite coupled with the minute size of most specimens, further hampers the identification of forms.

The taxonomy of holothurian sclerites has inherent difficulties as with all groups of fragmental microfossils. Hampton (1959) points out that different forms of sclerites may belong to one species and

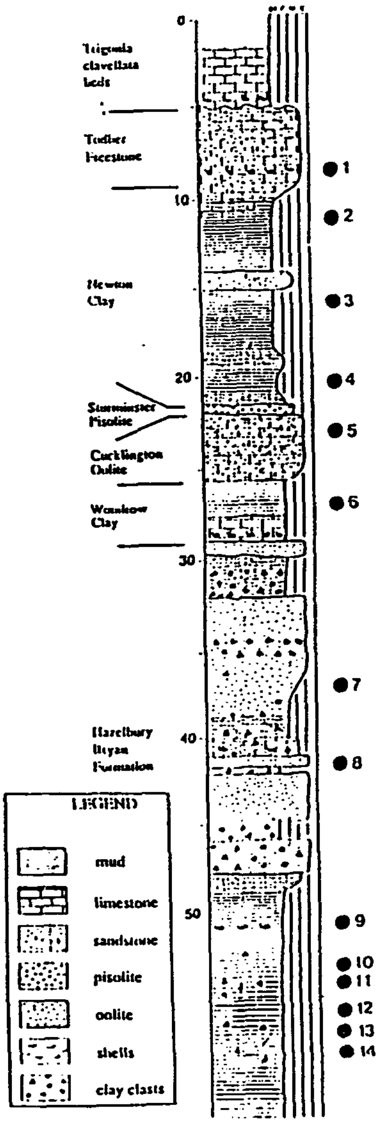

Figure 1: Corallian succession in East Stour borehole, showing location of samples studied (Modified after Bristow 1989).

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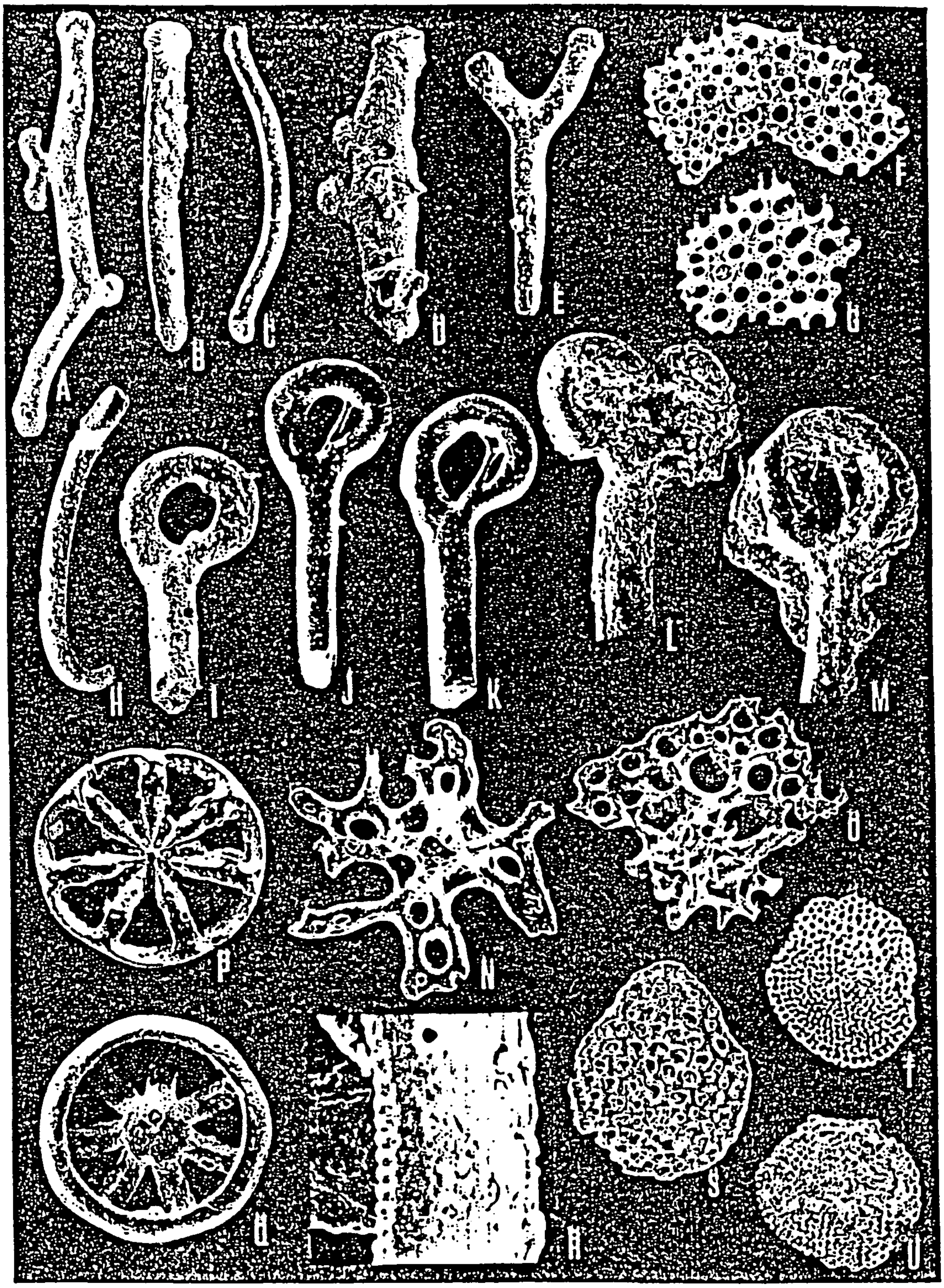

Plate 2: A-E) *Rhabdotites dorsetensis* Hodson, Harris and Lawson, emend. Hampton. A, MPK 9252; S9, × 150. B, MPK 9253; S9, × 150. C, MPK 9254; S9, × 150. D, MPK 9255; S10, × 200. E, MPK 9256; S9, × 200. F-G) *Eocaudina* type plates. F, MPK 9257; S6, × 200. G, MPK 9258; S2, × 200. H) *Achistrum* cf. *issleri* (Croneis). MPK 9259; S9, × 100. I-J) *Achistrum monochordata* Hodson, Harris and Lawson. I, MPK 9260; S2, crossbar broken, × 200. J, MPK 9261; S14, × 200. K) *Achistrum gamma* Hodson, Harris and Lawson. MPK 9262; S16, × 150. L) *[illegible]* sp. MPK 9263; S9, × 200. M) *Achistrum bichordata* Fletcher. MPK 9264; S9, × 200. N-O) *Priscopedatus* spp. N, MPK 9265; S10, × 350. O, MPK 9266; S10, × 350. P-R) *Theelia convexa* (Whidborne). P, MPK 9267; S13, × 500. Q, MPK 9268; S10, × 350. R, close up of rim showing dentition, × 2000. S) *Synaptites* sp. MPK 9269; S10, × 200. T-U) *Frizzellus* type elements. T, MPK 9270; S6, × 200. U, MPK 9271; S9, × 200.

All figured specimens are housed in the Palaeontological Collections of the British Geological Survey, Keyworth, Nottingham. S numbers refer to samples. MPK numbers are British Geological Survey catalogue numbers.

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nversely, similar forms may belong to different species. The nerally accepted classification is based entirely on disjunct mponents and is therefore essentially artificial (Frizzell and Exline, 55) but appears to be valid (Hampton *op. cit.*) and fossil suites can w be described with confidence. Following the proposals of ore and Sylvester-Bradley (1957), species of fossil holothurian lerites are here alluded to in terms of parataxa or form species.

YSTEMATIC DESCRIPTIONS

YLUM: Echinodermata

n-Holothurian 'Holothurian Sclerites'

llowing Gilliland (1992), certain species recognised in this study ve been placed under this heading. Previous authors have pressed doubts as to whether certain sclerites are holothuroid in igin. Gilliland (*op. cit.*) highlights and discusses this problem and o forms mentioned are encountered in this study.

***izzellus*-type elements (Plate 2, T, U)**

e genus *Frizzellus* Hampton, 1958, formally in the Holothurian mily Etheridgellidae Frizzell and Exline, 1955, has remained ntatively within the Holothuroidea. The forms encountered in the rehole are very similar to *F. irregularis* Hampton, 1958, and as illiland has shown precludes assigning them to the holothurians.

marks: This form is the most common, occurring in all the mples. The forms compare well with those described by Hampton 958b), but differ in being perforated towards the outer margin. The rface ornamentation is granular becoming almost reticulate nearer e centre, where the sclerite thickens slightly. The sclerites vary in orphology in accordance with forms (a) to (d), Gilliland, 1992: the ajority of specimens being type (a) forms.

***caudina*-type plates (Plate 2, F, G)**

hen considered holothurian in origin the genus *Eocaudina* Martin, 52 belonged to the Family Calclamnidae Frizzell and Exline, 1955, d formally incorporated all perforated plate forms which are scoidal or hexagonal in outline. As noted by Frizzell and Exline and y subsequent authors, *Eocaudina* can not be considered equivocally as holothurian in origin, since the plates are also und in other echinoderms. The fauna encountered here compares ell with that of the Blue Lias (Gilliland, 1992), in that *Eocaudina* cocurs with holothurian and various echinoderm skeletal elements. he authors agree with Gilliland that it seems preferable not to cept these plates as holothurian.

emarks: These plates are common, occurring in all samples udied. Unfortunately all the perforated plate forms examined ave a tendency to be invariably broken with the perforations lled with matrix and/or secondary calcite. This makes entification difficult.

LASS: **Holothuroidea**

AMILY: **Stichopitidae Frizzell and Exline, 1955**

ENUS: ***Rhabdotites*** **Deflandre-Rigaud, 1952**

PECIES: ***Rhabdotites dorsetensis*** **Hodson, Harris and Lawson 956, *emend.* Hampton 1960 (Plate 2, A-E)**

istribution: Samples 9, 10, 12. Very common.

emarks: This species was revised by Hampton (1960) who oncluded that previously separate species are in fact "variational spects of a single sclerite morphogroup" and are to be included in e single species *Rhabdotites dorsetensis*. The variety of forms ncountered in the present study all fall within these "variational spects". The preservation of all specimens is exceptional.

AMILY: ***Achistridae*** **Frizzell and Exline, 1955**

emarks: Aside from those belonging to the genus *Frizzellus*, the ajority of sclerites encountered in this study belong to this Family ooks), and all but one of the specimens belongs to the genus *chistrum*.

ENUS: ***Achistrum*** **Etheridge, 1881, *emend.* Frizzell and xline, 1955**

emarks: The authors do not follow Hampton (1958) in splitting the enus *Achistrum* into the subgenera *Achistrum s.s.*, *Spinum*, *Cancellrum* nd *Aduncrum*, but follow Frizzell and Exline, 1966. The preservation of e specimens is generally very good, but some forms have the eye wholly or partially filled with matrix and or secondary calcite. In the latter case it becomes difficult to assign forms to any distinct species, and they are lumped under the genus *Achistrum*. Almost all of the specimens are incomplete, in that the spear of each is lacking.

Species: ***Achistrum spp***

Remarks: There are a moderate number of indeterminable species of *Achistrum* in the study, occurring in Samples 8, 9, 11, 12.

Species: ***Achistrum* cf *issleri* (Croneis and McCormack, 1932) (Plate 2, H)**

Distribution: The second most common *Achistrum* species in the East Stour Borehole; occurring in Samples 6, 9, 10, 12, 13.

Remarks: Almost all specimens are incomplete (lacking a spear), but otherwise agree closely with those figured by Hodson *et al.* 1956, as *A.* sp. cf. *issleri*.

Species: ***A. monochordata*** **Hodson, Harris and Lawson, 1956 (Plate 2, I, J)**

Distribution: This form is very common in the samples studied occurring in Samples 2, 4, 6, 7, 8, 9, 10, 12, 13, 14.

Remarks: This is the most common species of this genus and aside from *F. irregularis* is the single most common species encountered in this study. The crossbar varies in its position within the eye, and in many cases is broken, resulting in two small protrusions which have been interpreted as spine-like processes by previous authors and recorded as the distinct species *A. bartensteini* Frizzell and Exline, 1955. This is synonymized here following Rioult (1961). All specimens are lacking the spear.

Species: ***A. gamma*** **Hodson, Harris and Lawson, 1956 (Plate 2, K)**

Distribution: Relatively rare in the samples studied. Occurring in Samples 6, 12, 14.

Remarks: The majority of the specimens have the 'Y'-shaped crossbar intact. All specimens are lacking the spear.

Species: ***A. bichordata*** **Fletcher, 1962 (Plate 2, M)**

Distribution: Only one specimen occurring in Sample 9.

Remarks: As the eye of this form is partially infilled with matrix, the nature of the crossbar is difficult to ascertain and hence assigning it to this species is uncertain. The specimen seems to have only two crossbars but a bifurcation of one of these bars could easily be obscured. The form would then be assigned to *A. trichordata*.

Genus: ***Aduncrum*** **Hampton, 1958**

Species: ***?Aduncrum sp.*** **(Plate 2, L)**

Distribution: One specimen only. Sample 9.

Remarks: Due to the specimen's relatively bad preservation, positive identification is difficult, however the form shows greatest affinity with this genus.

Family: **Priscopedatidae Frizzel and Exline, 1955**

Genus: ***Priscopedatus*** **Schlumberger, emend. Frizzel and Exline, 1955**

Species: ***Priscopedatus spp*** **(Plate 2, N, O)**

Distribution: Common in the samples studied. Occurring in Samples 8, 9, 10.

Remarks: One of the major characteristics for identification of taxa within this Family is the position and nature of the central spire, lattice cross and primary pore(s). Due to the common occurrence of secondary calcite on perforated plate forms, coupled with the invariable damaged outline it is difficult to assign these specimens to an individual taxon. Some forms hare an affinity to *Helfriedella mesojurassica* Kozur and Sadeddin (1990) from the Upper Bathonian and Callovian of Jordan.

Family: **Theeliidae Frizzell and Exline, 1955**

Genus: ***Theelia*** **Schlumberger, 1890**

Species: ***Theelia convexa*** **(Whidborne, 1883) (Plate 2, P-R)**

Distribution: Frequent in the samples studied. Occurring in Samples 7, 9, 10, 12, 13.

Remarks: Specimens of Theeliidae found in the present study belong to this species. The specimens compare well with the forms figured by Lord and Senior, 1973. All specimens have 7 spokes only.

4

Family: Synaptitidae Frizzel and Exline, 1955
Genus: *Synaptites* Deflandre-Rigaud, 1959 *emend.* Frizzel and Exline, 1955
Species: *Synaptites sp.* (Plate 2, 5)
Distribution: Only one specimen. Sample 10.
Remarks: Due to poor preservation it is only possible to classify this specimen to generic level. The genus *Synaptites* has not been previously reported from the Jurassic of Britain.

CONCLUSIONS

It can be seen that the species represented here have no real stratigraphic value within the interval studied. Sclerite species in general are long ranging. A notable exception is *Rhabdotites dorsetensis* which is restricted to the Oxfordian. It is hoped that with future study sclerites may prove to be useful when utilized alongside foraminifera and other microfossils in establishing a biozonation for the west Wessex Basin.

ACKNOWLEDGEMENTS

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5

Note of poster display at the Annual Conference of the Ussher Society, January 1992

SIMPLE GAMMA-RAY RESPONSE OF THE UPPER JURASSIC FROM THE DORSET COAST – A PRELIMINARY INVESTIGATION USING THE SCINTILLOMETER PROFILE TECHNIQUE

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Surface gamma-ray logs or scintillometer profiles are not widely used but are a potentially valuable approach to stratigraphic correlation in regional field surveys, given suitable continuous outcrop (Chamberlain, 1984); Myers (1987) gives a detailed review of surface gamma-ray spectrometry. The gamma-ray detector provides a rapid method of measuring the concentration of the three main naturally occurring radio-elements Th, U and ^{40}K (Myers, 1989) to be found in rocks. Where a total count of the radio-activity is obtained, this is known as a Simple Gamma-Ray Log (GR). An analysis may also be made allowing for the differentiation between the radio-elements to give the relative proportion of each, this is the Spectral Gamma-Ray Log (SGR), and is possible because the radio-elements concerned have distinct energy spectra.

This investigation was undertaken to assess the value and application of GR logs in the lithological interpretation of the coastal Corallian succession and, secondly, towards any pertinent correlations that might be made across the west Wessex Basin, as a result of comparing our own field-generated GR profiles with those provided by the British Geological Survey (BGS). This paper provides the first description of GR signatures for the Corallian succession at Osmington Mills and Bran Point, and also the first published attempt at using this technique for correlation purposes within the Wessex Basin.

Using a Gamma-Ray Integrating Spectrometer, a field study of GR emissions was conducted on part of the Upper Jurassic (Corallian) succession on the Dorset Coast at Osmington Mills and Bran Point.

Recent remapping by BGS in the Shaftesbury/Wincanton area, and the drilling of three cored boreholes has established a detailed stratigraphy for the Corallian Group of inland Dorset (Bristow, 1989, 1990; Freshney, 1990). In this study, two of the boreholes, East Stour [ST 8013 2297] and Cannings Court [ST 7187 6734] were examined. A correlation of the GR logs from East Stour and Cannings Court boreholes, with surface-generated GR profiles compiled on the coast is attempted (Figure 1).

The stratal nomenclature used in this work for the coastal sequence is taken from Wright (1986). The cliff section studied between Osmington Mills and Bran Point (see Wilson, 1968a,b; Talbot, 1973a,b; Wright, 1986; Sun, 1989) comprises the Bencliff Grit Member of the Redcliff Formation; the Upton Member, Shortlake Member and Nodular Rubble of the Osmington Oolite Formation, and the *Trigonia clavellata* Formation. The nomenclature used for the two BGS boreholes is taken from Bristow (1989).

The Gamma Ray Integrating Spectrometer used was a Scintrex Scintillation Counter (SSC). The unit comes in two parts: a hand-held probe (placed on the rock surface) and a control box (on a strap, hung around the neck), which houses the electronics and battery source. The two are connected with a cable. The circuitry includes gamma-ray energy discrimination enabling the determination of Th, U and ^{40}K anomalies for detailed quantitative studies (SGR) if required. For our purposes, a total count (GR) was all that was needed to make a comparison with the BGS logs. There is a feedback loop which stabilizes the gamma spectrum in energy, using a reference gamma-ray source and continuous re-calibration of the tool. This is essential as the response of the detector changes with temperature.

The units on the coast were logged and sampled (for micropalaeontological work). With the tape measure still in position, the sections were studied using the SSC, and the readings recorded alongside the lithological logs.

Fresh flat sections, vertical in this study, are needed to make accurate readings. Due to varying lithology, it was decided to take readings as close together as possible, to provide greater resolution. The SSC probe is 10 cm in width and so, with a 10 cm sampling frequency, the counter was placed end on end allowing total coverage of any given section. Sampling duration (or the time constant) was between 3 and 6 seconds, allowing the unit to re-calibrate and time to take averaged readings. Readings were averaged from a swinging pointer on a dial meter. Whilst appearing somewhat arbitrary, it is the relative values between readings which provide the distinctive profile and not the absolute values. The unit of measure used in both the BGS and coastal profiles was counts per second. Generally, the principal contribution to the radioactivity detected by the SSC will come from within 30 cm of the detector both horizontally and vertically (Rider, 1986).

The exposed Corallian sequence at Osmington Mills/Bran Point comprises shales, argillaceous sands and silts, heterolithic fine-grained sediments, oolitic limestones, bio-oomicrites, nodular limestones, nodular oolitic limestones and preserved organic carbon. As expected, this complex lithology elicited a varying signature response (Figure 1). By comparing the gamma-ray logs and the lithology, trends in the signature became apparent.

At the base of the Bencliff Grit Member, there are argillaceous fine sands/silts, these become sandier and slightly coarser-grained toward the top resulting in a lower gamma-ray count (Figure 1). There are also 'kicks' at unit boundaries, resulting from erosion or omission surfaces. The Upton Member is composed of a series of interbedded limestones and shales; the GR log responded well to this by producing a well-spaced, serrated signature, particularly towards the top, which consists of regularly interbedded limestones and shales with high frequency (Figure 1). The basal Shortlake Member is composed of oolitic limestone which produces a low response. The upper part of this member is composed of interbedded clays and micritic limestones, hence the higher values and a highly serrated signature.

Limited scope exists for correlation between the coast, Cannings Court and East Stour sections. The only unit lithologically equivalent between these areas is the *Trigonia clavellata* Formation: a peak within the lower part of this formation can be recognised from all three logs. In sand and shale sequences correlations become extremely complex (Rider, 1986). Combined with the presence of interbedded limestones and facies variations between the areas studied, direct correlation becomes subjective. Responses elicited below the *Trigonia clavellata* Formation after the digitization of the Osmington Mills/Bran Point section produce certain trends that may be considered equivalent (though do not appear to be directly correlatable) but it is felt that data from other borehole sections and de-classified company logs closer to the studied coastal section would initially produce more reliable comparisons. Whittaker *et al.* (1985) illustrated a gamma-ray log from the BGS Winterbourne Kingston Borehole and provide a useful account of varying signature responses from the Upper Jurassic of Britain. Unfortunately however,

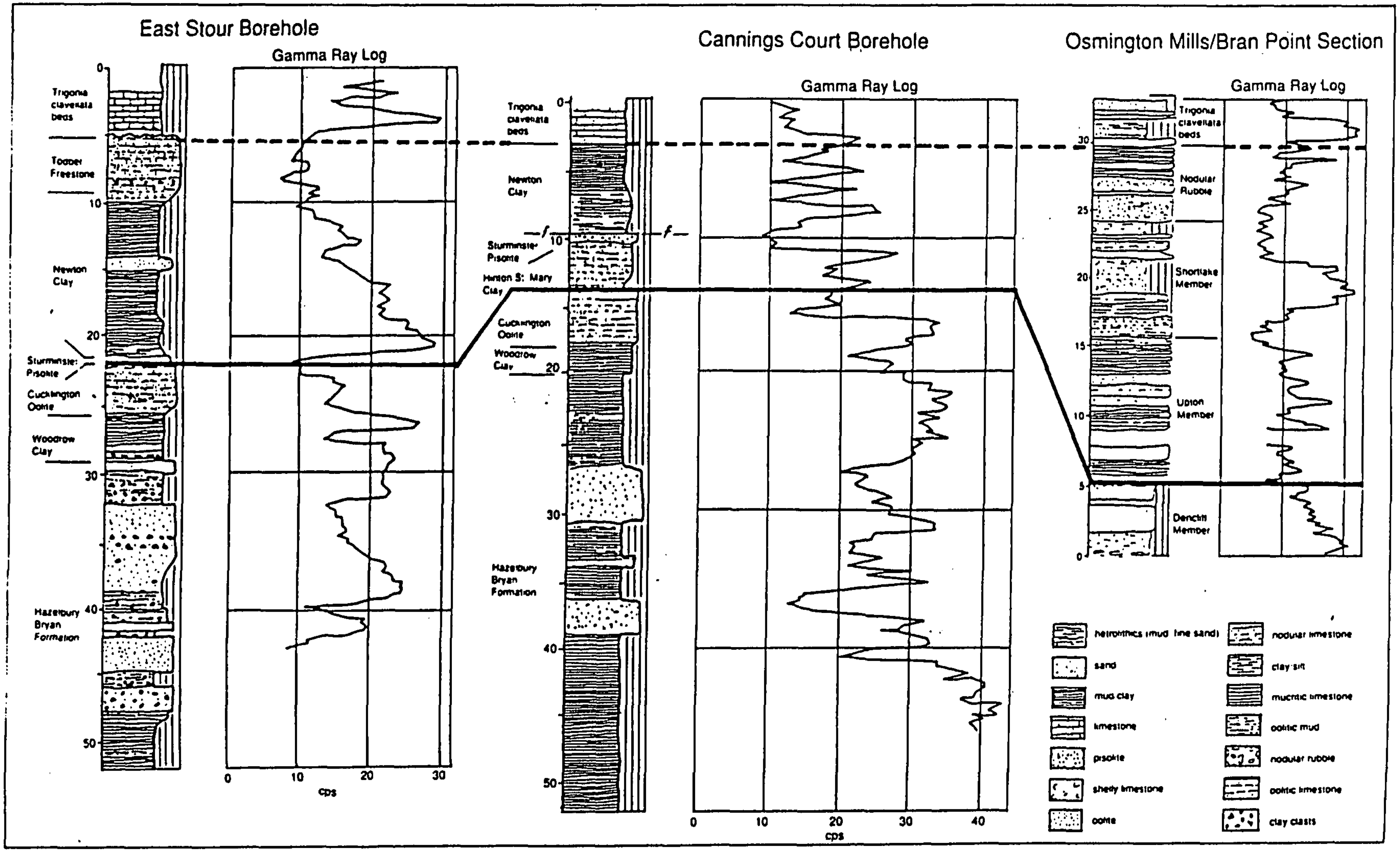

Figure 1: A comparison of the East Stour Cannings Court boreholes (courtesy, BGS) and the Osmington Mills/Bran Point log.

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the log produced does not have high enough resolution to permit direct comparisons with our surface-generated logs.

Gamma-ray logs are useful and have advantages for correlation especially when this concerns shale sequences, however, the lithologies under review in this area are not composed entirely of shales, and there is an obvious variability in the depositional environments which have shown themselves to be laterally impersistent over the basin. As a result, the gamma-ray signatures are seen to be individualistic.

We have attempted to apply GR field logging in our studies as a logical extension to normal data-gathering facilities, and have used GR profiles as an aid to our research, and not as an end in themselves. They have been, and are to be, used in conjunction with logged sections as well as macro/microbiostratigraphic control. Further investigations on the Th, ^{40}K and U contents will provide new data not available from borehole logs. We believe the GR technique will prove to be a useful addition to research. With on-going investigations into the microfaunal elements to be found in both inland and coastal sections, it may be possible in the future to determine a viable integrated event-stratigraphy for the area.

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Read at the Annual Conference of the Ussher Society, January 1994

THE LITHOSTRATIGRAPHY OF THE MID-UPPER JURASSIC OF NORTH DORSET; PRELIMINARY RESULTS FROM THREE NEW BOREHOLES

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INTRODUCTION

The mid-Upper Jurassic succession of north Dorset is poorly exposed but has become better known as a result of recent British Geological Survey (BGS) mapping (Bristow, 1989; 1990; Freshney, 1990; Bristow *et al.*, 1994). As part of their investigations, the BGS drilled 5 boreholes; at East Stour [ST 8013 2297], Cannings Court [ST 7187 0734], Combe Throop [ST 7260 2350], Hazelbury Bryan [ST 7715 0810] and Knackers Hole [ST 7791 1188]. The boreholes at East Stour, Hazelbury Bryan and Cannings Court, while providing useful information on detailed facies changes, nevertheless penetrated the same part of the succession. In order to recover the *complete* succession from the Oxford Clay to the Kimmeridge Clay, three boreholes were drilled in Summer 1993, between East Stour and Buckhorn Weston.

The boreholes were drilled using a trailer-mounted B24 Mobile Surveyor Drilling Rig. Cores were recovered using a combination of a T2-56 mm diamond core barrel and a TT-56 mm triple barrel diamond core barrel. The latter system uses a plastic liner system, which caused extrusion problems despite its ability to contain the sediments. One of the boreholes yielded poor recovery in the top 6-7 m. This part of the hole was re-sampled using a hollow stem auger. Water loss was severe in most parts of the succession. Polymer additives were used, on occasions, in order to control the water problems. Recovery was, in general, very good throughout the project.

Prior to sampling, the cores were inspected, photographed and logged in detail. Sampling for foraminifera, calcareous nannofossils, holothurians, ostracods and organic-walled microfossils was then undertaken. While the cores were being sampled, all macrofossil debris/specimens were isolated for later identification.

The sites of the boreholes are indicated on Figure 1, together with the site of the BGS East Stour Borehole.

As indicated above, this investigation had two aims:-

i. to document and confirm the regional stratigraphy;

ii. the recovery of fresh material for micropalaeontological research.

LITHOSTRATIGRAPHY

The original investigation of the north Dorset area was undertaken by Blake and Hudleston (1877). The subsequently published memoirs (Woodward, 1895; White, 1923) were based on that initial mapping. Advances in the understanding of the area were provided by Arkell (1933), Mottram (1956), Gutman (1970), and Wright (1981).

Wright (1981) provides a fairly comprehensive lithostratigraphy based on a succession of Formations and Members (see Figure 2). More recently, the BGS has re-mapped the area and produced a revision of the lithostratigraphy (Bristow, 1989a, b and 1990; Freshney, 1990; Bristow *et al.*, 1994; Bristow and Freshney, *pers. comm.*). The lithostratigraphy of the BGS has been adopted here with only minor modification (Figure 2).

The East Stour Borehole (Bristow, 1989a; Henderson *et al.*, 1992; Bristow *et al.*, 1994) recorded the succession between the Clavellata Beds and the Hazelbury Bryan Formation, but missed the transition upwards into the Kimmeridge Clay and downwards into the Oxford Clay. The current boreholes were drilled to prove these boundaries. As indicated in Figure 1, the Halletts Farm Borehole recorded the complete Clavellata Beds, together with the overlying Sandsfoot Formation. At the present time, we have been unable to ascertain if the overlying clays belong to the "Ringstead Waxy Clay" and/or the local equivalent of the Ampthill Clay (Bristow and Freshney, *pers. comm.*). At the base of this hole, the Sturminster Pisolite Member and the Cucklington Oolite Member were recorded; both of which are distinctive lithostratigraphic units. The Bowden Farm Borehole overlapped with that at Hallett's Farm and recorded the succession below the Sturminster Pisolite member. Like the East Stour Borehole, it terminated within the Hazelbury Bryan Formation. The Hartmoor Hill Borehole is more difficult to correlate with the other cores, as it began within the Hazelbury Bryan Formation. We have attempted a lithostratigraphic correlation using the sand/silt units within the Formation. This correlation appears to tie in with the East Stour Borehole (see Figure 1). While it was anticipated that the site of the Hartmoor Hill Borehole would allow recovery of the uppermost Oxford Clay, we are uncertain as to whether it was reached.

The cores recovered during the investigation will, when fully studied, yield useful information on the stratigraphy of the Upper Jurassic rocks in north Dorset.

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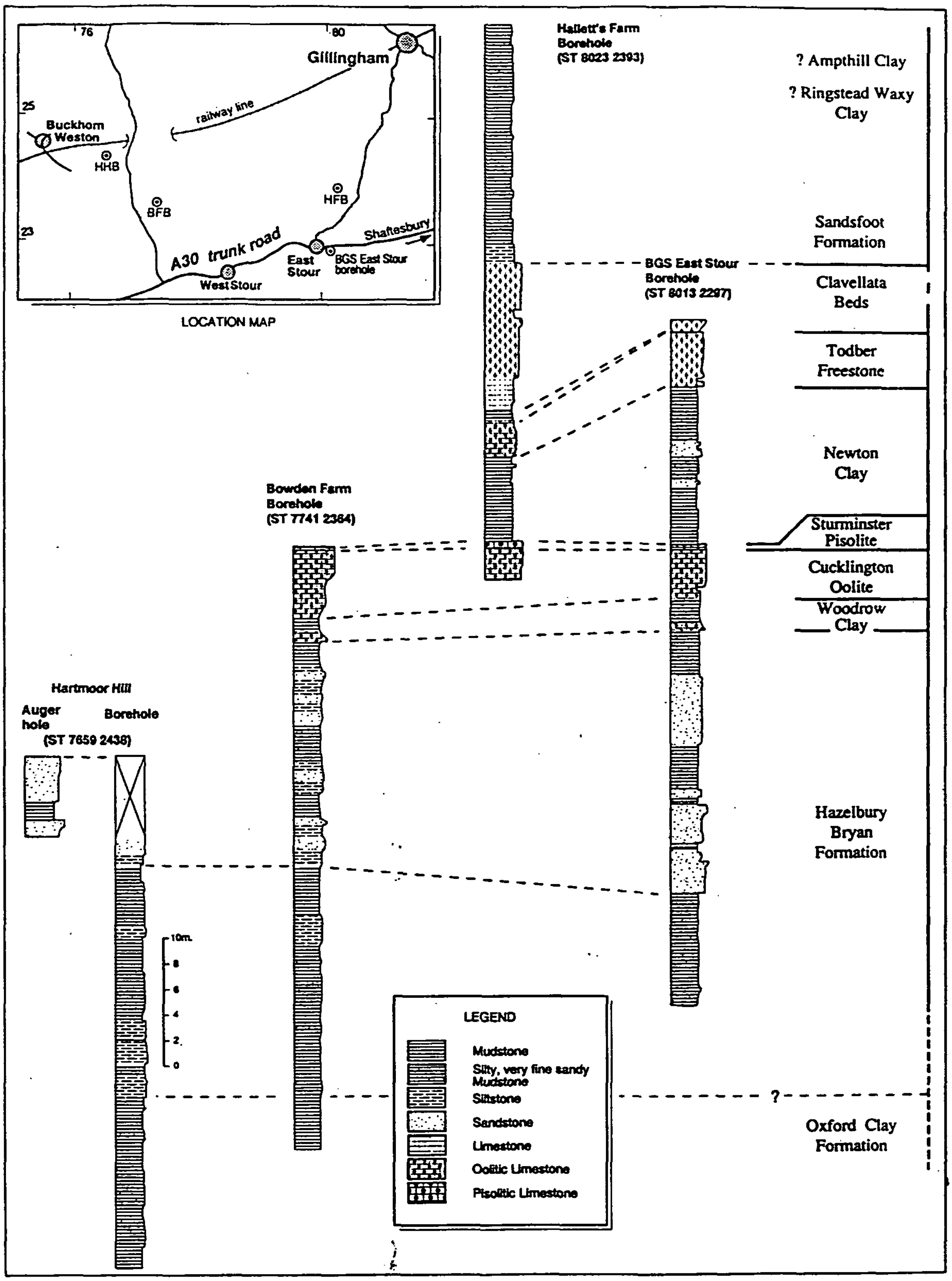

Figure 1. Preliminary correlation of the East Stour, Hallett's Farm, Bowden Farm and Hartmoor Hill boreholes. See inset map for borehole location.

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WRIGHT (1981)		THIS ACCOUNT	
Kimmeridge Clay Formation		Kimmeridge Clay Formation	
Passage Bed Fm. (part)	Ringstead Clay Mbr.		Ringstead Clay Mbr.
Sandsfoot Formation	Sandsfoot Grit Mbr.	Sandsfoot Formation	Sandsfoot Grit Mbr.
	Sandsfoot Clay Mbr.		Sandsfoot Clay Mbr.
Trigonia clavellata Formation		Clavellata Beds	
Coral Rag Formation			
Osmington Formation	Todber Freestone Mbr.	Stour Formation	Todber Freestone Mbr.
	Sturminster Pisolite Mbr.		Newton Clay Mbr.
	Newton Oolite Mbr.		Sturminster Pisolite Mbr.
Stour Formation	Nothe Clay Mbr.		Hinton St. Mary Clay Mbr.
	Cucklington Oolite Mbr.		Cucklington Oolite Mbr.
	Woodrow Clay Mbr.		Woodrow Clay Mbr.
Lower Calcareous Grit Formation		Hazelbury Bryan Formation	
Oxford Clay Formation		Oxford Clay Formation	

Figure 2. Lithostratigraphy of the Corallian Group in north Dorset used by Wright (1981); and in this account, after Bristow (1989a, b and 1990) and Bristow et al. (1994)