THE PALAEOENVIRONMENTS AND STRATIGRAPHY OF THE LINCOLNSHIRE LIMESTONE FORMATION (MIDDLE JURASSIC: BAJOCIAN) OF NORTHAMPTONSHIRE AND SOUTHERN LINCOLNSHIRE.

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Above all, I thank my wife.

Abstract

The Lincolnshire Limestone Formation, which crops out in eastern England from the Humber south for over 100 kilometres, is well exposed in the study area in the quarries of Cowthick, Clipsham, Copper Hill and Brauncewell. Nine members recognised by previous authors in this formation can be distinguished on gross lithology within this southern region, the lateral and vertical changes in carbonate lithology being indicative of a complex of marginal marine shallow-water environments. A macrofauna dominated by gastropods (but associated with bivalves, bryozoa, rare brachiopods and fragmentary echinoderms) has been recorded from several horizons within the complex stratigraphy sampled at Cowthick, three horizons at Clipsham, three of eight samples at Copper Hill, but is not known from Brauncewell. A low diversity microfauna of ostracods and benthic foraminifera is known from more of the sampled horizons at Clipsham and Copper Hill and up to four horizons at Brauncewell. This fauna has not been recorded at Cowthick. The ostracod *Praeschuleridea subtrigona* occurs with other species characteristic of the *Pneumatocythere carinata* (ostracod) Subzone, consistent with parts of the (ammonite) *Laeviuscula* Zone age ascribed to at least part of the strata by earlier authors. The size distributions and morphological forms displayed by the ostracod and foraminifera faunas suggest periods of vegetative cover on the sea floor, periods of sediment anoxia and the reworking of material from adjacent sedimentological environments at Clipsham, Copper Hill and Brauncewell. Sedimentological breaks between members and individual beds have allowed previous authors to correlate over distances in the study area, this technique has allowed a temporal link to be suggested between the erosion of Aalenian deposits and the deposition of material and both Cowthick and Copper Hill.

Chapter 1. Introduction.

1.01. Aims of the research.

This research aims to identify the palaeoenvironments and depositional histories of those exposures studied, producing a biostratigraphic zonation scheme of the Middle and Upper Lincolnshire Limestone Formation in mid Lincolnshire and north Northamptonshire. This research aims to correlate the southernmost edge of the Lincolnshire Limestone Formation (north of Kettering), with the bulk of the stratigraphic succession further north (Figures 1-2). The need arises because the Lincolnshire Limestone Formation in Northamptonshire is poorly constrained as a result of its lithological, preservational and faunal complexities. This research uses the stratigraphic nomenclature defined in Ashton (1977, 1980). This study aims to use the "holistic community concept" of Kauffman and Scott (1976), to look at the entire fauna in order to better understand the complex structure and ecological interactions within the Formation and its associated members.

Figure 1. The outcrop of Middle Jurassic rocks in England. From Coleman (1981).

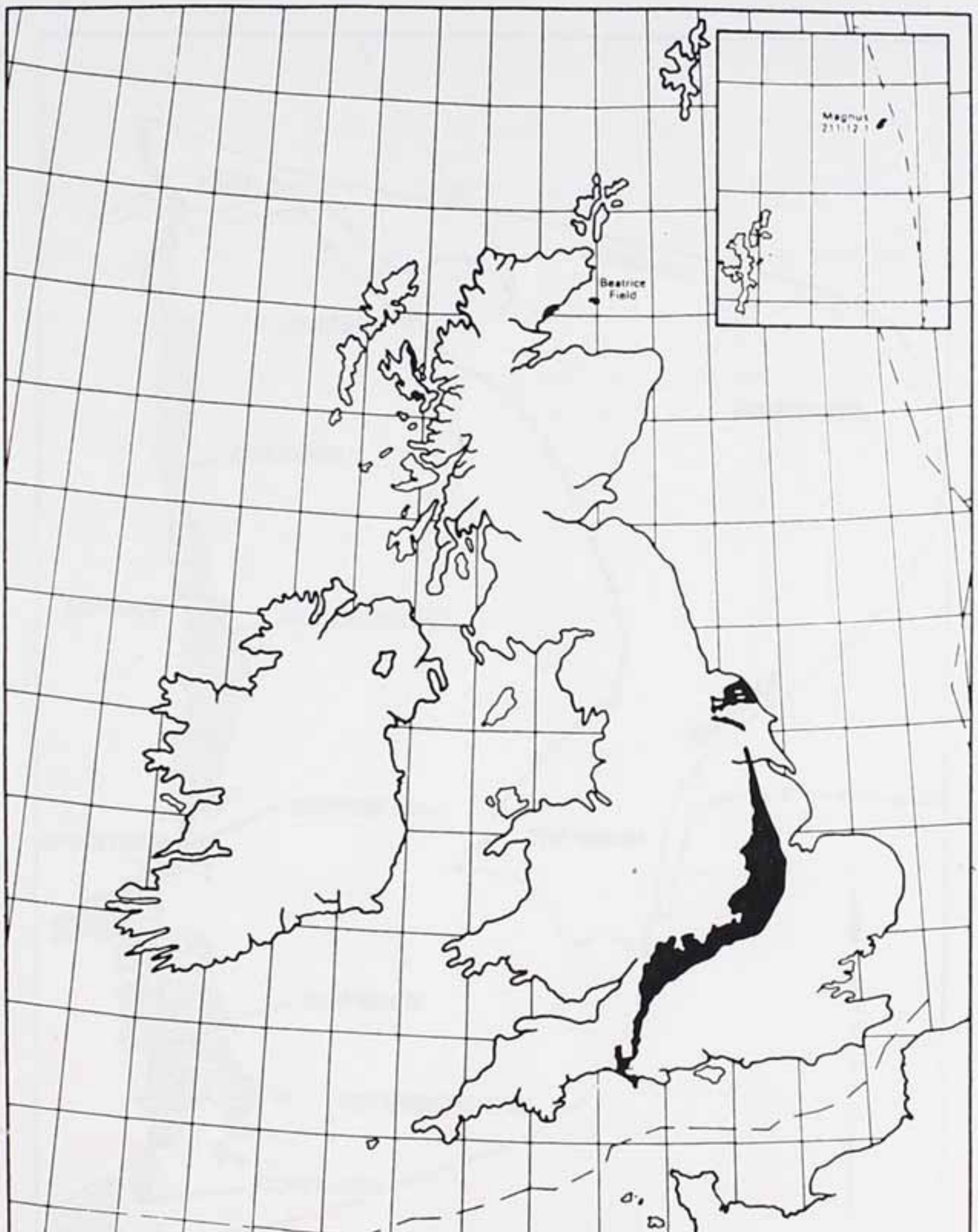
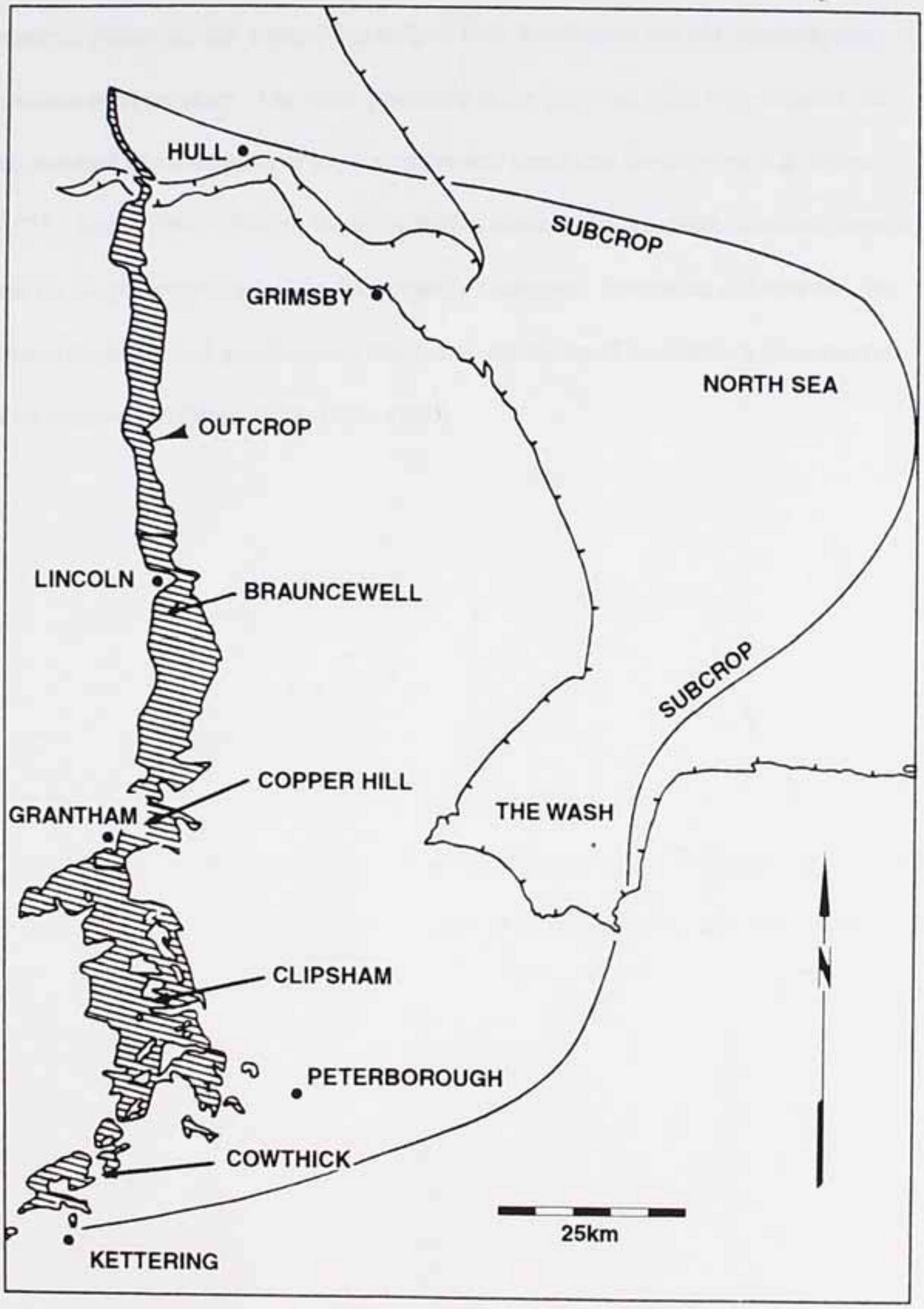


Figure 2. The outcrop and subcrop of the Lincolnshire Limestone Formation indicating study area. (Adapted from Emery and Dickson, 1991).



1.02. Geological setting.

Since the middle of the 19th century, concerted efforts have been made to define and correlate the strata of the Lincolnshire Limestone Formation (Figure 3). Much of the research during the last century has utilised both lithological and bio-stratigraphical methods of correlation. The work produced in the past was often very detailed, but has resulted in a confusion of local stratigraphic terms and descriptions e.g. Evans (1952), Kent (1966). During the latter half of this century, research has concentrated less on the palaeontology of the Lincolnshire Limestone Formation and more on the lithostratigraphy and geochemistry and some resolution of the plethora of names has been achieved (Ashton, 1977, 1979, 1980).

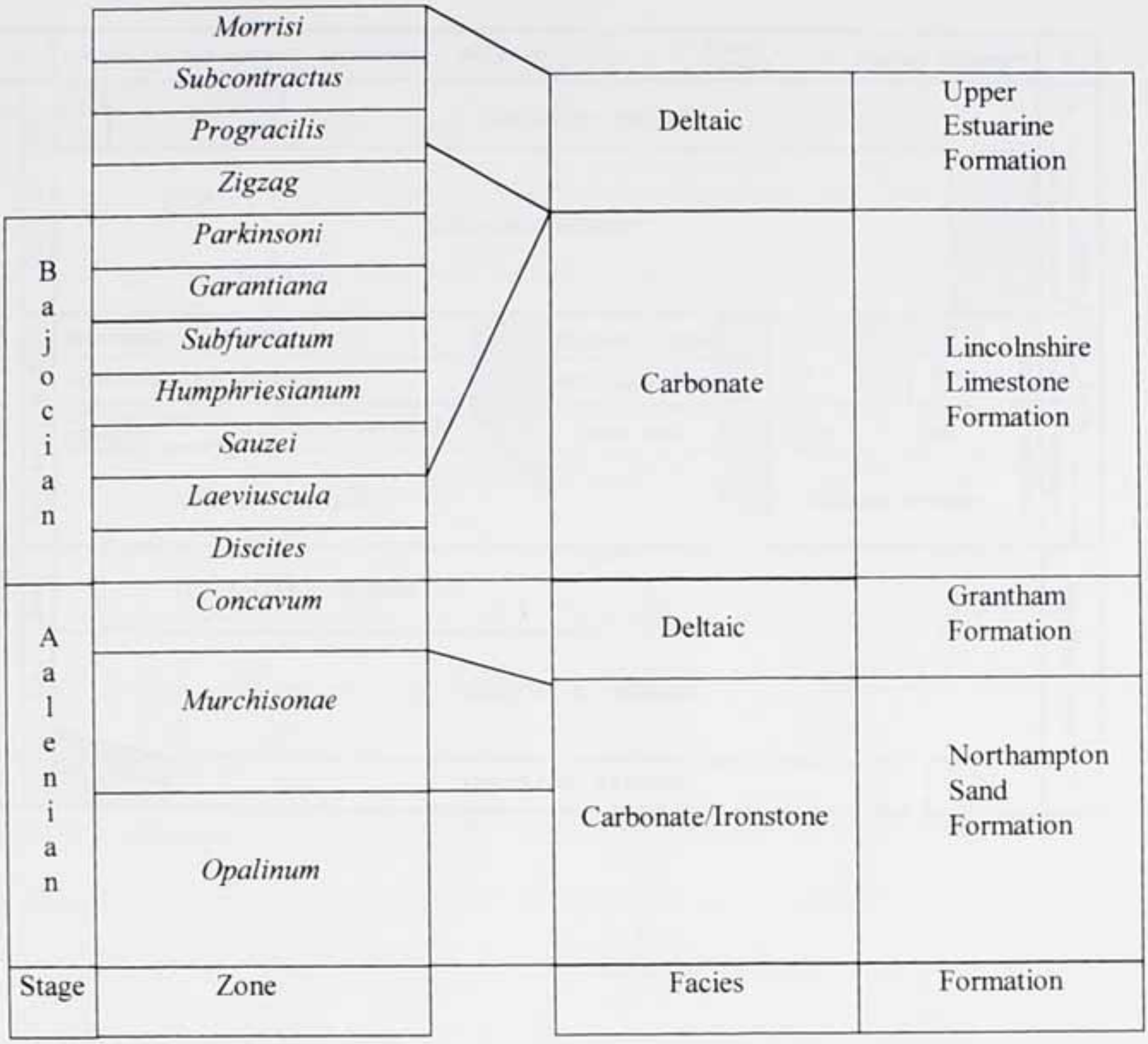


Figure 3. A generalised Middle Jurassic succession of the East Midlands (not to scale). Compiled from Ashton (1977, 1980), Cope *et al.* (1980) and Harland *et al.* (1990).

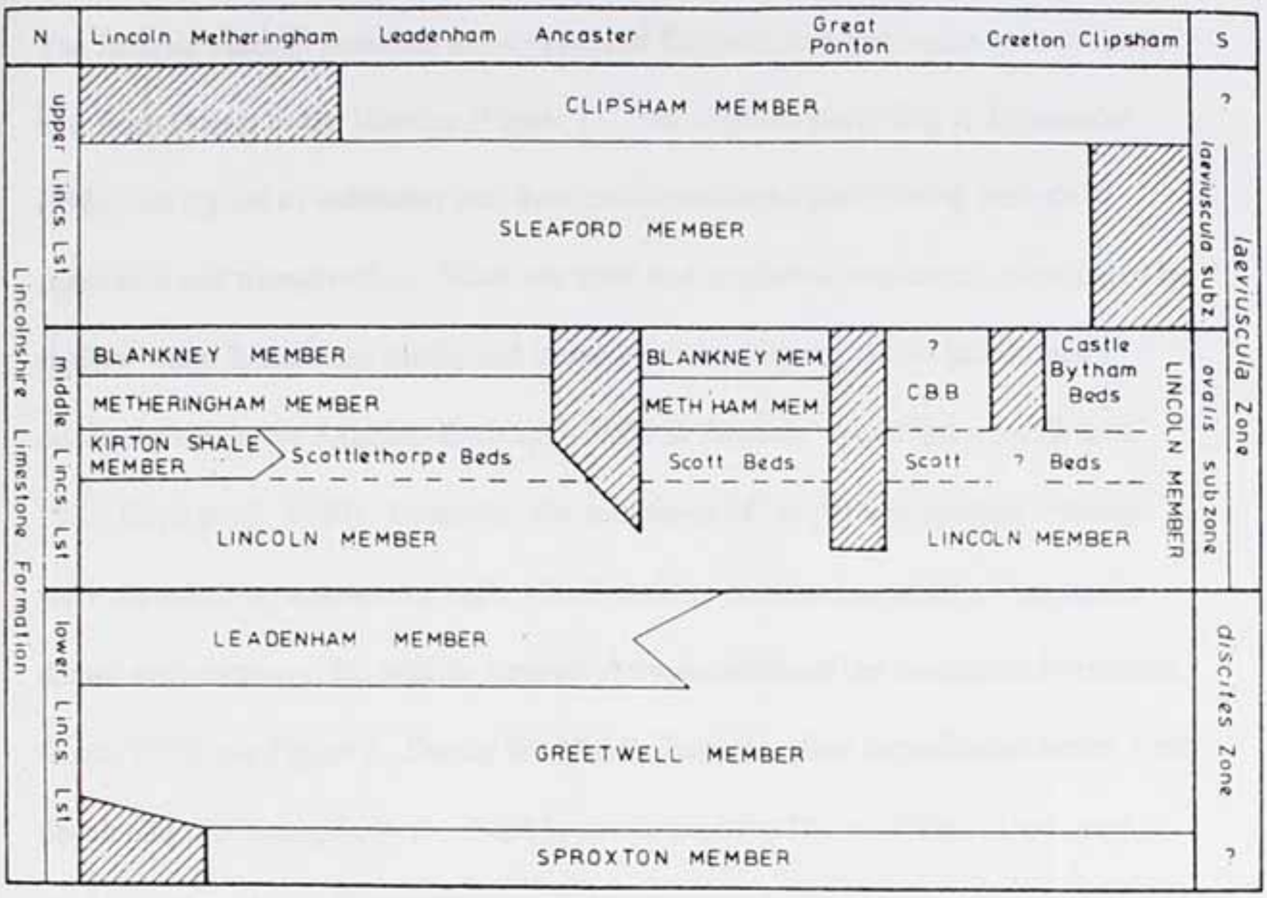


Figure 4. The generalised lithostratigraphy proposed for the Lincolnshire Limestone Formation according to Ashton (1977, 1980).

Shaded areas relate to missing strata.

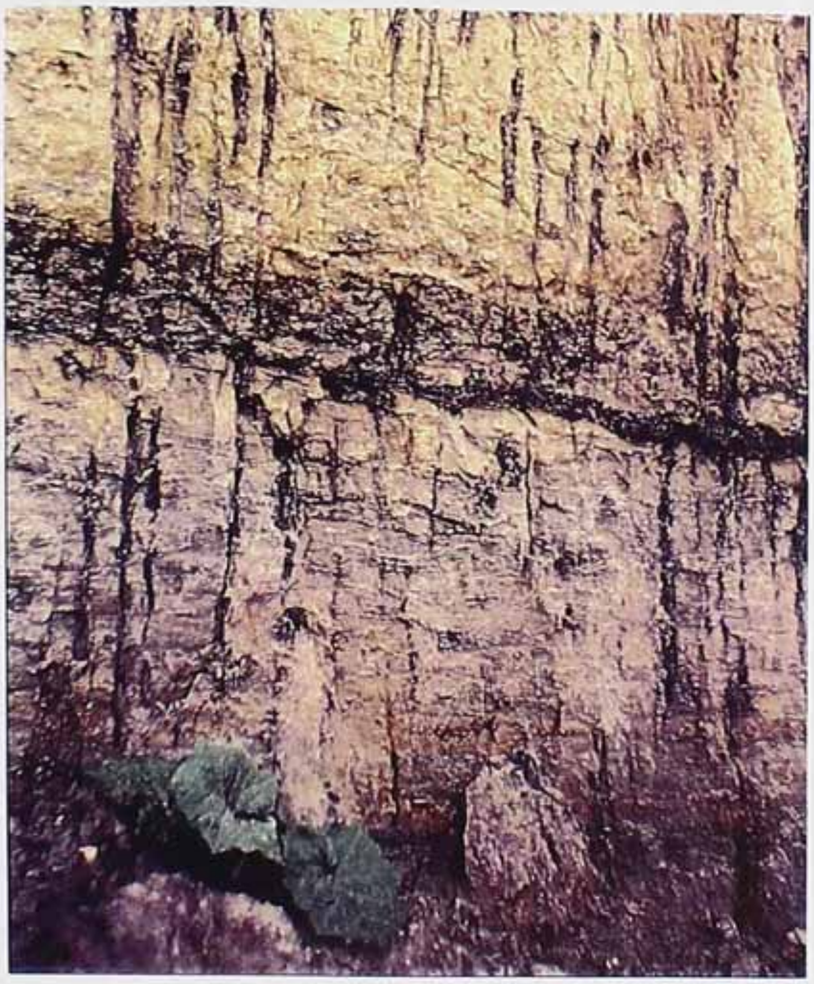
1.03. Regional geological setting.

The Jurassic outcrop stretches through central England on a line south-west to north-east from Dorset to the Humber (Figure 1). The deposits according to Copestake (1989) are typical of sediments that form on a continental shelf during periods of regression and transgression. There are shale and mudstone sequences, punctuated by shallow water limestones, sands, and ironstones: the majority of the limestones occurring within the Aalenian-Bathonian "Middle Jurassic" (see Figure 3), (Arkell, 1933; Cope *et al.*, 1980). Generally, the sediments of the present Jurassic outcrop were deposited on a structural high, which at times became emergent giving rise to deltaic sequences e.g. the Middle Jurassic Aalenian strata of the Grantham Formation, (Kent, 1975) see Figure 3. During the Middle Jurassic, other depositional basins were developing, for example, to the south in the form of the Wessex-Weald Basin and in the North Sea. In the Cotswolds, the Middle Jurassic succession consists primarily of the Inferior and Great Oolites, with other limestones, up to the Cornbrash, which indicate a more stable marine environment. However, non-marine strata do occur for example, in the Sharps Hill Beds of Oxfordshire (Bathonian). Eventually with the onset of deeper water conditions, the Jurassic succession was submerged beneath the clays of the Callovian and Kimmeridgian. Despite a brief shallowing during the Upper Oxfordian, which gave rise to coralliferous limestones in some areas, conditions remained relatively constant until the Cretaceous. At this time thin sands were deposited on an unconformity caused by the period of uplift of the London Brabant Massif. These sands were in turn overlain during the Upper Cretaceous by Chalk before the region finally became emergent during the Tertiary.

1.04. Local geological setting.

The majority of the strata outcropping in the present study area occur within the Middle Jurassic. This period was characterised by repeated periods of emergence with deltaic deposits interspersed by limestone deposition (Figure 3). At the base of the Aalenian in the study area is the Northampton Sand Formation. This consists of shallow water sandy ironstones up to 18 metres thick. For centuries, these have been exploited by industry in the area, especially around north Northamptonshire (Kent, 1966; Elford, *pers comm.*). The Ironstone rests unconformably on clays of the Upper Lias.

Figure 5. Rootlet beds in the Upper Estuarine Formation exposed at Cowthick in the 1970's. Leaves up to 15 centimetres across.



A shallowing of the sea then resulted in the deposition of the Grantham Formation, formerly called the Lower Estuarine Series (Kent, 1975). This is a deltaic deposit which exhibits rootlet beds (Taylor, 1963) which suggest periods of at least partial emergence (Figure 5). The fine clays of the Grantham Formation, (sandy in places) often contain quantities of mica (Kent, 1966). The next series of strata, known as the Lincolnshire Limestone Formation, comprise three discrete units - Lower, Middle and Upper (Figure 4 and Ashton 1977, 1979, 1980). The Lincolnshire Limestone Formation stretches from North Humberside (where it is known as the Cave Oolite), through central Lincolnshire where it reaches a maximum thickness of 40 metres, before thinning at its southern edge in central Northamptonshire (Kent, 1966; Elford, *pers comm.*; see Figure 2). This thinning is most probably due primarily to erosion prior to the deposition of the Upper Lincolnshire Limestone in this area (see Chapter 4); but possibly some original variation in the thickness of deposited material may also be represented. The Lincolnshire Limestone Formation comprises a range of transgressive carbonate and minor clay lithofacies, which constitute the most significant carbonate unit in the East Midlands. It is also an important aquifer (Emery and Dickson, 1991).

Oolitic and skeletal carbonates are deposited in warm, clear, oxygenated marine environments, quite unlike the conditions implied by the deposition of deltaic clays such as those of the underlying Grantham Formation and overlying Upper Estuarine Formation. The Lincolnshire Limestone Formation is of proven Bajocian age with faunas indicative of at least *Discites* and *Laeviuscula* ammonite Zones (Figures 3 and 4) (Ashton, 1976, 1977, 1980; Cope *et al.*, 1980). The Lincolnshire Limestone Formation exhibits a dearth of ammonites that are typically crucial to comparative correlation within the present zonal scheme for the Middle Jurassic (Figure 3). In fact, there is no record between the top of the Lincolnshire Limestone and the Upper Estuarine Formation of seven of the conventional ammonite zones.

This paucity of ammonites is due (in varying degrees), to three factors.

1) It is possible that some environmental parameters (for example salinity) were not conducive to the survival of ammonites.
2) A marine barrier may have restricted their access to the area of deposition.
3) Large sections of the formation have been stripped away by erosion possibly removing any ammonites that were once present.

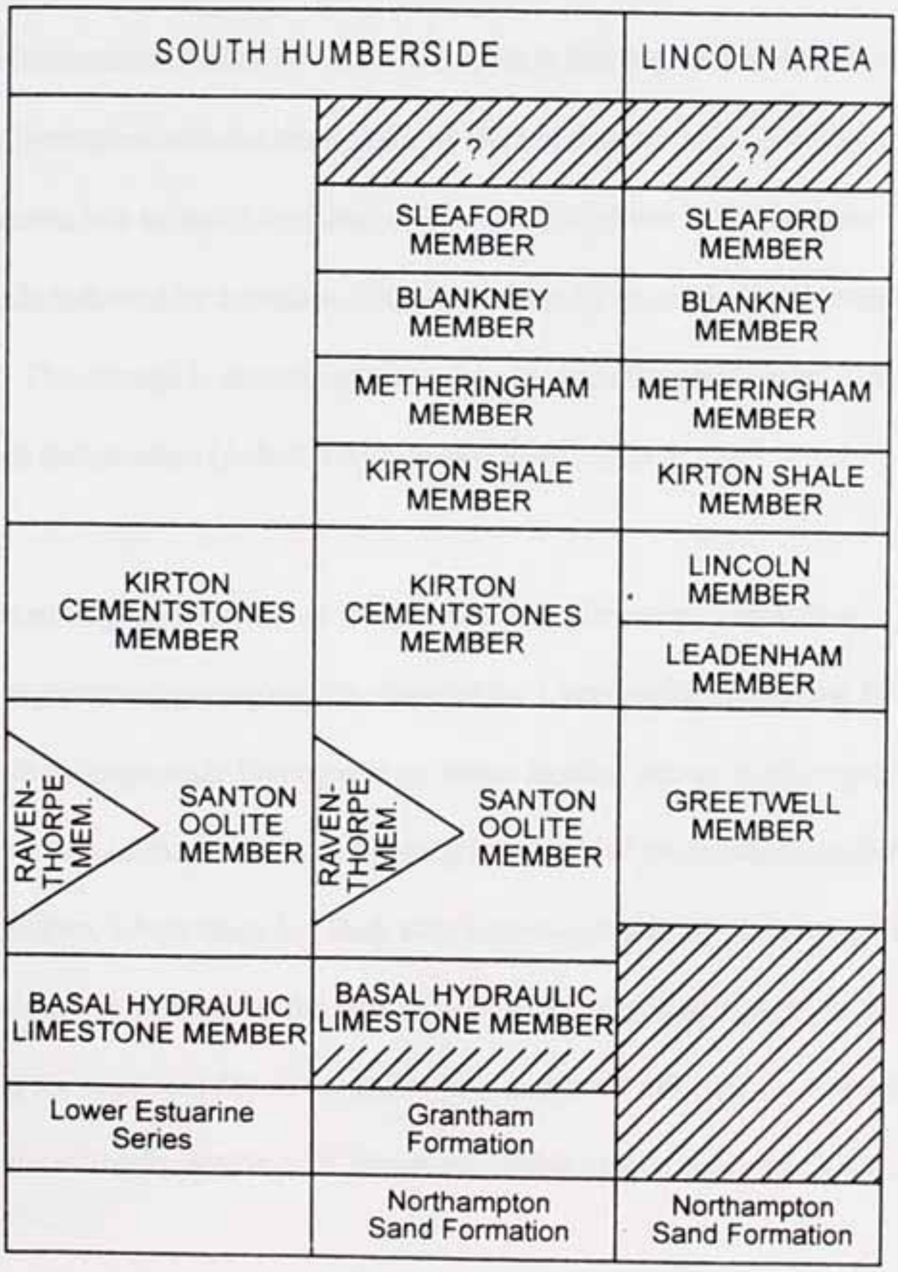
The general consensus concerning the deposition of the Lincolnshire Limestone Formation suggests that it represents a complex of depositional environments produced as a barrier bar migrated across a protected lagoon (Ashton, 1977; Tucker, 1985). Study of the formation over recent years has been hindered by the rapid vertical and lateral facies variations that occur, an almost total lack of established (and reliable) index fossils, together with a dwindling number or exposures available for study due to the decline in the British steel industry.

Some ammonites have been found and identified from the Lincolnshire Limestone Formation over the years but their use has been limited as a result of their occurrence at only a few localities and horizons. Those ammonites discovered (Barker and Torrens, 1971; Ashton, 1976), indicate strata spanning the *Discites* Zone and the *ovalis* and *laeviuscula* Subzones of the *Laeviuscula* Zone (Bajocian) (Figure 3). However, as these finds are confined to the strata considered of Middle Lincolnshire

Limestone Formation age, these fossils give no indications as to the upper and lower ages of the Lincolnshire Limestone Formation.

The Lincolnshire Limestone Formation is believed to correlate with strata around South Humberside (Figure 6), notably the Santon Oolite correlating with the Greetwell Member (Ashton, 1980).

Figure 6. A correlation of the strata in the study area with those of adjacent depositional areas. From Ashton (1980).



Furthermore, the Lincoln Member is considered equivalent by Ashton (1977, 1980) to unit F of the Kirton Cementstones (Packer, 1986). These authors also recognise the Kirton Shale Member from the Lincolnshire Limestone Formation around Lincoln (Figure 1). The Kirton Cementstones are also believed by Ashton (1980) and Packer (1986) to correlate with the sequence from the Basement Beds/Hydraulic Limestone south of Market Weighton and into the lower Middle Deltaic Series of North Yorkshire. Bradshaw and Bate (1982) substantiate this view.

Overlying the Lincolnshire Limestone Formation is the Upper Estuarine Series (Lower to Middle Bathonian) (Figure 3). This formation is lithologically similar to the Grantham Formation with the deposition of clays and sands, which appear to have been laid down in a series of rhythmic units. These rhythms comprise green clay with marine shells followed by a decline of shelly content as brackish / fresh water begin to dominate. This change is associated with an increase in the numbers of plant remains, rootlets and darker clays (Arkell, 1933; Dawn, *pers comm.*).

1.05. The geological structure of the Lincolnshire Limestone Formation.

The post-depositional geological structure of the Lincolnshire Limestone Formation is simple, with no large scale folding and no major faulting except in the exposures on the southern borders of the Formation. Faulting is notable at the southern end of Cowthick Quarry, Weldon, where there is a fault with a throw of at least 10 metres. However, synsedimentary movements at the time of deposition may well have been significant in influencing the thickness deposited and in turn may have affected the stratigraphical relationships of the formation with lithostratigraphic units elsewhere. Two of the structural systems active at the time, which may well have affected deposition, were the Spital Anticline and the Nocton Uplift.

Around the Spital Anticline region, the Upper Estuarine Series (Bathonian) can be seen to rest on an eroded contact with the underlying Middle Lincolnshire Limestone (Kent, 1966; Ashton, 1977). This suggests the removal by erosion of the Upper Lincolnshire Limestone Formation during a period prior to the deposition of the Upper Estuarine Series (Figure 3). Elsewhere these movements are indicated by synclinal structures, such as that believed responsible for the preservation of beds at Great Ponton, which have been considered the youngest strata in the Lincolnshire Limestone Formation. It is therefore possible that minor structural movements have had an effect on the sedimentology and stratigraphy of the rocks formed and on their relationships with contemporary sediments in other areas.

The Nocton Uplift is apparently related to deep seated Palaeozoic structures and appears to have exerted some influence on sedimentation during the deposition of the Lincolnshire Limestone (Ashton, 1977) in that it acted as a stable block, with the Lincolnshire Limestone Formation deposited horizontally over it. This uplift may therefore be of some significance as a control to sedimentation. The Lias is known to thin across it between Coleby and Lincoln (Ashton, 1977). Here the Lincoln Member is absent leaving the Lincolnshire Limestone Formation resting directly on the Northampton Sand Ironstone (Swinnerton and Kent, 1976; Ashton, 1977, 1980).

1.06. History of research.

1.06.1. Lithostratigraphy.

The earliest known studies on the Lincolnshire Limestones (Brodie, 1853; Morris 1853, 1869) were unable to define its true stratigraphic position. It was not until the work of Sharp (1873) and Judd (1875) that the rocks were established as being of Inferior Oolite age. Woodward (1894) collated the data collected by various authors of this period. Later workers such as Richardson and Kent (1938), Muir-Wood (1939, 1952), Kent (1940, 1953, 1966, 1970, 1975), Hollingworth and Taylor (1946, 1951) and Barker and Torrens (1971) all added to our understanding of the correlation, relative age and subdivision of the formation.

The major advance in the understanding of the lithological correlation of the formation came with Ashton (1977, 1979, 1980) when the older schemes and terminologies were reappraised in the light of detailed study of outcrops and cores (Figure 3). In his studies, Ashton discarded the old and often contradictory bipartite correlation scheme and terminology, to replace them with a simple tripartite scheme, subdivided into nine members, which were correlated according to sedimentary structure and lithology (Figure 3, and Ashton 1977, 1980). Lithologically Ashton considered the Lower Lincolnshire Limestone Formation to represent lagoonal deposition, the Middle to represent back-barrier deposition and the Upper barrier deposition. However, the Ashton scheme took little account of the faunas present in each member. There is no difficulty using Ashton's scheme in the field in the central and northern part of the Lincolnshire Limestone Formation outcrop. This is not, however, the case in Northamptonshire, with its complex erosional / depositional history and nearshore influences. The Northamptonshire region is one area that would greatly benefit from a faunal zonation scheme. This should facilitate improved internal correlation of the members of the Lincolnshire Limestone Formation.

1.06.2. Geochemistry and diagenesis.

After the publication of Ashton (1980), most research has been concerned with the chemistry and diagenesis of the limestone, much of which has been driven by interest in the role of the formation as an aquifer, particularly in terms of its diagenesis (Emery and Dickson, 1989, 1991). These studies used core, gamma log and thin section techniques to produce a subsurface correlation of the Lincolnshire Limestone Formation, the outcomes of which broadly agreed with the views of Ashton (1977, 1979, 1980). Furthermore, their research suggested that the Clipsham Member was sub-aerially exposed at some point. Marshall and Ashton (1980) and Emery *et al.* (1988) were more concerned with the origin of the cementation of the limestone, especially the many hardground (Figures 7a, 7b and 8) occurrences within the Formation. These are important structures because they represent breaks in sedimentation either due to erosion or reduction in sediment supply. They are also structures of value for the sub-division and correlation of the Lincolnshire Limestone Formation (Ashton, 1977, 1980). These however are often small-scale and their recognition can be difficult in the field.

Figure 7a Cowthick hardgrounds, side view. Specimen 16 centimetres long.

Figure 7b. Cowthick hardgrounds, top view. Specimen 16 centimetres long.

Figure 8. *Bactroptyxis cotteswoldiae*, in a fragment of Cowthick hardground. Internal cast 3 centimetres long

1.06.3. Gastropods.

The fauna of the Lincolnshire Limestone Formation is exceptionally varied with many species that appear to be endemic. The major publication that examined the fauna of this formation is that of Hudleston (1888). This work was largely concerned with the gastropod fauna of the Lincolnshire Limestone Formation, although some discussion was made concerning other groups and localities. It is possible that more forms were described as species than actually existed (e.g. several of the species of *Cerithium, Phasianella* and particularly *Ptygmatis* (*Bactroptyxis*) appear synonymous). The species *Ptygmatis (Bactroptyxis) implicata* (d'Orbigny) for example may include a dozen of the species described by Hudleston (Barker, 1976 and *pers comm.*). This is possibly due in part to the degree of internal variation between individual nerinoideans (Barker, 1994). Nevertheless, as Hudleston (1888, p.195-196) said "When to these difficulties (poor preservation) we add the prevalence of dimorphism, it must be allowed that the Nerinaea of the upper beds of the Upper Lincolnshire Limestone (Weldon and Great Ponton), constitute about as undesirable a group as any one could have to investigate."

1.06.4. Brachiopods and associated faunas.

Muir-Wood (1939, 1952) reviewed the brachiopod faunas, concluding that they appear to be of limited use for correlation. The most stratigraphically important brachiopod in the formation has been considered by Kent (1940) to be *Acanthothiris crossi* (Walker). This species was long considered to occur in marker horizons (known as the *Crossi* Beds), which could be used to divide the entire formation into an Upper and Lower Lincolnshire Limestone. Ashton (1979) however, reviewed the occurrences of this brachiopod in the context of the few ammonite discoveries that had been made and the latter's relationship to his proposed correlation scheme. He found that the biostratigraphic use of *A. crossi* was limited only to the *laeviuscula* Subzone and that it was too unconstrained to be used as a zone fossil. This brachiopod can now only be used confidently to indicate the Middle Lincolnshire Limestone Formation (the Lincoln, Kirton Shale, Metheringham, and Blankney Members) according to Ashton (1979).

Trigonia hemisphaerica var. *gregaria* was considered a biostratigraphic indicator within the formation, as were the various brachiopods of the *Acanthothiris crossi* beds. The brachiopods from the *Crossi* Beds – *A. crossi*, and terebratulids resembling

Lobothyris buckmani and *Trigona painswickensis* were also formerly considered by Kent (1940) to be index forms due to their similarity to forms from the Buckmani Grit of the Cotswolds (*Discites* Zone). However later work has disproved these suppositions. Not only have the Buckmani Grit species been found to be different to those of the Lincolnshire Limestone Formation (Kent, 1966), but ammonites of the *Ovalis* Subzone have also been found in both the *Trigonia hemisphaerica* and *A. crossi* Beds.

1.06.5. Ammonites.

The current consensus is that the Limestone spans the *Discites* Zone and the *ovalis* and *laeviuscula* Subzones of the *Laeviuscula* Zone (Figures 3 and 4). Although as already stated, the Upper and Lower Beds have yet to yield many ammonites, with only the Middle Limestone Formation being productive.

1.06.6. Microfossils.

The microfaunas of the Lincolnshire Limestone Formation period have often been largely overlooked in the past.

The ostracoda have undergone much study through the work of Bate (1963a, 1963b, 1964, 1967a, 1967b). However, the majority of these works have concentrated on material from other Middle Jurassic localities that have more prolific microfaunas than those of the Lincolnshire Limestone Formation. Other such works used include Nagy *et al.* (1981), Morris (1983) and Packer (1986). Only those ostracod species cited by these authors are referred to in this study. Other than the work of these authors there has been little research into the palaeoenvironmental uses of Bajocian ostracods.

The foraminiferal faunas of the Lincolnshire Limestone Formation have undergone little research. The most notable work was that of Packer (1986), his samples being taken from South Humberside. This work is considered of similar enough age and environment to be applicable to the sediments of the Lincolnshire Limestone Formation in this study. Further studies on coeval sediments were published by Morris (1982) from the Cotswolds and Nagy *et al.* (1981) from the Middle Bajocian Yons Nab Beds . Reference must be made to Coleman (1981) who states "The only English Bajocian material studied has been a cored sequence from Lyme Bay in Dorset…The most diverse assemblages are found in the *Murchisonae-Discites* Zones, in which occur the upper range limits of several Lower Jurassic species viz.: *Lenticulina dorbignyi*, *Nodosaria regularis*, *N. tenera*, *N. pulchra*, and *Vaginulina* cf. *listi*…Few Foraminifera were obtained from the *Laeviuscula* and *Sauzei* Zones." These observations suggest that foraminiferal diversity should be greatest in the Lower Members of the Lincolnshire Limestone Formation.

1.06.7. Scope of the Thesis.

In order to identify the palaeoenvironments and depositional histories of the Lincolnshire Limestone Formation in the study area it is first necessary to understand the context of the material to be studied in terms of its geology and fauna as has been discussed in Chapter 1.

The next step has been to choose which field and laboratory techniques are best suited to the fulfilment of this studies aims whilst taking into account time constraints, the type of exposed material, health and safety and faunal identification as will be discussed in Chapter 2.

To best communicate the results gained using the techniques discussed in Chapter 2 the next Chapter is dedicated to the systematic description of each quarry sampled in turn. The quarries are described in Chapter 3 which outlines each quarry in terms of its lithological character and palaeontology, these results being given within the framework of Ashton's (1977, 1980) scheme of lithological members.

In Chapter 4 the results are discussed within the framework outlined in Chapter 3 on a member by member basis. Detailed hypotheses are discussed with conclusions being reached regarding all aspects of the sedimentological and faunal histories of each quarry.

Chapter 5 is dedicated to tying the sedimentological history of each quarry, tracing changes in both the lithological and faunal aspects of each exposure with examples of environmental analogues being given.

The attempts to correlate the Lincolnshire Limestone Formation both internally and into other depositional are discussed in Chapter 6. This chapter also discusses the efforts made to produce a biostratigraphic zonation scheme.

The conclusions reached as a result of this research are discussed in Chapter 7, including aspects of correlation and the impact of the loss of exposures.

The final section of this thesis contains illustrations of the macro and microfaunas an field logs. This final section also includes "Stratabugs" charts which illustrate the changing microfaunas of each quarry in turn.

Chapter 2 Techniques of study.

The standard logging techniques described by Tucker (1981) and Goldring (1991) were employed.

It was decided to only use data collected in the field rather than that collected by previous researchers. This decision was reached on various grounds.

1. Fieldwork only gives a snapshot in time for any given exposure due to commercial excavations, cliff falls and safety issues etc.
2. It was felt that by using fresh data, collected in the same way and to the same criteria the degree of bias might be reduced.
3. No studies had been done on the exposures in this study area with the same research agendas, the previous work being confined to lithological and post depositional studies.

2.0.1. Sampling techniques.

As with the logging, all sampling was undertaken from the basal strata upwards, this was to reduce the potential for contamination by material falling onto horizons yet to be sampled. To reduce further the risk of contamination, the "surface crust" of the least consolidated horizons was cleared prior to sampling. Samples were taken from each bed that was easily broken up by hammer. The sizes of sample taken were partially dependent on the thickness of stratum and the friability of the rock, but most limestone samples were 1000 grams, and clay samples were 500 grams. The samples were double bagged with date, location, bed and height marked clearly in indelible ink on both of the bags, their positions were also marked on the field log (Appendix 1) and quarry plan.

2.0.2. Processing the most friable limestones and clay samples.

Each sample was broken up and placed in a carefully cleaned enamel dish with its sample number clearly marked on the side. Care was taken when breaking up the material so as not to damage any of the more delicate components present. Prior to the processing of any clay the sample was first tested with hydrochloric acid to help determine carbonate content: if it reacted it might be classed as a marl. The dish was then placed overnight in an oven at 50° Celsius. Once oven-dry, each sample was placed in a carefully cleaned beaker, with the sample number clearly marked in indelible ink on the side. Into this beaker a 10% solution of hydrogen peroxide was added. This was added to break down any organic material which might prevent easy sieving, and this was left for several hours. The resulting release of gas also breaks up the clay fraction. When bubbling had stopped, and if clay had become a paste, the samples were then wet-sieved in turn using a 63μm sieve. This method achieved two results. First, it removed all of the clay-sized particles revealing the lithoclastic and bioclastic components present. Second, it cleaned the bioclasts making them more easily identifiable. Once all of the clay was removed the washed samples were returned into their re-washed enamel dishes, with care being taken at all stages to ensure that each sample remained correctly labelled throughout. These were then dried again in the oven under the same conditions as before.

Using a binocular, reflected light microscope, all of the samples were examined at 20-30x magnification. Care was taken to note not only the fauna present but also the various types of other sedimentary particles present as these may be of use in interpreting depositional environment. Small quantities of the processed material were sprinkled on to a sample dish marked into a grid, enough to cover the surface with a single layer of material. The dish was then systematically searched grid by grid for fossil material. Once a fossil was found fragmentary or complete, it was removed from the dish with a moist 0 gauge artist's brush, and was placed in a clean sealable container. The remaining material in the tray (after all the larger macrofossils had been removed) was then discarded. This continued until approximately 300 individuals (or all that were present) had been removed. In instances where it was apparent that there was a large number of species present in the sample, particularly when they represented a number of fossil groups, more were picked. This was done in an effort to not only create the best picture of the fauna present, but also to pick up any species which, however rare, might be used to identify a particular environment or stratum.

Once sufficient material had been removed, a micropalaeontological slide was prepared. First, the slide was marked up carefully with the sample number and date. The gridded paper surface of the slide was then charged with a film of gum arabic, to which the material was affixed. The material was firmly stuck to the gum by dampening the gum surface with a sample brush. The material was mounted in groups according to fossil group and species on the slide, with miscellaneous material on a different part of the slide. Any material too large to fit in the covered slide was placed in the numbered compartments of a sample tray, for example *Alaria* in one compartment *Actaeonina* in another. Again, the sample number and date was clearly marked on each tray.

From this point, identification of fossils could take place using relevant papers, reference collections and publications. Where the fossil could be identified down to a genus, e.g. *Alaria,* it was recorded as *Alaria* sp. Where a species was distinct from other forms but no available text figured or described it, it was described for example as Bryozoan sp. A, until it could be correctly identified. Forms initially descriptively referred to in this research as, "Owls face ossicles" proved to be the sysygial facets of crinoids as identified from diagrams in Taylor (1983).

It was often the case at some exposures, that some gastropods could be identified no further. They were recorded as Unidentified Gastropods (or Unidentified nerinoideans). In all cases the macrofaunal mode of preservation was noted as this could have value later in environmental analysis of the sample location. During the studies of microfauna, not only was preservation noted, but also environmental indicators were recorded such as valve separation.

2.0.3. Preparing gastropod thick-sections.

The identification of nerinoidean gastropods using external characteristics alone of nerinoidean gastropods is difficult. Where nerinoideans were present of sufficient size, a pencil line was drawn down the shell to mark the exact position of its longest axis. The shell was then placed on a flat glass plate charged with a paste of water and coarse silicon carbide powder. The shell was then rubbed with the plate parallel to the pencil line. As the shell was ground close to the line the paste was changed to one containing a finer silicon carbide powder. Grinding continued until the shell was ground exactly to the pencil line.

2.04. Sampling strategy

As calcareous skeletal types dominated the faunas the uses of chemical preparation techniques were restricted as the matrix material was also calcareous. The techniques employed for removing calcareous fossils from hard limestones are often highly destructive with pulverisation of the rock often being necessary. In order for the faunas to remain identifiable this approach was not used. This was to ensure that as much information as possible could be obtained from the exposures. Some processing of the harder horizons could have been carried out (as omission introduces a degree of sampling bias) but it was felt that this would not (for the time involved) further this research to any degree. As a result the faunas of the hardest limestones were only studied from careful field observations using material on the exposed surfaces. Softer limestones, shales and clays can be processed using less aggressive techniques which preserve the information potential of the sediment. This is the strategy that was chosen as it was felt that by employing this method the largest range of faunal elements would be available for study. Therefore every marl, clay, and soft limestone horizon was sampled (that were both accessible and safe) for later study.

Therefore the decision whether to sample a particular horizon for microfossils was broadly dependent on these criteria;

1. Safety and accessibility.
2. Whether the material would break up enough to remove from the exposure.
3. Whether the material (limestone) was crumbly enough to break up during processing.

2.0.5. Taxonomy and identification

This study uses the following methodologies, taxonomies and articles.

1) Gastropoda; Hudleston (1888), Barker (1976, 1990), Knight *et al.* (1960), and Kohn and Arua (1999).

2) Ostracoda; Bate (1963a, 1963b, 1964, 1965, 1967a, 1967b), Bate and Robinson (1979), Bate *et al.* (1984), Morris (1983), Packer 1986) and Morris and Coleman (1989).

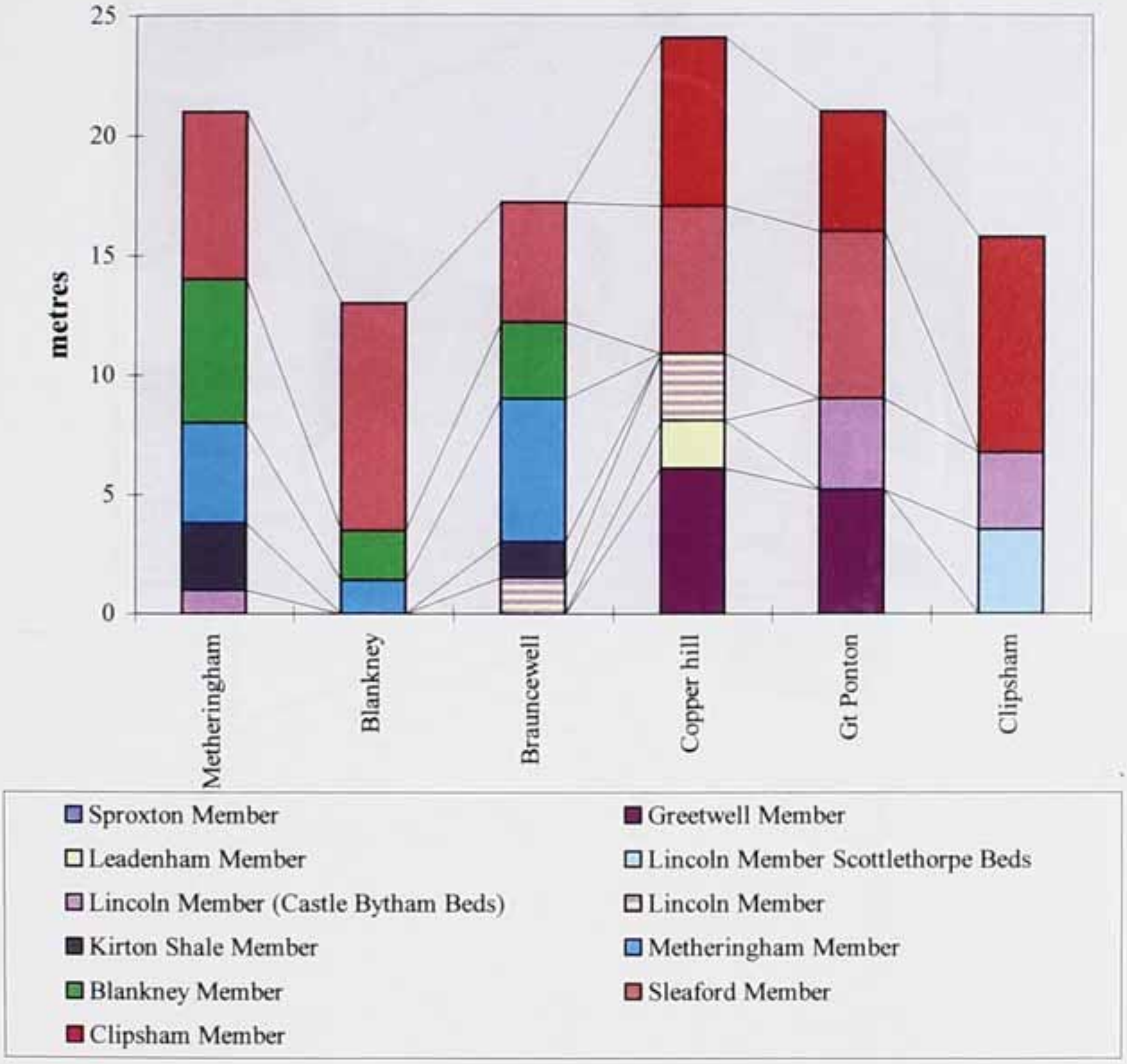
3) Foraminifera; Loeblich and Tappan (1964), Shipp (1978), Haynes (1981) Coleman (1981), Morris and Coleman (1989), Nagy *et al.* (1981), Morris (1982) and Packer (1986).

4) Brachiopods and bivalves; Muir-Wood (1939, 1952) and Martill and Hudson (1991).

5) Limestone and clay classification; Jones and Sellwood (1989), Tucker (1981, 1991, 1994), Raymond (1995) and Goldring (1991, 1995).

Figure 9

The Quarries visited and the Members present in them including non-sampled quarries. See (Figure 1 for horizontal scale).

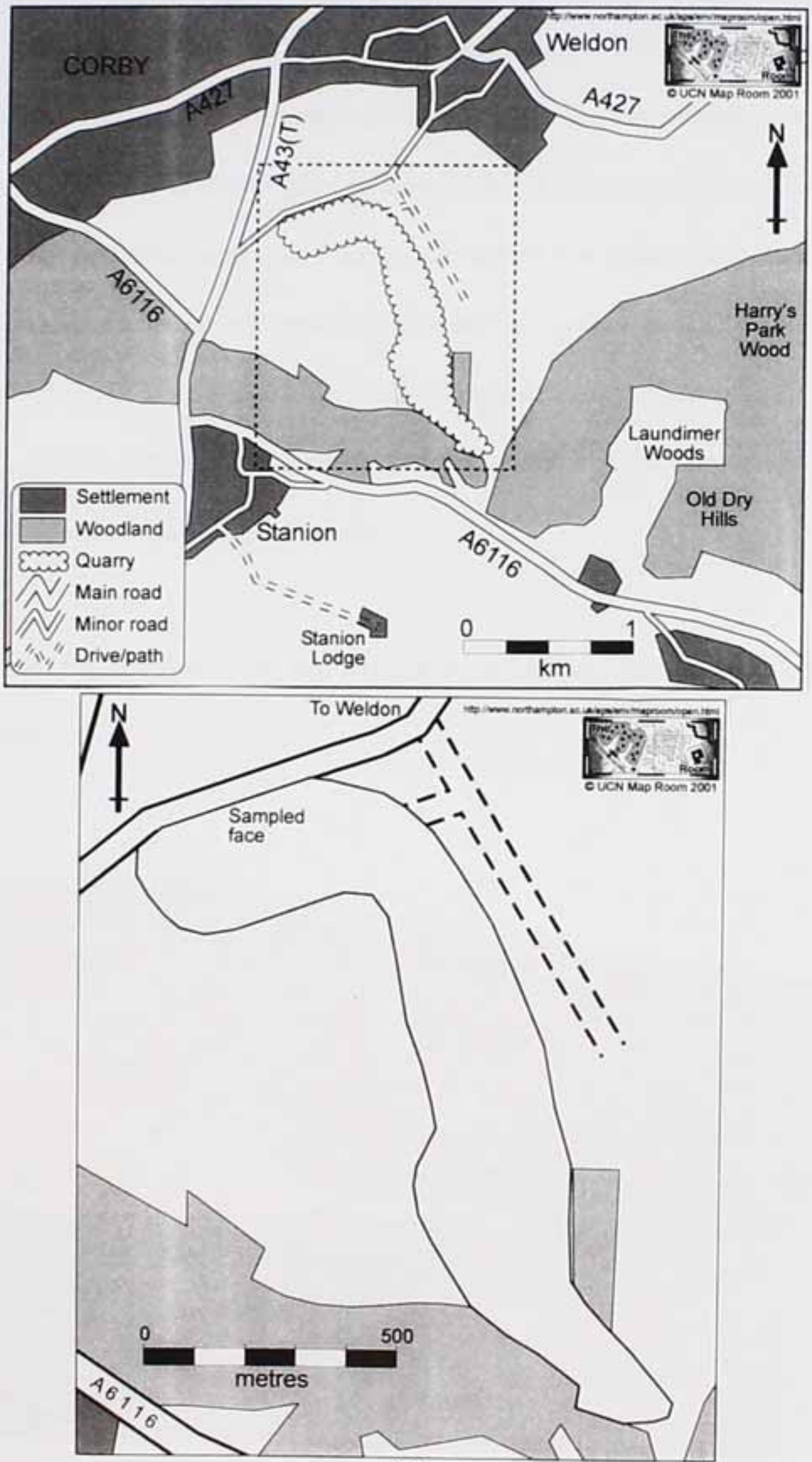


Cowthick Quarry is not included in this figure as the exposure at this quarry does not fit within the member scheme used by Ashton (1977, 1980) see figure 12.

3.01 Cowthick Quarry, Weldon, north of Kettering, Northamptonshire SP920885

(Figure 10)

Figure 10. The floor plan of Cowthick Quarry showing the sampled face.



This Ironstone / Limestone Quarry is situated in the historically highly productive Northamptonshire Ironstone fields. It has been studied extensively since the last century. Important studies concerned gastropod faunas (Hudleston, 1888), sub-marine erosion and channelling (Figures 11-12) and depositional history (Taylor, 1946; Marshall and Ashton, 1980), and diagenesis (Emery *et al.*, 1988). It has long been established that the Lincolnshire Limestone Formation in Northamptonshire represents the southernmost edge of the range of its deposition. It is representative of the most landward edge deposited nearer the London - Ardennes Landmass rather than the rest of the Lincolnshire Limestone Formation to the north. At Cowthick, the faunas and sediments reflect the more variable depositional regimes typical of nearshore deposition. This results in lithological characteristics different from those of coeval sediments that accumulated further north.

Figure 11. A channel fill exposed at Cowthick in the 1970's. The channel is over 20 metres across.

The sediments of the studied face can be divided into a number of depositional and erosional Phases (see Figure 12).

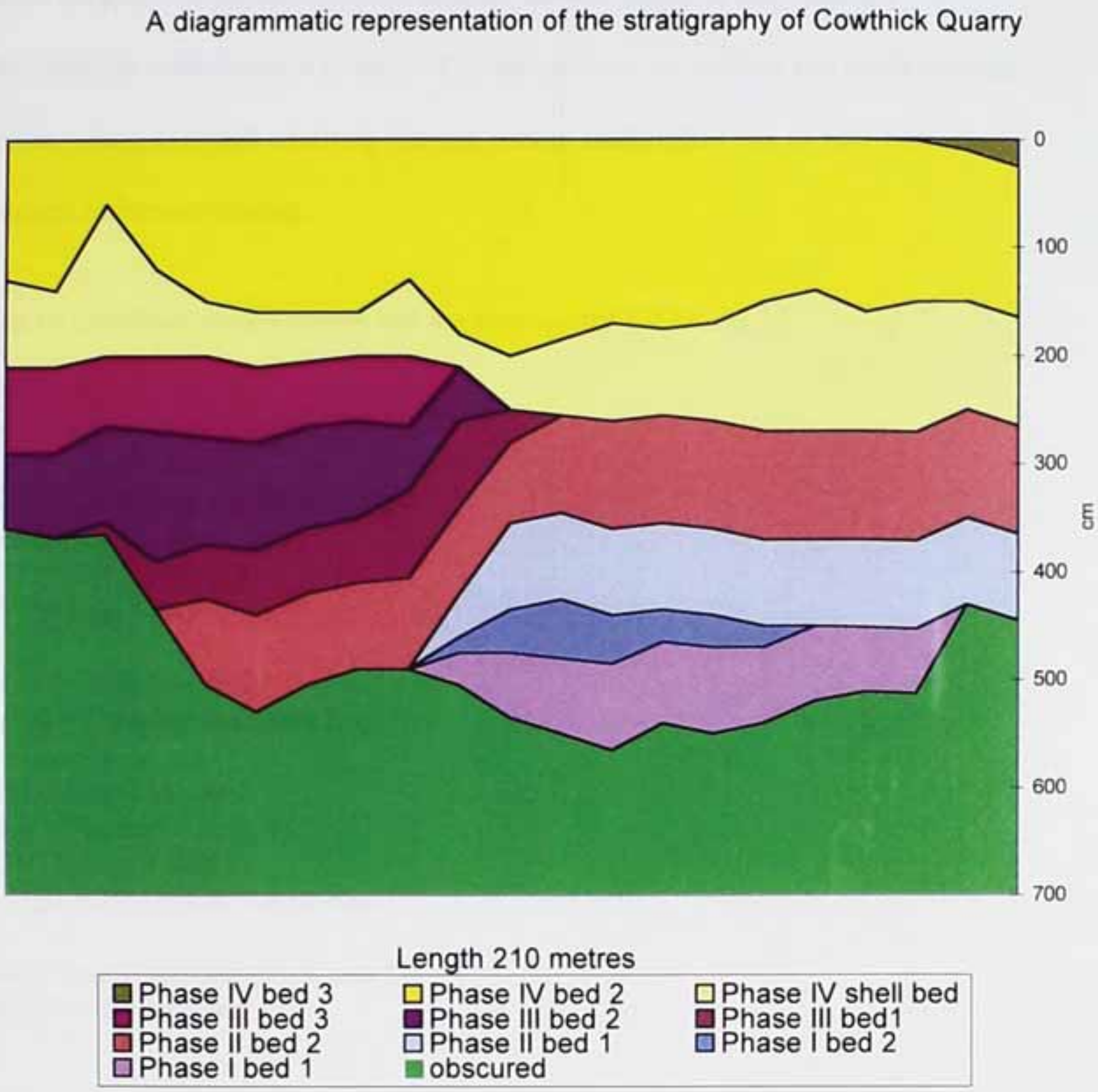


Figure 12.

3.01.1. Phase I.

This is the earliest material exposed and consists of tabular bedded peloidal biosparites with varying textural and mineralogical maturity, exhibiting both orientation of bioclastic material and bedding at scales from 2 millimetre lamina to beds of over a metre (Appendix 1a, Log 1). Micro-morphic gastropods (axial length 1-5 millimetres), faecal pellets, echinoderm fragments, and the oyster *Lopha* (Figure 13) dominate the fauna present. Of the nerinoideans present, the vast majority identified are *Bactroptyxis cotteswoldiae* (Figure 14). Also present are solitary and small colonial corals, which although relatively unworn remain unidentified due to post-mortem calcium carbonate coating.

Key to Cowthick sample names and log annotations for Figure 13

B4 = Base of Log 4
B4 L8 = 5m before Log 8
L5C = Log 5 Clay
6COH = Crumbly Limestone Log 6
L6LB = Log 6 lower bed
L71 = Log 7 sample 1
L7C = Log 7 clay

1↓sh = 1m below shells
Cmy4 = Crumbly limestone Log 4

2bII = Log 2 sample 2
Ch4 = Channel 4 (Log 4)
L3B1 = Log 3 Bed 1
B42B1 = Bed before Log 2 Bed 1

Sb1 = Log 2 bivalves (Shell bed 1)
B.V.B. = Bivalve bed

Figure 13 Sample Counts for Cowthick Phase I. See Appendix 2 for selected systematics.

Cowthick Data	Phase I						
	B 4	b4 L8	L5C	6COH	L6LB	L71	L7C
Smooth echinoid spines	43	10	286	30	34	30	50
Ornamented echinoid spines	5	3	65	4	3	4	21
Echinoid test fragments	7	1			4		15
Echinoid elongate ossicles							
Echinoid "jaw-elements"		2	11			27	
Crinoid elements	21	4	188	8	18	9	5
"Owls-face" ossicles							
Crab claws							
Sponge spicules							
Ophiuroid elements			1				
Arcidae sp.							
Camptonectes sp.							
Freiastarte sp.							
Gervillia sp.							
Lopha sp.							
Liostrea. sp.							
Lucina bellona							
Lucinidae sp.							
Modiolus imbricatus							
Opis sp.							
Pholadomya lirata							
Pholadomya ovalis							
Pinna sp.							
Pseudolimea cf. *duplicata*							
Trigona cf. *costata*							
Acanthothiris crossi							
Microrhynchia pontonensis							
Microrhynchia barnackensis		1					
Parvirhynchia kirtonensis							
Weldonithyris weldonis							
Zeilleria wilsfordensis							
Bivalve fragments	3	2	2	13	9	2	61
Bryozoa							
Collapora straminea	7		27	1	6	2	22
Mecynoecia thomasi							
Entalophrorecia sp.							
Microciella sp.							
Reptomultisparsa ventricosa							
Theonca sp.							
Reptomultisparsa cricophora							
Stomatophora sp.							
Filograna (serpulids).	3	3	37	3		6	5

	B 4	b4 L8	L5C	6COH	L6LB	L71	L7C
Gastropods (using Hudleston 1888)							
Actaeonina glabra		1		1		1	
A. gigantaea							
A. "pulloides"							
A. gigantaea var. *attenuata*							
Ataphrus acis							
Ataphrus laevigatus							
A. cf. *lucidus*							
A. hamoides							
A. hamus							
A. pinguis		3					1
A. pontonis							
A. pontonis var. *spinifera*							
A. varicifera							
Brachytrema binodosum							
B. wrightii var. *destecta*							
Capulus rugosus							
Ceritella lindonensis							
C. lindonensis var. *pinguis*							
C. stokensis							
Cerithium. sp. 2/w							
C. sp. 3/w		41	1		16	11	22
C. sp. 6/w							
C. *attritum*							
C. beanii		9					
C. beanii var. *weldonis*				1		1	3
C. "commaoides"					1		
C. georgii							
C. latisulcatum				1			
C. limaeforme							
C. obornense							
C. polystrophum							
C. turris							
Capulus rugosus							
Crossostoma cf. *pratti*							
Cryptaulax spp.							
Cylindrites brevispira					7		
C. turriculatus						1	
Diartema varicifera							
Discohelix cotteswoldiae							
D. sp. A (ornamented)							
D. sp. B (fine ornament)							
D. sp. C (smooth)							
D. sp. D							
Emarginula spp.							
Exelissa pulchra							
E. strangulata							
E. weldonis				1			
Fibula spp.							
Littorina aedilis							
L. phillipsii					1	2	
Monodonta/Turbo sp. A							
M/T sp. B					1		
M. lyelli	2						
Unidentified nerinoideans		3	15	58	45	39	28

The majority of nerinoideans thin sectioned were not from the samples, large individuals being extracted from the strata prior to sampling.

	B 4	b4 L8	L5C	6COH	L6LB	L71	L7C
Natica bajociensis							
Nerita tumidula	1			1	1		1
Neritopsis cf. *herbertana*							
Patella romer							
P. (scurria) nana							
Phasianella spp.			7	2	6	7	10
P. latiscula	47				12	12	
P. pontonis							
P. subumbilicata							
Pleurotomaria mirabilis (juvenile)							
Purpurina elaborata							
Rimula clathrata							
Rissoina gymnoides			1			5	
R. obliquata	8		3	3	12	8	10
R. obtusa					1	1	
Scaphopoda							
Trochus attrochus				15	4		
T. dimidatus/zetes							
T. duryanus							
T. "subimbricatus"							
T. vicinus							
Trochactaeonina tumidula							
Unidentifiable gastropods	138	19	130	39	185	87	138

Figure 14. *Bactroptyxis cotteswoldiae* in thick section. The fossil is 6 centimetres long.

3.01.2. Phase II.

This Phase represents an erosive event through Phase I into the underlying Grantham Formation (Upper Aalenian, *concavum* Subzone?). This channel infill comprises both intraclasts and bioclasts in a matrix of higher micrite content than Phase I. The basal few centimetres of the phase also contain a visible component of mica. A minor hardground of encrusting oysters occurs at the base of the channel filling sediment.

3.01.3. Phase III.

This Phase represents the bulk of the studied face consisting of a major sub-marine channel infill some 3 metres deep. The channel is infilled with intraformational conglomerates (Appendix 1a) punctuated by cross bedding (sometimes herringbone). The beds comprise of a number of lithologies with increasingly fine-grained material being deposited as the channel is filled. The sediments present occur both as event beds and as sub-aqueous dunes, these being easily distinguished by depositional structure. The dunes are often punctuated by the occurrence of bivalve accumulations (Figure 15a/b, 16). Hardgrounds occur at the top of the sequence. These hardgrounds exhibit successional fungal and lithophagid borings, with serpulid worms, oysters, (including *Lopha*), and bryozoa (Figure 7a/b, 8).

3.01.4. Phase IV.

The troughs of the submarine dunes contain reef-like associations of *Nanogyra nana* and serpulid worms (some of these accumulations occur in Phase III). Associated with the oysters are mass accumulation of shells (coquinas), consisting of both single valves and complete shells. These bivalve accumulations are associated with terebratulids, rhynchonellids, brachiopods and bivalves especially *Modiolus imbricata* (Sowerby) with associated encrusters including serpulid worms and bryozoa (Figure 16).

Figure 15a Weldon Roach. Hand for scale.

Figure 15b The Weldon Roach showing orientation as a bysally attached community. Maximum shell width 2 centimetres.

Figure 15c The Weldon Rag. Maximum shell width 1 centimetre.

Figure 15d. The Weldon rag. Length of exposure approximately 5 metres.

Figure 16. Sample counts for Cowthick faunas in Phases II-IV

	Phase II		Phase III				Phase IV	
	1↓sh	Cmy4	2bII	Ch4	L3B1	B42B1	SB1	B.V.B.
Smooth echinoid spines		2	28	62	32	34	55	13
Ornamented echinoid spines		3	14	1	1	10	2	
Echinoid test fragments			6			6	1	4
Echinoid elongate ossicles								
Echinoid "jaw-elements"		1	12	1		11	2	
Crinoid elements	3	13	46	7	9	17	8	2
"Owls-face" ossicles								
Crab claws								
Sponge spicules								
Ophiuroid elements								
Belemnites								
Arcidae sp.							2	5
Camptonectes sp.							4	9
Freiastarte sp.							1	
Gervillia sp.								
Lopha sp.							1	
Liostrea. sp.							2	7
Lucina bellona								2
Lucinidae sp.								
Modiolus imbricatus								23
Opis sp.								5
Pholadomya lirata								
Pholadomya ovalis								
Pinna sp.								
Pseudolimea cf. *duplicata*							3	12
Trigona cf. *costata*							1	2
Bivalve fragments	13	1	2		20	15	26	59
Acanthothiris crossi								
Microrhynchia pontonensis								2
Microrhynchia barnackensis					1			38
Acanthothiris crossi								1
Parvirhynchia kirtonensis								
Weldonithyris weldonis	1					4		
Zeilleria wilsfordensis								
Bryozoa								
Collapora straminea			1	1		7		
Mecynoecia thomasi								
Entalophrorecia sp.								
Microciella sp.								
Reptomultisparsa ventricosa								
Theonca sp.								
Reptomultisparsa cricophora								
Stomatophora sp.								
Filograna (serpulids).	8	6	8	14		22	2	8

	1↓sh	Cmy4	2bII	Ch4	L3B1	B42B1	SB1	B.V.B.
Gastropods (using Hudleston 1888)								
Actaeonina glabra					1			2
A. gigantaea								
A. "pulloides"			2		1			1
A. gigantaea var. *attenuata*								
Ataphrus acis								
Ataphrus laevigatus								
A. cf. *lucidus*								
A. hamoides								
A. hamus								
A. pinguis			3			5		
A. pontonis								
A. pontonis var. *spinifera*								
A. varicifera								
Brachytrema binodosum								
B. wrightii var. *destecta*								
Capulus rugosus								
Ceritella lindonensis								
C. lindonensis var. *pinguis*								
C. stokensis								
Cerithium. sp. 2/w								
C. sp. 3/w	19	3	12	14				19
C. sp. 6/w								
C. attritum								
C. beanii								
C. beanii var. *weldonis*			3		10	2	3	
C. "commaoides"								
C. georgii								
C. latisulcatum	4		93			14		4
C. limaeforme								
C. obornense								
C. polystrophum								
C. turris								
Cloughtonia cincta								
Crossostoma cf. *pratti*								
Cryptaulax spp.								
Cylindrites brevispira	2	1	1		1			2
C. turriculatus			1		1			
Diartema varicifera								
Discohelix cotteswoldiae								
D. sp. A (ornamented)								
D. sp. B (fine ornament)								
D. sp. C (smooth)								
D. sp. D								
Exelissa pulchra								
E. strangulata								
E. weldonis								
Emarginula spp.					1			
Fibula spp.								
Littorina aedilis								1
L. phillipsii			1				4	3
Monodonta/Turbo sp. A				14			5	
M/T sp. B								
M. lyelli								

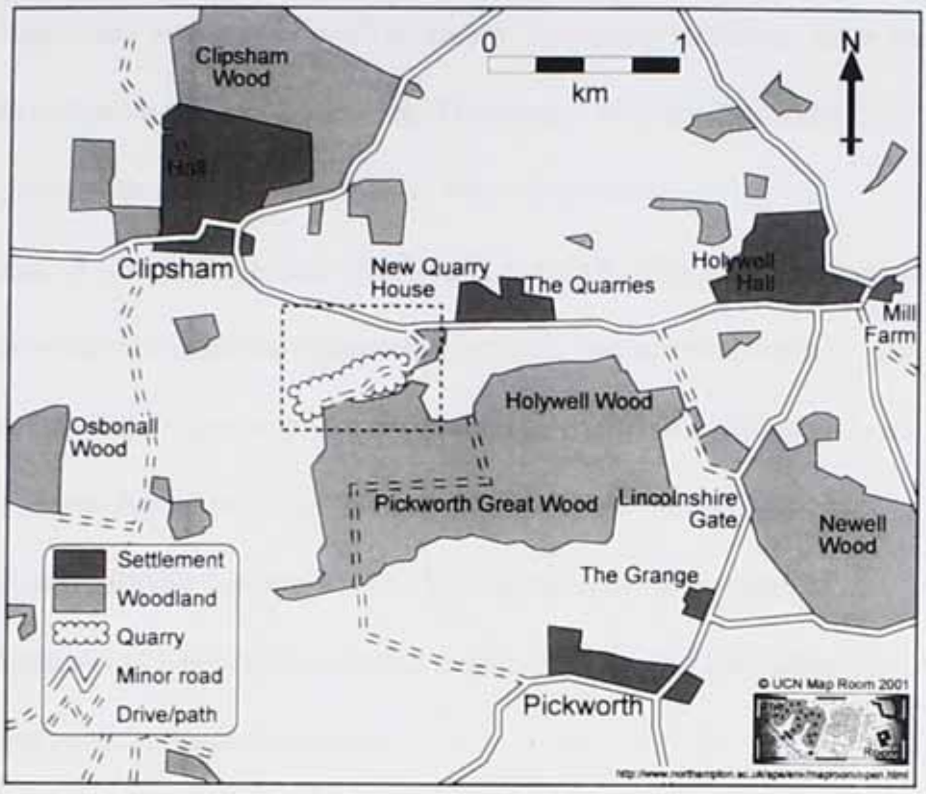
	1↓sh	Cmy4	2bII	Ch4	L3B1	B42B1	SB1	B.V.B.
Unidentified nerinoideans		13	74	20	18	80	13	2

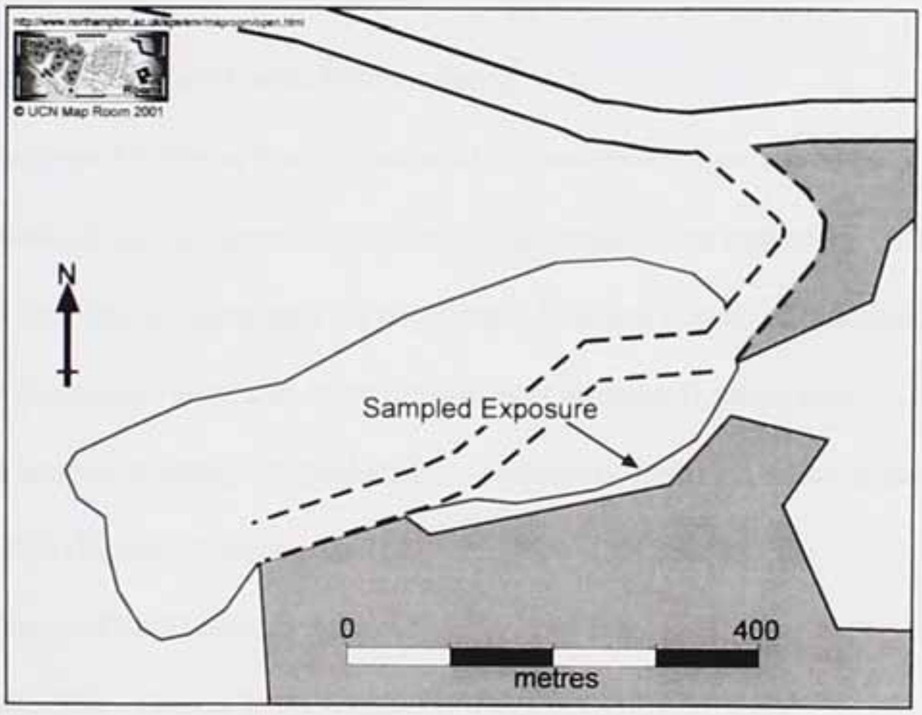
The majority of nerinoideans thin sectioned were not from the samples, large individuals being extracted from the strata prior to sampling.

Natica bajociensis								
Nerita tumidula								
Neritopsis cf. *herbertana*								
Patella romer								
P. (scurria) nana								
Phasianella spp.	2		1	49	2	31	1	30
P. latiscula			32	7		14	9	
P. pontonis								
P. subumbilicata			6		5			
Pleurotomaria mirabilis (juvenile)		1						
Purpurina elaborata								
Rimula clathrata								
Rissoina gymnoides						4		2
R. obliquata	2		20	5	1	12		14
R. obtusa								2
Scaphopoda								
Trochus attrochus				3		31	8	7
T. dimidatus/zetes	2							
T. duryanus								
T. "subimbricatus"							4	
T. vicinus							1	
Trochactaeonina tumidula							1	
Unidentifiable gastropods	6	33	226	80	106	118		41

3.02. Clipsham Old Quarry, Clipsham, Lincolnshire (SK978154).

Figure 17. The floor plan of Clipsham Old Quarry illustrating sampled locations.





3.02.1. The Lincoln Member (Scottlethorpe Beds).

These beds comprise the basal 3.55 metres of exposure and are characterised by pale grey micritic limestones interspersed with ooids and iron oxide streaking, these having been subject to extensive infaunal burrowing (Goldring, 1995; see Appendix 1b). Although no gastropods or bivalves occur, *A. crossi* is present.

The macrofaunas of sample (Clipsham Old Quarry I) COQI, (Figure 18, Appendix 1b) contain regular echinoids, crinoids, ophiuroids, bryozoa and serpulid worms. The ostracod fauna includes *Progonocythere cristata* Bate, *Cytherella fullonica* Jones and Sherborn, *Paracypris bajociana* Bate, *Praeschuleridea subtrigona* (Jones and Sherborn) and unidentifiable ostracods. The foraminiferal fauna consists of *Lenticulina muensteri* (Roemer), *Lenticulina exgalatea* (Dieni), *Lenticulina* var. A and B and *Dentalina pseudocommunis* Franke.

3.02.2. The Lincoln Member (Castle Bytham Beds).

These beds are some 3.2 metres thick. The basal 0.5 metres are represented by a visible component of quartz, intraclasts, ironstone and echinoderm fragments. After a series of clays (too thin for sampling) the overlying 1.5 metres consist of biomicrites with *Bactroptyxis guisei* (Witchell), *Bactroptyxis cotteswoldiae* (Lycett) (up to 10 centimetres in length), brachiopods (including *A. crossi*) and bivalves, noted at the top by sample COQII (Figure 18, Appendix 1b).

The macrofaunas of COQII contain echinoid and crinoid fragments, bivalves, bryozoa and gastropods. The ostracod fauna consists *of Progonocythere cristata, Praeschuleridea subtrigona, Cytherella fullonica* and *Ektyphocythere triangula* (Brand). The foraminiferal fauna includes *Lenticulina muensteri, Lenticulina quenstedti* (Gümbel), *Lenticulina* var. A, *Spirillina infima* (Strickland), *Dentalina* *pseudocommunis*, *Vaginulina contracta* (Terquem) and *Vaginulina jurassica* (Gümbel).

The next horizon consists of 1.71 metres of micritic sediment containing quartz, ooids and angular shell fragments with *Bactroptyxis cotteswoldiae* and *Bactroptyxis guisei*. The top 10 centimetres of this bed are made up of comminuted shell material, the top surface of which having an irregular contact with the bed above.

3.02.3. The Clipsham Member.

This member comprises 9 metres of strata. The basal 80 millimetres consist of a bed of decalcified solitary corals. Above the corals the lithology comprises well-cemented oosparites, the first 0.5 metres of which being dominated by brown (iron-stained) ooids and gastropods (*Cerithium* sp.). This is followed by crossbedded oocalcarenites the top of which being marked by an undulating contact with the beds above.

The succeeding bed consists of finer material, colonised by *Modiolus* and gastropods, topped by sample COQIV (Figure 18, Appendix 1b).

The fauna of COQIV was dominated by unidentifiable gastropods, echinoderm fragments, bryozoa and serpulid worms. The ostracod fauna includes *Progonocythere cristata*, *Praeschuleridea subtrigona* and *Ektyphocythere triangula*. The foraminiferal fauna includes *Tetrataxis*, *Ammobaculites agglutinans* (d'Orbigny), *Epistomina* sp., Nodosaria sp. A and *Lenticulina muensteri*.

The 5 metres of sediment following COQIV consist of blue-hearted shelly bioclastic oolites. These strata although too high for safe inspection, pinch and swell as stacked-channels.

Figure 18. Sample counts for faunas from Clipsham Old Quarry

	COQI	COQII	COQIV
Smooth echinoid spines	112	170	68
Ornamented echinoid spines	1	40	2
Echinoid test fragments	23	5	7
Echinoid elongate ossicles	1		
Echinoid "jaw-elements"			
Crinoid elements	10	39	12
"Owls-face" ossicles	16	10	4
Crab claws			
Sponge spicules			
Ophiuroid elements	19	2	P
Belemnites			
Arcidae sp.			
Camptonectes sp.			
Freiastarte sp.			
Gervillia sp.			
Lopha sp.			
Liostrea. sp.			
Lucina bellona			
Lucinidae sp.			
Modiolus imbricatus			
Opis sp.			
Pholadomya lirata			
Pholadomya ovalis			
Pinna sp.			
Pseudolimea cf. *duplicata*			
Trigona cf. *costata*			
Bivalve fragments		1	11
Acanthothiris crossi			
Microrhynchia pontonensis			
Microrhynchia barnackensis			
Parvirhynchia kirtonensis			
Weldonithyris weldonis			
Zeilleria wilsfordensis		1	
Bryozoa			
Collapora straminea	2	9	2
Mecynoecia thomasi			
Entalophrorecia sp.			
Microciella sp.			
Reptomultisparsa ventricosa			
Theonca sp.			
Reptomultisparsa cricophora			
Stomatophora sp.			
Filograna (serpulids).	11	5	3

	COQI	COQII	COQIV
Gastropods (Identifications according to Hudleston 1888)			
Actaeonina glabra			
A. gigantaea			
A. "pulloides"		1	2
A. gigantaea var. *attenuata*			
Alaria hamoides			
A. hamus			
A. pinguis			2
A. pontonis			
A. pontonis var. *spinifera*			
A. varicifera			
Ataphrus acis			
A. laevigatus			
A. cf. *lucidus*			
Brachytrema binodosum			
B. wrightii var. *destecta*			
Capulus rugosus			
Ceritella lindonensis			
C. lindonensis var. *pinguis*			
C. stokensis			
Cerithium. sp. 2/w			2
C. sp. 3/w			
C. sp. 6/w			
C. *attritum*			
C. beanii			
C. beanii var. *weldonis*			
C. "commaoides"			
C. georgii			
C. latisulcatum			
C. limaeforme			
C. obornense			
C. polystrophum			
C. turris			
Crossostoma cf. *pratti*			
Cryptaulax spp.			
Cylindrites brevispira			
C. turriculatus			1
Diartema varicifera			
Discohelix cotteswoldiae			
D. sp. A (ornamented)			
D. sp. B (fine ornament)			
D. sp. C (smooth)			
D. sp. D			
Exelissa pulchra			
E. strangulata			
E. weldonis			
E. pulchra			
F. Emarginula spp.			
Fibula spp.			
Littorina aedilis			

	COQI	COQII	COQIV
L. phillipsii			
Monodonta/Turbo sp. A			
M/T sp. B			
M. lyelli			
Unidentified nerinoideans			2
Nerinaea pseudopunctata			

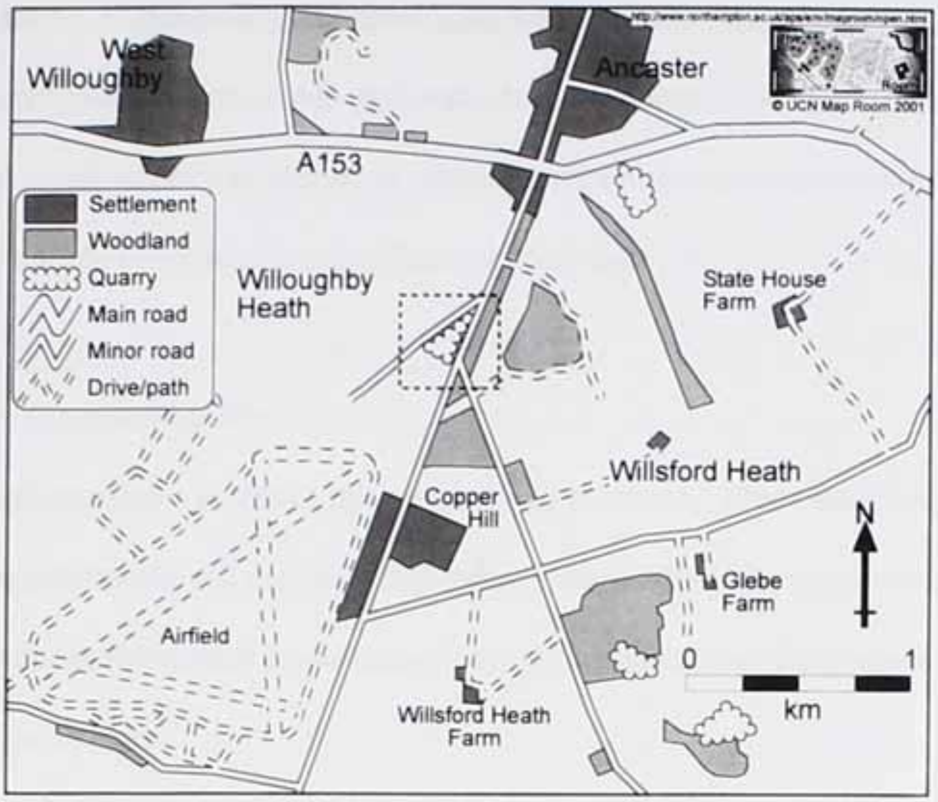
The majority of nerinoideans thin sectioned were not from the samples, large individuals being extracted from the strata prior to sampling.

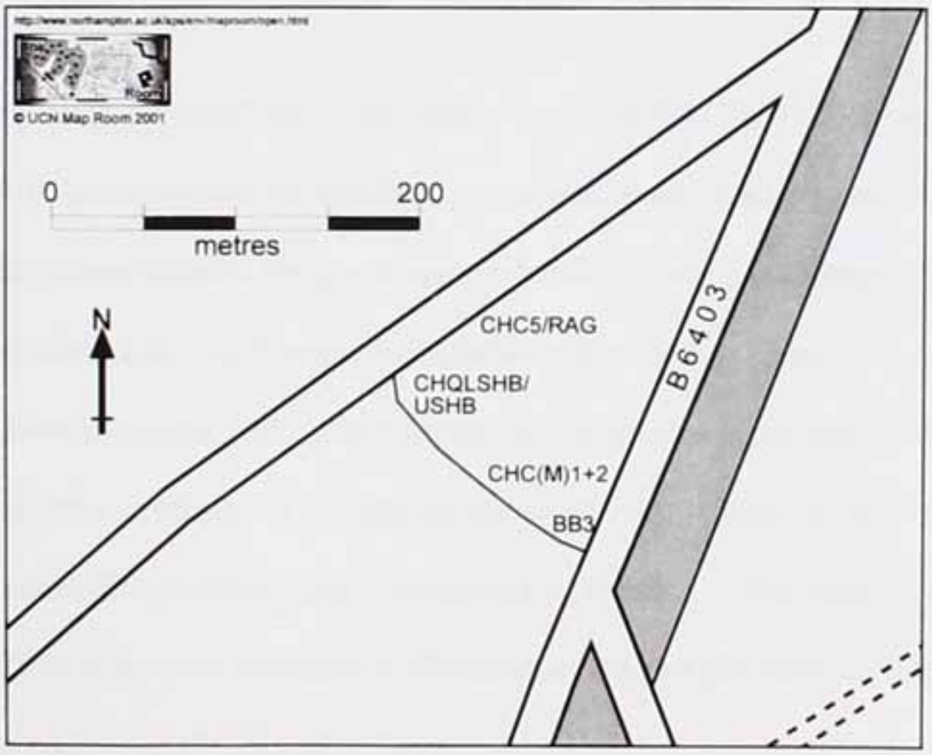
	COQI	COQII	COQIV
Natica bajociensis			
Nerita tumidula			
Neritopsis cf. *herbertana*			
Patella romer			
P. (scurria) nana			
Phasianella spp.		1	
P. latiscula			
P. pontonis			
P. subumbilicata			
Pleurotomaria mirabilis (juvenile)			
Purpurina elaborata			
Rimula alta			
Rimula clathrata			
Rissoina gymnoides			
R. obliquata		1	
R. obtusa			
Scaphopoda			
Trochus attrochus			
T. dimidatus/zetes			
T. duryanus			
T. "subimbricatus"			
T. vicinus			
Trochactaeonina tumidula			
Unidentifiable gastropods	29	2	150
Ostracod Species			
Cytherella fullonica	1	2	
Cytherelloidea catenulata			
Platella jurassica			
Paracypris bajociana	2		
Bairdia hilda			
Monoceratina vulsa			
Monoceratina cf. *scrobiculata*			
Progonocythere cristata	4	7	4
Pneumatocythere bajociana			
Acanocythere (P) faveolata			
Aulacocythere punctata			
Pleurocythere kirtonensis			
Praeschuleridea subtrigona	2	3	1
Kirtonella plicata			
Systenocythere exilofasciata			
Ektyphocythere triangula		1	1
Cytheremorpha greetwellensis			
"*Terquemula-like*" species ?			
UnID ornamented spp.			
Unidentified (worn) ostracods	7		1

Foraminifera Species	COQI	COQII	COQIV
Ammobaculites agglutinans			1
Tetrataxis sp.			2
Opthalmidium cf. *strumosum*			
Nodosariid ? sp. A			
Nodosaria sp. A			1
Nodosaria fontinensis			
Citharina clathrata			
Citharina aff. *flabellata*			
Citharina heteropleura			
Citharina aff. *inconstans*			
Citharina sp. A			
Dentalina nuda			
Dentalina pseudocommunis	1	1	
Frondicularia lignaria?			
Frondicularia terquemi/nympha			
Lagena? sp.			
Lenticulina exgalatea	2		
Lenticulina muensteri	4	2	3
Lenticulina quendstedti		2	
Lenticulina var. A.	2	2	
Lenticulina var. B.	1		
Planularia beierana			
Vaginulina sp.			
Vaginulina sp. A.			
Vaginulina contracta		1	
Vaginulina jurassica		1	
Vaginulina legumen			
Eoguttulina liassica			
Spirillina infima?		1	
Spirillina numisimalis			
Conicospirillina trochoides			
Epistomina sp.			1
UnID calcareous benthonic A			
UnID calcareous benthonic B			
UnID calcareous benthic C			
UnID calcareous benthic D			

3.03. Copper Hill Quarry, Ancaster, Lincolnshire. (SK979427; see Figure 19).

Figure 19. The floor plan of Copper Hill Quarry, showing sampled locations.





This quarry, formerly known as Newton and Scotts Quarry, represents a more offshore environment than the Cowthick Quarry, being approximately 55 kilometres further north (Figure 1). Consequently, the lithologies present reflect depositional environments typical of more stable carbonate shelf conditions. The Quarry is now disused and mostly cleared of rubble. It exhibits deeper exposures than were available for Ashton's studies two decades ago (Figure 9, Appendix 1c).

3.03.1. The Greetwell Member.

Due to unsafe exposures access to this member was restricted. These basal beds consist of approximately 6.2 metres of fine grained micritic horizons with coarsening upward structures (increasing proportions of the sediment being made up ooids to 1.5 millimetres in diameter).

Bioturbation occurs at the top of the beds although some laminar bedding can be observed.

These beds contain sample (Copper Hill Quarry Base of bed 3) CHQBB3 (Appendix 1c, Figure 20) which contains bivalve fragments and echinoderm fragments. The ostracod microfauna includes *Progonocythere cristata*, *Cytherella fullonica*, *Pneumatocythere bajociana*, *Paracypris bajociana*, *Kirtonella plicata*, *Acanthocythere favaeolata* and *Cytherelloidea catenulata* (Jones and Sherborn). The foraminiferal fauna consisting of *Lenticulina quenstedti*, *Lenticulina* var. A, *Dentalina pseudocommunis*, Unidentified (UnID) calcareous benthonic C., *Nodosaria fontinensis* Terquem, UnID calcareous benthonic A, *Planularia beierana* (Gümbel), *Citharina* sp. A, *Eoguttulina liassica* (Strickland), *Vaginulina jurassica*, *Vaginulina legumen* (Linne) and *Vaginulina* sp. A.

3.03.2. The Leadenham Member.

At this Quarry, this member consisted of bioturbated micrite beds containing gastropods and infaunal bivalves. The 2 metres of sediment being punctuated by marl horizons.

The marl sampled as CHC (M) 1 (Copper Hill Clay (Marl) I) 1metre from the base of the member (Figure 20, Appendix 1c), is dominated by echinoderm fragments. The ostracod fauna of the sample consisted of *Progonocythere cristata, Praeschuleridea subtrigona, Pleurocythere kirtonensis* Bate, *Pneumatocythere bajociana* Bate, *Cytherelloidea catenulata*, unidentified ornamented spp., *Kirtonella plicata* Bate and *Acanocythere favaeolata* Bate. The foraminiferal fauna of the sample consisted of *Spirillina infima*, *Lenticulina exgalatea, Ammobaculites agglutinans, Dentalina pseudocommunis*, *Frondicularia lignaria*? Terquem, *Conicospirillina trochoides* (Berthelin) and *Frondicularia terquemi / nympha*.

3.03.3. The Lincoln Member.

This is represented by 2.8 metres of white micritic limestones, with corals, small-articulated terebratulids, a belemnite, and a reduction in sediment size compared to that of the previous member. The top of the member is marked by an increase in nerinoidean numbers especially *Bactroptyxis cotteswoldiae*. The sediments of the member are mud-supported and interspersed with pisoliths and ooids.

The base of the member yielded sample (Copper Hill Clay (Marl) 2) CHC (M) 2 (Figure 20, Appendix 1c) characterised by the dominance of echinoderm fragments. The ostracod fauna is characterised by the *Progonocythere cristata, Cytherelloidea catenulata, Paracypris bajociana, Ektyphocythere triangula* and *Praeschuleridea subtrigona*. The foraminiferal fauna is essentially the same as that of the previous sample with UnID calcareous benthonic D and *Lenticulina* var. B appearing. Also present are crab fragments (claws), ophiuriod material, and large quantities of sponge spicules. The gastropods *Bactroptyxis cotteswoldiae* and *Bactroptyxis guisei* are also present.

Coral patch reefs up to 0.8 metres across occur at the top of the Lincoln Member.

3.03.4. The Sleaford Member

Ashton (1977, 1980) regarded Copper Hill Quarry as the type locality for this member. The member is characterised by a coarsening of the grain size and the introduction of dune bedding, ooids and intraclasts becoming a major component (Appendix 1c). This member is characterised by the fact that only robust/durable bivalves and gastropods are preserved in an identifiable state. The base of the member provided the sample CHC4 that consisted entirely of echinoderm fragments. Depositional features include cross bedding of up to 0.3 metres in height and current-orientation of bioclasts that produced small-scale coquinas (bivalve valves up to 7 millimetres across). Fragile bryozoa and heavily worn gastropods appear side by side.

Sample (Copper Hill Quarry Lower Shell Bed) CHQLSHB some 28 centimetres above sample CHC4 is dominated by ooids and bioclasts being essentially grain-supported, gastropods becoming the most important faunal component (Figure 20, Appendix 1c). The ostracod fauna is marked by the disappearance of several species including *Cytherelloidea catenulata* and *Ektyphocythere triangula* and the introduction of several others including *Bairdia hilda* Jones, *Kirtonella plicata* and *Cytheremorpha greetwellensis* Bate.

The foraminiferal fauna is different from that of the previous samples with species disappearing or being greatly reduced in number (Figure 20, Appendix 1c). They are replaced by species such as *Ammobaculites agglutinans, Citharina* aff. *flabellata*, Nodosariid? sp. A?, *Tetrataxis* sp., *Epistomina* sp., and *Lenticulina muensteri*.

Some 1.72 metres above the previous sample, within the same bed is the sample (Copper Hill Quarry Upper Shell Bed) CHQUSHB (Figure 20, Appendix 1c). Although lithologically identical to CHQLSHB, its fauna shows an increase in the numbers of bivalve species (9 species), a decrease in the proportion of unidentifiable gastropods, and increase in bryozoan diversity (8 species) (Figure 20, Appendix 1c).

The ostracod fauna is marked by the disappearance of *Cytherella fullonica* and *Cytheremorpha greetwellensis*. They occurred in such small numbers previously, however, that their absence might be due to chance. Many ostracod species appear in CHQUSHB. These include *Platella jurrasica, Monoceratina vulsa* (Jones and Sherborn), *Aulacocythere punctata* Bate, *Systenocythere exilofasciata* Bate, and the *Terquemula*-like species. Several species reappear including *Paracypris bajociana, Pneumatocythere bajociana, Ektyphocythere triangula* and *Pleurocythere kirtonensis*.

The composition of the foraminiferal fauna remains essentially unchanged from that of CHQLSHB, the only changes being the introduction of *Lenticulina quenstedti, Citharina heteropleura* (Terquem), *Vaginulina legumen, Vaginulina* sp. A and Unidentified calcareous benthonic C.

3.03.5. The Clipsham Member.

The member consists of around 7 metres of well-sorted, cross-bedded oosparites exhibiting unidirectional current orientation. This member is first marked by an iron rich clay (Copper Hill Clay 5) sampled as CHC5 which is dominated by crinoids, bryozoa and serpulid worms (Figure 20).

The next sample CHQRAG is essentially similar to those of the underlying Sleaford Member, the difference being the marked drop in gastropod, bivalve and bryozoan diversity.

The ostracod fauna of the sample contains *Progonocythere cristata*, *Bairdia hilda*, *Monoceratina vulsa*, *Monoceratina* cf. *scrobiculata* Triebel and Bartenstein, *Kirtonella plicata*, *Pleurocythere kirtonensis*, and *Praeschuleridea subtrigona*.

The foraminifera in this sample are essentially identical to those of CHQUSHB, the only significant changes being the appearance (in small numbers) of *Citharina clathrata* (Terquem), *Citharina* sp. A, *Opthalmidium* cf. *strumosum* (Gümbel), and Nodosariid*?* sp. A?.

Figure 20. Sample counts for Copper Hill Quarry.

	BB3	(M)1	(M)2	CHC4	LSHB	USHB	CHC5	RAG
Smooth echinoid spines	13		57	54	57	119	102	142
Ornamented echinoid spines					25	14	25	5
Echinoid test fragments	7	2	118	1	26	16	31	
Echinoid elongate ossicles				2	1		2	
Echinoid "jaw-elements"	1	1		15	14	27	36	13
Crinoid elements	6	375	27	133	63	89	225	149
"Owls-face" ossicles	1	7		26	14	26	15	36
Crab claws				3	2	4	1	3
Sponge spicules				10				
Ophiuroid elements		1					1	2
Belemnites								
Arcidae sp.					4	7		
Camptonectes sp.					7	5		
Freiastarte sp.						3		
Gervillia sp.						1		
Lopha sp.								
Liostrea. sp.						3		
Lucina bellona								
Lucinidae sp.						8		
Modiolus imbricatus								
Opis sp.					3	4		
Bivalve fragments	79	44	28	16	22	70	12	134
Pholadomya lirata								
Pholadomya ovalis								
Pinna sp.								
Pseudolimea cf. *duplicata*					6	12		
Trigona cf. *costata*						5		
Acanthothiris crossi								
Microrhynchia pontonensis								
Microrhynchia barnackensis								
Parvirhynchia kirtonensis								
Weldonithyris weldonis					7	4		
Zeilleria wilsfordensis								
Bryozoa					71 incl.	114 incl.		
Collapora straminea					present	present	6	67
Mecynoecia thomasi					present	present		
Entalophrorecia sp.						present		
Microciella sp.						present		
Reptomultisparsa ventricosa						present		
Theonca sp.						present		
Reptomultisparsa cricophora					present	present		
Stomatophora sp.						present		
Filograna (serpulids).	4			1	10	39	7	32

The bryozoan abundance's are for the entire bryozoan fauna, only selected individuals underwent the specialist study required for confident identification.

	BB3	(M)1	(M)2	CHC4	LSHB	USHB	CHC5	RAG
Gastropods (after Hudleston 1888)								
Actaeonina glabra								
A. gigantaea					1	2		
A. "pulloides"					2	5		
A. gigantaea var. *attenuata*					1	2		
Alaria hamoides							1	
A. hamus								2
A. pinguis					2	3		
A. pontonis								
A. pontonis var. *spinifera*								
A. varicifera					1	4		
Ataphrus acis								
Ataphrus laevigatus					1	4		2
A. cf. *lucidus*					3	2		
Brachytrema binodosum								
B. wrightii var. destecta					1			
Capulus rugosus								
Ceritella lindonensis						1		
C. lindonensis var. *pinguis*								
C. stokensis						1		
Cerithium. sp. 2/w						4		
C. sp. 3/w					12	33		8
C. sp. 6/w					2	2		
C. *attritum*								
C. beanii								
C. beanii var. *weldonis*								
C. "commaoides"								
C. georgii								
C. latisulcatum								
C. limaeforme								
C. obornense						1		
C. polystrophum								
C. turris								
Crossostoma cf. *pratti*					2	3		6
Cryptaulax spp.						1		
Cylindrites brevispira								
C. turriculatus						2		3
Diartema varicifera								3
Discohelix cotteswoldiae						2		1
D. sp. A (ornamented)					1			
D. sp. B (fine ornament)					2			
D. sp. C (smooth)						2		
D. sp. D					1			
Emarginula spp.								
Exelissa pulchra								
E. strangulata					4	4		
E. weldonis								
E. pulchra						5		
Fibula spp.								
Littorina aedilis								
L. phillipsii					3	1		

	BB3	(M)1	(M)2	CHC4	LSHB	USHB	CHC5	RAG
Monodonta/Turbo sp. A								
M/T sp. B								
M. lyelli								
Unidentified nerinoideans					29	156		42
Nerinaea pseudopunctata					1	2		

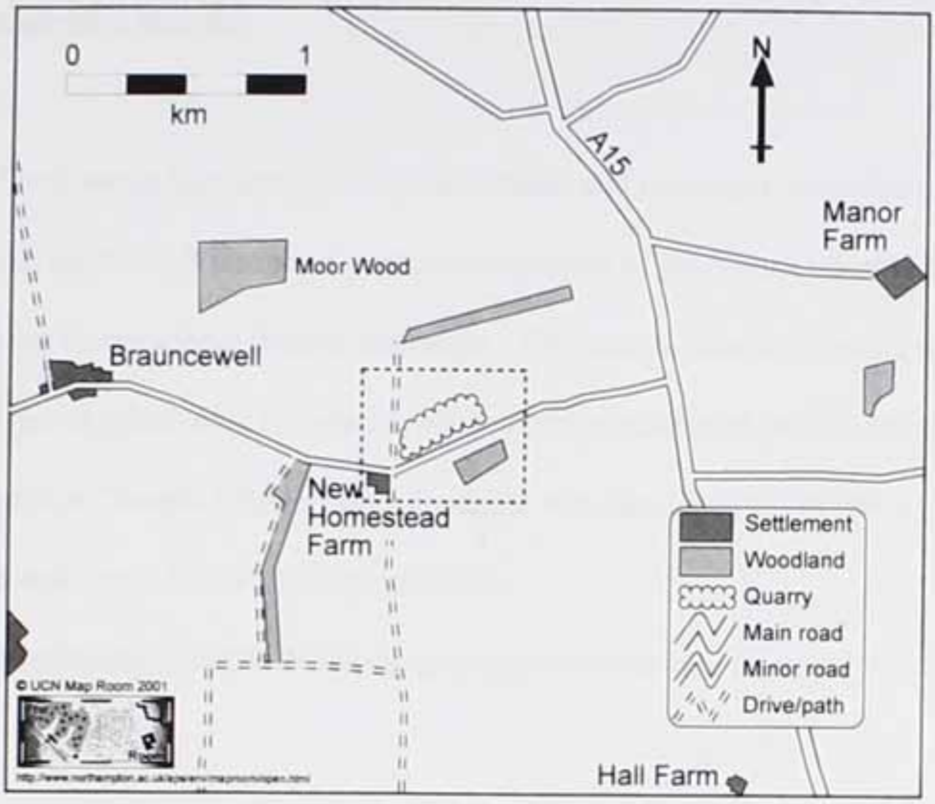
The majority of nerinoideans thin sectioned were not from the samples, large individuals being extracted from the strata prior to sampling.

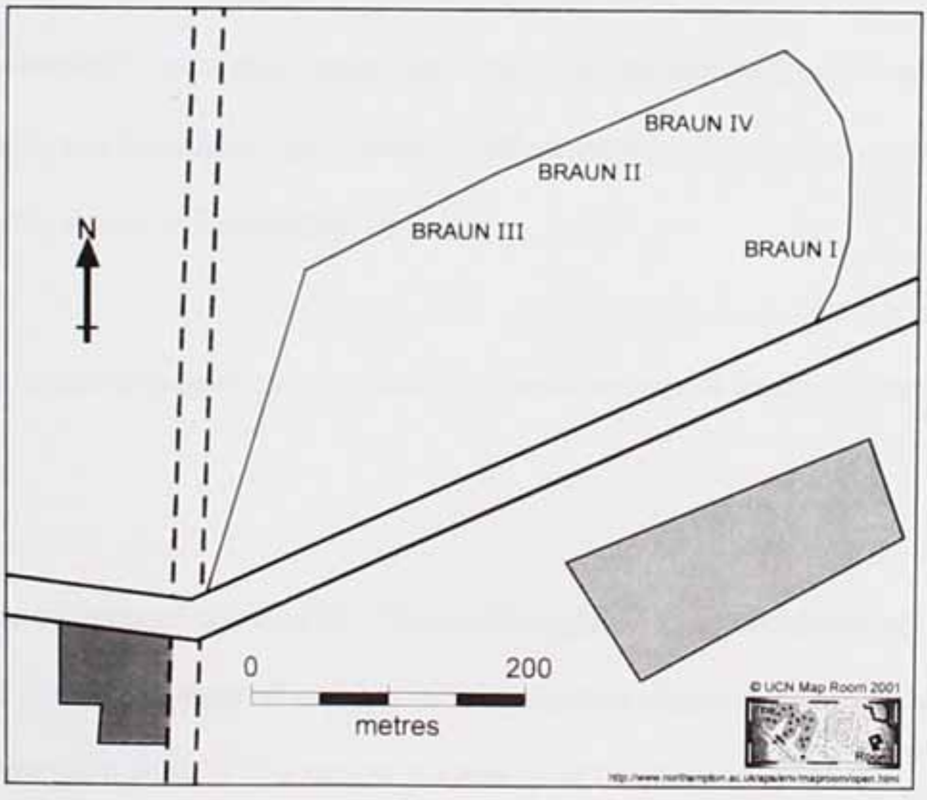
	BB3	(M)1	(M)2	CHC4	LSHB	USHB	CHC5	RAG
Natica bajociensis					2			
Nerita tumidula					1	3		
Neritopsis cf. *herbertana*					1			
Patella romer								
P. (scurria) nana								
Phasianella spp.						4		9
P. latiscula						2		
P. pontonis					1	1		
P. subumbilicata						5		
Pleurotomaria mirabilis (juvenile)					1			1
Purpurina elaborata								
Rimula alta					1			
Rimula clathrata						7		
Rissoina gymnoides					1	2		
R. obliquata					2	17		
R. obtusa					1	4		11
Scaphopoda								
Trochus attrochus						2		
T. dimidatus/zetes						1		1
T. duryanus								
T. "subimbricatus"								
T. vicinus								
Trochactaeonina tumidula								
Unidentifiable gastropods	57	42	5		91	64	26	177
Ostracod Species								
Cytherella fullonica	16				1			
Cytherelloidea catenulata	1	9	1	2				
Platella jurassica						1		
Paracypris bajociana	7		4			1		
Bairdia hilda					23	42		7
Monoceratina vulsa						1		1
Monoceratina cf. *scrobiculata*								1
Progonocythere cristata	72	63	47		5	5		20
Pneumatocythere bajociana	22	1				16		
Acanocythere (P) faveolata	1	2						
Aulacocythere punctata						2		
Pleurocythere kirtonensis		4				1		1
Praeschuleridea subtrigona		3	6		2	2		4
Kirtonella plicata	7	12			3	5		1
Systenocythere exilofasciata						15		
Ektyphocythere triangula			9			1		
Cytheremorpha greetwellensis					1			
"*Terquemula-like*" species?						1		
Unidentified ornamented spp.	1	3						
Unidentified (worn) ostracods	35	47	27		27	9		18

	BB3	(M)1	(M)2	CHC4	LSHB	USHB	CHC5	RAG
Foraminifera Species								
Ammobaculites agglutinans		2			5	16		3
Tetrataxis sp.					4	10		17
Opthalmidium cf. *strumosum*					2			1
Nodosariid sp. A					4			5
Nodosaria sp. A						11		9
Nodosaria fontinensis	4							
Citharina clathrata								1
Citharina aff. *flabellata*					4	1		3
Citharina heteropleura						1		
Citharina aff. *inconstans*								
Citharina sp. A	1							1
Dentalina nuda						3		
Dentalina pseudocommunis	3	12	3		1			
Frondicularia lignaria?	1	1	1		1			
Frondicularia terquemi/nympha		2	1					
Lagena? sp.				1		1		1
Lenticulina exgalatea		1	2					
Lenticulina muensteri	28				9	3		10
Lenticulina quendstedti	6					2		1
Lenticulina var. A.	2							
Lenticulina var. B.			1					
Planularia beierana,	2							
Vaginulina sp.								
Vaginulina sp. A.	2					1		
Vaginulina contracta								
Vaginulina jurassica	2							
Vaginulina legumen	5					1		
Eoguttulina liassica	1							
Spirillina infima		45	2					
Spirillina numisimalis,								
Conicospirillina trochoides		5						
Epistomina sp.					1	5		
UnID calcareous benthonic A	1							
UnID calcareous benthonic B				1	1	1		
UnID calcareous benthonic C	1					11		5
UnID calcareous benthonic D			1					

3.04. Braunceweil Quarry, Braunceweil, Lincolnshire (TF028518; see Figure 21).

Figure 21. The floor plan of Brauncewell Quarry, showing sample locations.





This quarry is some 64 kilometres north of Cowthick Quarry (Figure 1). It provides an 18.5 metre high outcrop (Figure 9, Appendix 1d). No gastropods were recovered from the sampled material.

3.04.1. The Lincoln Member (Scottlethorpe Beds) and the Kirton Shale Member.

These beds represent 3 metres of exposure consisting of grey-black micritic limestones interspersed by occasional bivalve fragments. The basal 0.6 metres contain banding. This member is punctuated by a clay horizon which pinches and swells, resting on an eroded surface (Sample BRAUN II). A sample was also taken at 1m (BRAUN III) (Brauncewell II etc; Figure 22, Appendix 1d).

The ostracod fauna of BRAUN II is largely unidentifiable due to wear.

The foraminiferal fauna consists of *Lenticulina muensteri, Lenticulina quenstedti, Lenticulina* var. A, *Conicospirillina trochoides. Spirillina infima. Dentalina pseudocommunis, Nodosaria fontinensis, Frondicularia lignaria*?, UnID calcareous benthonic A and D, *Lagena*? sp., *Citharina* aff. *inconstans, Vaginulina legumen* and foraminifera similar to *Eoguttulina liassica.*

The sample also contained quartz, spine-like structures, wood fragments and ophiuroid ossicles.

The ostracod fauna of BRAUN III (Figure 22) is again largely comprised of unidentifiable valves, many of which exhibiting signs of algal and /or fungal boring. The foraminiferal fauna of this sample is made up of *Lenticulina muensteri, Lenticulina quenstedti, Spirillina infima* and *Dentalina pseudocommunis.*

3.04.2. The Metheringham Member.

Is represented by 6 metres of buff micrites with a varying oolitic and peloidal content. These contain *Acanthothiris crossi, Bactroptyxis cotteswoldiae, Bactroptyxis implicata* and occasional bivalves. The basal 5 centimetres of this member occur as a black clay (BRAUN IV) which contains spine-like structures and oyster fragments (Figure 22, Appendix 1d).

The ostracod fauna is largely unidentifiable, with many individuals having undergone boring.

The foraminiferal fauna of the sample consists of *Lenticulina muensteri, Lenticulina quenstedti, Citharina* aff. *inconstans, Spirillina infima. Frondicularia lignaria*?, UnID calcareous benthonic C, and *Dentalina pseudocommunis.*

Another of the weakly cemented horizons of the Metheringham Member was sampled as BRAUN I (Figure 22). Lithologically this sample was rich in quartz grains.

The ostracod fauna of BRAUN I was again made up largely of unidentifiable material.

The foraminiferal fauna consists of *Spirillina infima, Spirillina numisimalis* (Terquem and Berthelin), *Conicospirillina trochoides, Lenticulina muensteri, Lenticulina quenstedti, Citharina* aff. *flabellata, Opthalmidium strumosum* and UnID calcareous benthonic D.

3.04.3. The Blankney Member

The Blankney Member (Appendix 1d) is represented by 3.2 metres of buff pellet-rich limestones often containing iron oxide coated ooids and pisoliths. The bivalve infauna includes large bivalves, terebratulids and pectenids. The gastropod infauna includes *Bactroptyxis cotteswoldiae* and *Bactroptyxis implicata*. Vertical burrows dominate the sediment.

3.04.4. The Sleaford Member

This member comprises of approximately 5 metres of buff/dark buff, cross-bedded oolitic to pisolitic limestones (Appendix 1d). The basal 20 centimetres consist of epifaunal bivalves, *Bactroptyxis cotteswoldiae* and *Bactroptyxis implicata* as a bioclast-supported accumulation, possibly representing a concentration deposit. The basal 2m is cross-bedded with the overlying material cross-bedded in the opposite direction. The dune scale cross bedding is present throughout the rest of the member.

Figure 22. Sample counts for Brauncewell Quarry.

	BRAUNII	BRAUNIII	BRAUNIV	BRAUNI
Ostracod Species				
Cytherella fullonica				
Cytherelloidea catenulata				
Platella jurassica				
Paracypris bajociana	2			
Bairdia hilda				
Monoceratina vulsa				
Monoceratina cf. *scrobiculata*				
Progonocythere cristata	3	1		2
Pneumatocythere bajociana				
Acanocythere (P) faveolata	4			
Aulacocythere punctata			2	
Pleurocythere kirtonensis				
Praeschuleridea subtrigona	2		8	
Kirtonella plicata			2	
Systenocythere exilofasciata			6	
Ektyphocythere triangula				
Cytheremorpha greetwellensis				
"*Terquemula*-like" species?				
UnID ornamented spp.				
Unidentified (worn) ostracods	16	12	43	14
Foraminifera Species				
Ammobaculites agglutinans				
Tetrataxis sp.				
Opthalmidium cf. *strumosum*				2
Nodosariid ? sp. A				
Nodosaria sp. A				
Nodosaria fontinensis	1			
Citharina clathrata				
Citharina aff. *flabellata*				2
Citharina heteropleura				
Citharina aff. *inconstans*	2		2	
Citharina sp. A				
Dentalina nuda				
Dentalina pseudocommunis	12	2	1	
Frondicularia lignaria?	2		3	
Frondicularia terquemi/nympha				
Lagena? sp.	5			
Lenticulina exgalatea				
Lenticulina muensteri	17	16	10	10
Lenticulina quendstedti	2	17	25	2
Lenticulina var. A.	3			
Lenticulina var. B.				
Planularia beierana				
Vaginulina sp.				
Vaginulina sp. A.				
Vaginulina contracta				
Vaginulina jurassica				
Vaginulina legumen	2			
Eoguttulina liassica?	6			
Spirillina infima	128	14	2	265

	BRAUNII	BRAUNIII	BRAUNIV	BRAUNI
Spirillina numisimalis				30
Conicospirillina trochoides	8			5
Epistomina sp.				
UnID calcareous benthonic A	1			
UnID calcareous benthonic B				
UnID calcareous benthic C			6	
UnID calcareous benthic D	9			1

Chapter 4. Discussion

4.0.1. Cowthick Quarry, Weldon, north of Kettering, Northamptonshire.

4.01.1. Phase I.

This is the earliest material exposed (Figure 12) and is characterised by tabular bedded peloidal oosparites with variable textural and mineralogical maturity. Current aligned particles up to 30 millimetres axial length are common. Beds range from 2 millimetre thick lamina to up to 1metre in thickness. Where clays occur they may be diagenetic in origin. Those clays considered as depositional, are thin (less than 50 millimetres thick) and impersistant. The sparry nature of much of the limestone suggests that post-depositional current activity must have been sufficient to remove the fine-grained material. These currents also result in unidirectional current bedding as indicated by the scatter-plot on Figure 23 which illustrates the positions in which the sedimentary particles were deposited. (It must be noted that the collection of palaeocurrent data was restricted due to the destruction of the site).

The absence of terrestrial fossils in these beds suggests that there was limited terrestrially derived sediment entering this environment. Post-depositional wear appears to have been a major influence in this environment with much of the gastropod fauna being heavily abraded by currents loaded with sediment (Brett, 1990). Carbonate coating of gastropods is also common suggesting that sedimentary particles spent a significant period at the sediment/water interface. Furthermore, the coatings are of similar thickness around each shell suggesting slow deposition, and possibly, sufficient current activity to rework the material.

Figure 23.

Scatter plot for Cowthick Phase I

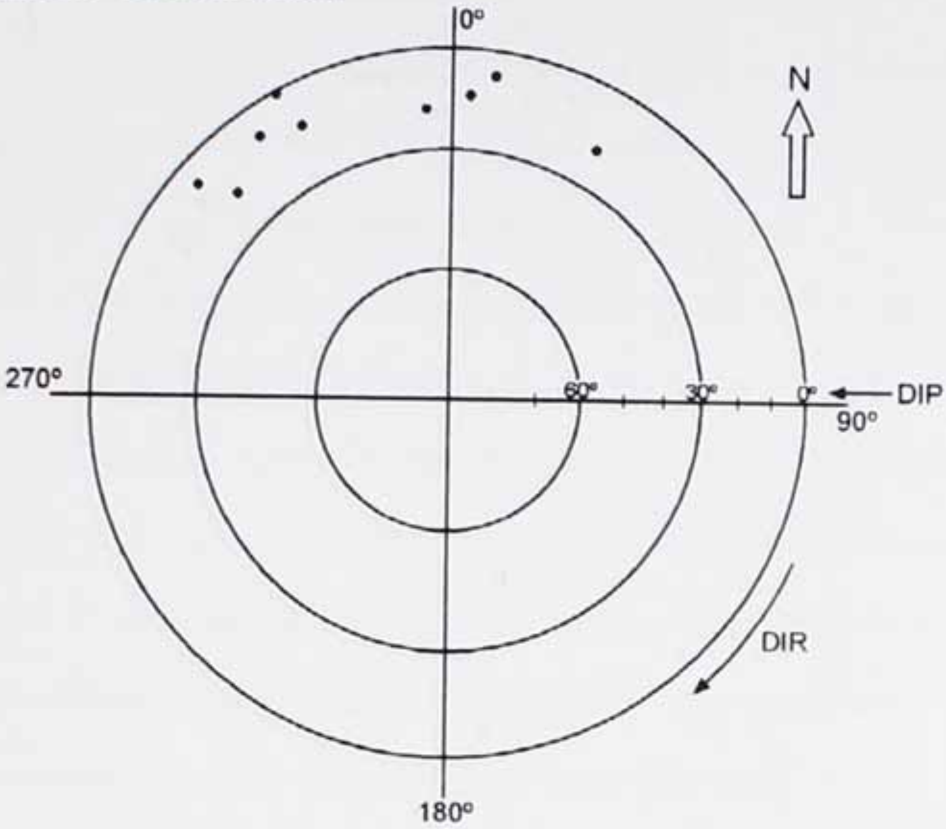


Figure 24.

Scatter plot for Cowthick Phase II

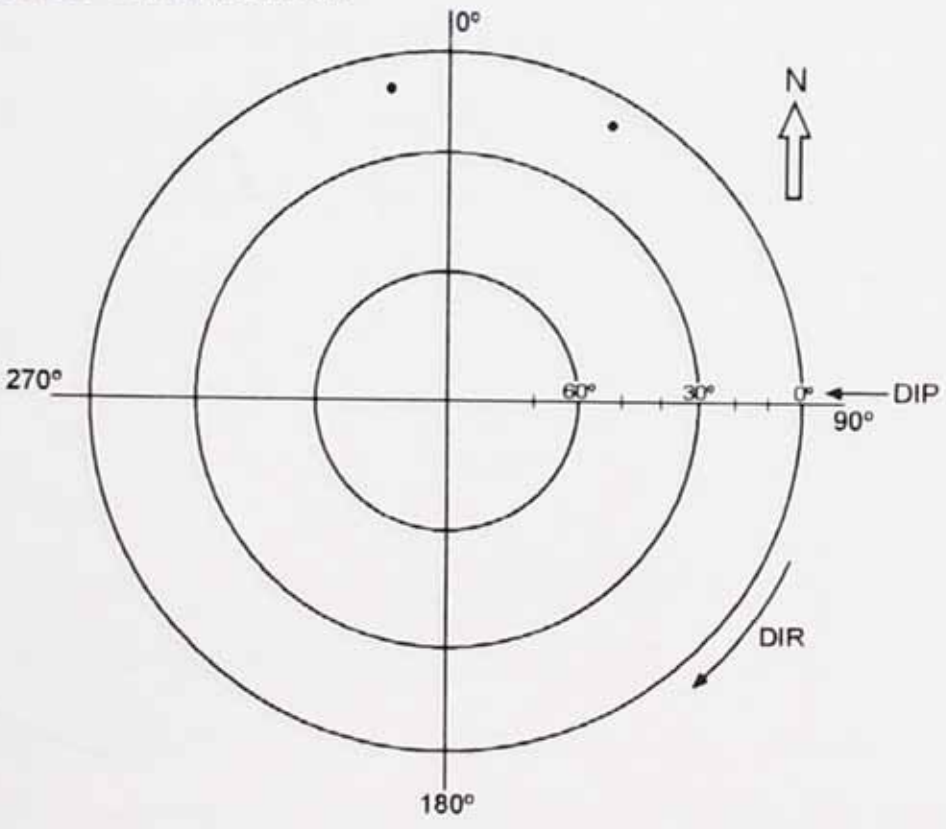


Figure 25.

Scatter plot for Cowthick Phase III

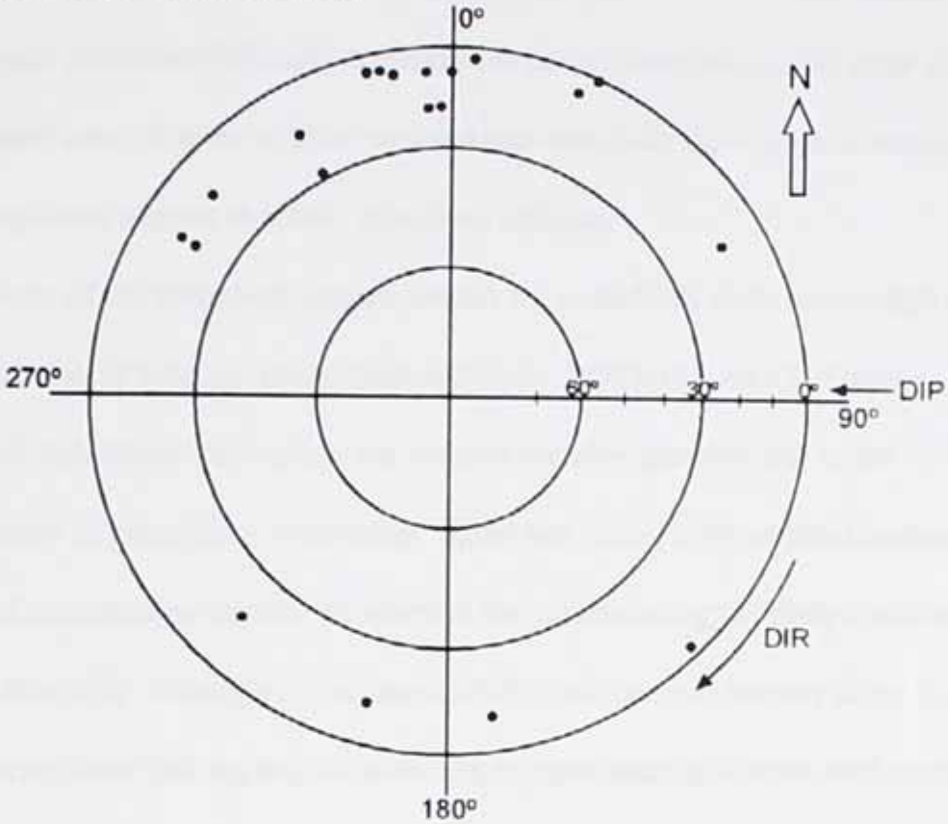
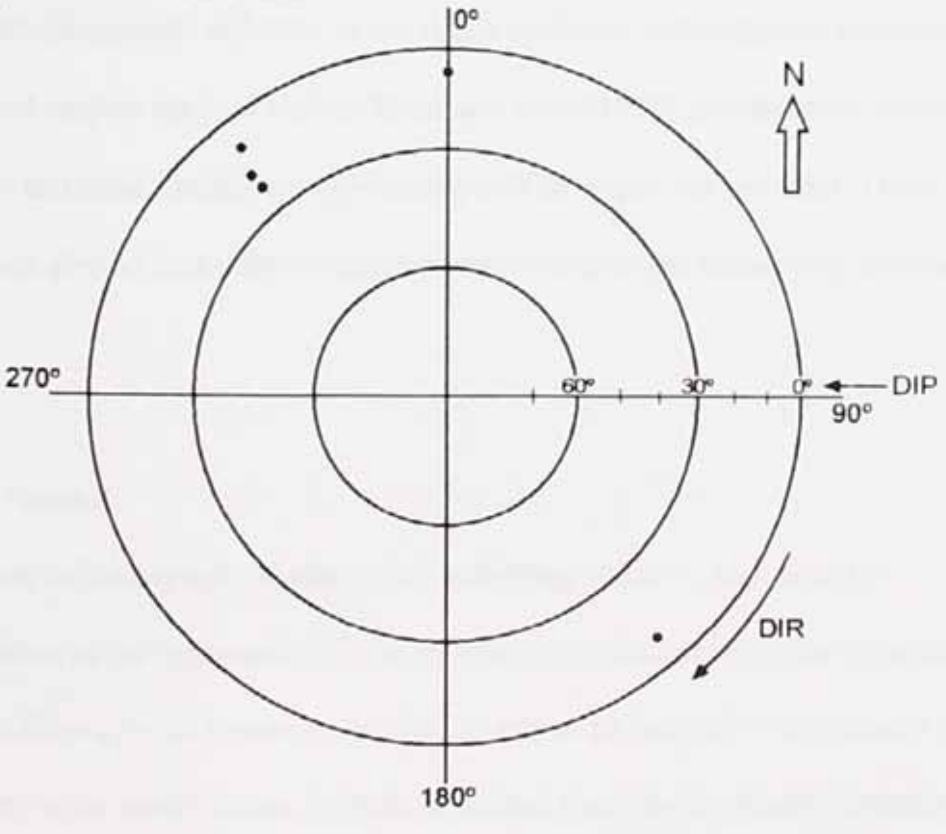


Figure 26.

Scatter plot for the bivalve bed



Worn micromorphs (1-5 millimetres axial length) of *Nerinella gracilis* (Lycett), *Nerinaea weldonis*, *Nerinaea cingenda* (Phillips), *Nerinaea altivoluta* Witchell and *Bactroptyxis pisolitica* (Witchell) dominate the nerinoidean fauna. The large size and good preservation of some of these nerinoideans especially *Bactroptyxis cotteswoldiae* and *B. implicata* suggest they may have been infaunal.

The majority of the gastropod species present are considered to be micro-algal grazers and detritivores (Clarkson, 1993; Kohn and Arua, 1999), (Figure 13, 27a/b). Gastropod distribution throughout the phase is variable, possibly due to the redistribution of material by winnowing. Kohn and Arua (1999) studied modern reef gastropod communities in order to interpret the palaeoecology of Early Pleistocene material from Fiji. Although it is understood that modern species may differ in habitat requirements from their ancient counterparts, comparisons have been used successfully in many areas of palaeontology for example Koutsoukos and Hart (1990), Nagy (1992) and Hylton (1999). These studies are used on the understanding that despite the range of ages morphogroups will recur as the result of similar environmental pressures. The tables used employ the approach of Kohn and Arua (1999) and show the maximum, minimum and mean abundances (percentages of the entire macrofauna). These gastropods give an indication of sediment redistribution and winnowing from local habitats.

4.01.2. Phase II.

This Phase is lithologically similar to the underlying Phase I (Appendix 1a). Examination of the exposures suggests a higher proportion of clay and intraclasts than in the underlying beds, however, this may be due to an increase in terrestrially derived sediment, or the redistribution of material eroded from the Grantham Formation or

Phase I. Sedimentation was not continuous, as breaks in deposition are present within Phase II. The major structure within Phase II is its basal channel fill indicating an erosive phase at, or prior, to the beginning of deposition of this phase. Alternatively it may indicate erosion during Phase II which removed the preceeding Phase II sediment, some of Phase I and some of the Grantham Formation (Upper Aalenian, *Concavum* Subzone?). The first 50 millimetres of limestone deposited in the bottom of the channel above the Grantham Formation is marked by the inclusion of reworked mica and encrusted hardgrounds. These hardgrounds may represent unspecified periods of reduced levels of deposition or erosion. Present also during this phase are minor "hiati" consisting of non-orientated and unsorted particles, which appear to fine-upwards (progressively reducing the proportions of coarse-grained sediment). These beds may represent storm events. Again there is no terrestrial fauna or flora, the intraclasts were derived from lithified/semi-lithified intrabasinal material from below and elsewhere.

The nerinoidean fauna includes *Nerinella gracilis, Nerinaea weldonis, Nerinaea cingenda, Nerinaea altivoluta, Bactroptyxis cotteswoldiae* and *Bactroptyxis pisolitica* identical to that of Phase I. This indicates either the same environmental conditions as Phase I, or reworking of material. Micro-algal grazers and detritivores (Kohn and Arua, 1999) dominate the gastropod faunas (Figure 27a/b), with similarities with the fauna of Phase I. This suggests that despite sediment redistribution, the catchment areas from which the material originates were of similar faunal composition. It is of note, however, that no *Actaeonina* are present, suggesting a reduction in either the availability of polychaetes or the redistribution of material from more lagoonal environments. The currents operating during this phase are difficult to interpret due to the lack of palaeocurrent data (see Figure 24).

4.01.3. Phase III.

This phase represents the bulk of the studied face (Figure 12). It consists of a major submarine channel infill (possibly overprinting several older channels like the remnant in Phase II). It is infilled with intraformational conglomerates deposited by a series of events, punctuated by cross-bedded (sometimes herringbone) sedimentary structures (Appendix 1a sheet 2b). The variable nature of the depositional environment gave rise to a number of chaotic lithologies. These became proportionally more micritic in character, as the channel infilled.

This phase is also punctuated by hardgrounds (Figures 7a, 7b and 8) but on a larger scale than previously described. One hardground measured some 20 metres across and was 1m in thickness, suggesting a period of time sufficient for deep boring lithophagid and fungal burrowers (Goldring 1995, p.152) together with encrusting bryozoans to establish tiering in numbers. These hardgrounds contain oysters (including *Lopha*) and the bryozoan genus *Berenicea.* The latter is recognised by Clarkson (1993), as slow growing and as being a *k*-strategist equilibrium genus. It may therefore be suggested that a succession of more opportunistic species, that were not preserved, may have previously colonised the hardground. Another feature of Phase III is submarine dune bedding. Such dunes (over 1 metre high) suggest quite powerful currents (Tucker 1981, p. 26). These may have removed what fine material was present leaving a grain-supporting oopelsparite with "rag-knolls", oyster-serpulid bioherms occurring between the dunes (Figures 15a-d). The growth of these rag-knolls appears to have been dependant on the height of the dunes. The other major lithological structures within this bed are stacked intraformational conglomerates. These comprise some 3 metres of deposit, often containing allochthonous exotic faunal elements such as corals. The lack of internal depositional structure, size sorting, and lack of fossil orientation suggests very rapid deposition. The intraformational conglomerates may contain both material reworked from earlier deposition and allochthonous elements swept into the channel by currents. This explanation may in part account for the degree of post-mortem wear exhibited by the fossil materials present. However, it is notable that all taxa identified have a range of growth stages, indicating a limited degree of size sorting by current activity (Allen, 1990; Brett, 1990). These properties suggest that beds may have been subject to periodic storms. There is an indication of tidal influence on the section as indicated by the occurrence of herringbone cross bedding and the strongly bipolar current orientations of sediment (Figure 25). The beds must therefore have been under a degree of near-shore influence despite the absence of any non-marine flora or fauna. This possibly reflects an environment on the edge of terrestrial influence. The nerinoidean fauna consists of *Nerinella* A4, *Nerinella* A3, *Nerinella* BI, *Nerinella* BII, *Nerinaea attenuata* (Witchell), *Nerinaea weldonis, Nerinaea eudesii* (Morris and Lycett), *Nerinaea expansa, Nerinaea* cf. *strictlandi* (Morris and Lycett) and *Bactroptyxis implicata.* These forms are in many cases very different to those in the lower beds, especially in terms of the presence in the fauna of the more simply ornamented *Nerinella* species. The Figures 27a and 27b quantify the abundance (and range of abundance) of some gastropod groups considered indicative of particular communities. Algal grazers (Figures 27a and 27b) dominate the gastropod fauna with rare *Actaeonina* indicating lagoonal influences (Kohn and Arua, 1999); the occurrences of all elements are variable, consistent with sediment redistribution.

4.01.4. Phase IV.

These sediments are characterised by the occurrence of the Weldon Roach and Weldon Rag Beds (Figures 15a-d), both being local names for two characteristic lithologies (Taylor, 1963). With the onset of Phase IV, the troughs of the submarine dunes became sites for the growth of reef-like associations of *Nanogyra nana,* (previously *Ostrea nana*) and encrusting serpulid worms (Figure 12, Appendix 1a sheets 1 to 7). The Weldon Roach is associated with the rag-knolls and contains large accumulations of shells (coquinas), of both single valves and complete shells, which on solution produced bio-mouldic porosity. These bivalve accumulations became the stable substrate for a diverse attached filter-feeding epifauna including, terebratulids, rhynchonellids, brachiopods and bivalves especially *Modiolus imbricata* with associated encrusters including serpulid worms and bryozoa (Taylor, 1990).

The environmental conditions during this episode in the deposition of the Lincolnshire Limestone Formation appear to have been less stressful than in the previous phases. This may have been due to either a local or more widespread trend. Rag-knoll growth and dune building appear to have been linked. The rag-bioherms grew between the dunes probably until they reached a critical height (sometimes as high as 1.3 metres) when local current flow was modified, reintroducing dune building. This in turn overwhelmed the bioherms. It is likely that in order for such a diverse community (Figure 16) as the Weldon Roach to form, conditions may have remained relatively stable for a sufficient length of time for its development. It is possible, however, that the diversity of both the Weldon Rag and Weldon Roach may have been exaggerated by the effects of time-averaging and mixing between habitats (Staff *et al.* 1986), in a similar way to that observed by Radley *et al.* (1998). These Weldon Roach faunas, however, appear to be largely autochthonous as the species present not only exhibit orientation (Figure 26) as an associated fauna, but also because the entire range of growth stages are observed with little wear present.

The sediment may have been sufficiently coherent to enable byssal forms (Stanley, 1972) to attach. Such forms may, however, have anchored on bioclastic material (Taylor, 1990). There must also have been sufficient particulate nutrients in the water for the filter-feeding molluscs to feed upon. Current activity must have been sufficient to move the community into a position where it was current orientated (as an extensively bysally-attached community), and continuous in order for the community to thrive. These currents may have been tidally influenced as the bysally-attached fauna appears (from field observations) to exhibit bimodal orientation at 180° to each other (Kidwell *et al.*, 1986). This hypothesis is supported by the organism's oxygen requirements. Where the water was not mobile the respiration of so many organisms would soon have reduced the availability of free oxygen.

Although there is a visible pelletal component in this Phase, there is also a noticeable lack of fine-grained material in both the Rag and Roach Beds. Sediment input was restricted, as too much sediment would hamper the filter-feeding fauna.

The nerinoidean fauna of Phase IV is very different to that of the preceeding strata. It includes *Bactroptyxis implicata* and *Bactroptyxis cotteswoldiae*. There appears to have been a shift in faunal diversity away from the *Nerinella* and *Nerinaea* faunas of the previous phases towards dominance by *Bactroptyxis* species. This may be a response to the environmental conditions that prevailed in Phase IV, possibly suggesting that at least some of the *Bactroptyxis* species favoured environments with hard substrates. The occurrence of *Bactroptyxis cotteswoldiae* (Figure 8) is of some correlative importance (Hudleston, 1888). The gastropod faunas of this phase are dominated by algal-grazers with rare lagoonal forms, an amount of sediment redistribution being suggested by the variation in sediment type and faunas between samples, this possibly being the result of the rag-knoll building process.

As several samples comprise each phase the minimum, maximum and mean abundance ratios are given.

Figure 27a. Ecologically indicative gastropods, ratios from Cowthick Quarry.

Phase	*Trochus*	*Phasianella*	*Cerithium*	*Rissoina*	*Actaeonina*
Phase I	Mean 1.3% min 0% max 8%	Mean 4.87% min 0% max 16%	Mean 9.6% min 0% max 49.5%	Mean 2.47% min 0% max 6.58%	Mean 0.28% min 0% max 0.99%
Phase II	Mean 1.5% min 0 % max 3%	Mean 1.5% min 0% max 3%	Mean 19.7% min 2.94% max 35.4%	Mean 1.5% min 0% max 3%	Mean 0% min 0% max 0%
Phase III	Mean 2.03% min 0% max 6.76%	Mean 10.6% min 3.46% max 22.8%	Mean 7.91% min 3.49% max 17.5%	Mean 2.3% min 0.495% max 3.49%	Mean 0.33% min 0% max 0.99%
Phase IV	Mean 1.99% min 2.26% max 12.22%	Mean 9.56% min 9.4% max 9.72%	Mean 5.136% min 2.82% max 7.452%	Mean 0.485% min 0% max 0.97|%	Mean 0.632% min 0.324% max 0.94%

These ratios represent the proportions of the entire gastropod fauna being made up by these gastropod groups. As several samples represent each depositional Phase a mean, maximum and average figure is given.

Figure 27b. Gastropod palaeoecology and substrate (Kohn and Arua, 1999).

Trochus	Most modern trochids are epifaunal grazers on benthic plants and encrusting invertebrates.
Turbinidae (Phasianella)	Turbinids today are algal grazers, most diverse on carbonate substrates in tropical and subtropical regions.
Cerithium	Most spp. are associated with shallow water sands, feeding on algae, micro-organisms and detritus.
Rissoina	The modern representatives of this family feed on fine algae, deposited detritus and foraminifera, and are often found among shallow water seaweed.
Actaeonina	This family inhabits soft substrates from the shoreline to 100 metres, predating upon cirratulid and sabellid polychaetes.

4.02. Clipsham Old Quarry, Clipsham, Lincolnshire (SK978154).

No studies were made of ostracod completeness at this locality, as none of the material was entire.

4.02.1. The Lincoln Member (Scottlethorpe Beds).

These pale grey micritic limestones with ooids have been subject to extensive infaunal burrowing (Appendix 1b sheet1). This burrowing is unlikely to have been by gastropods or bivalves (Figure 18) as neither occurs in the fauna. In order for non-specialised organisms to burrow successfully the substrate must be sufficiently soft to allow efficient movement (Goldring, 1995). The clay must also have been sufficiently coherent however to have prevented the collapse of burrows of any filter feeders. It is assumed that along with the burrows of infaunal detritivores, a filter-feeding community may have been present alongside *Acanthothiris crossi* (an epifaunal filterfeeder found in these beds). As a result it is possible that other organisms would have exploited this nutrient source (assuming adequate nutrient supply). The presence of an infauna suggests that, despite the grey coloration of the beds, the conditions were well oxygenated. This being the case, any "blue-hearting" of the limestone caused by the formation of iron pyrites (Dawn *pers comm.*; Tucker, 1991) may be the result of post-depositional changes in pore water chemistry. *Acanthothiris crossi* is present suggesting that the increased surface area afforded the species by their spines may have facilitated its colonisation of these muds.

The water must have been circulating in order to provide both oxygenated water, and organic material for the filter feeders, without being sufficient to erode the finer grained material.

The major macrofaunal components in sample COQI (Appendix 1b) include echinoids, crinoids, ophiuroids, bryozoa and serpulids (Figure 18). Regular echinoids are macroalgal grazers, using their Aristotle's lanterns to rasp their food from the sediment surface (Levinton, 1982; fragments of these echinoid structures being described in the samples as elongate ossicles). The presence of algal films suggests that the environment was within the photic layer and probably shallow. The presence of *A. crossi* and echinodermata indicates it must also have been fully-marine. The presence of crinoid ossicles and the absence of hard substrates within the studied outcrop suggests that there may have been a firm substrate near the site (in the absence of any evidence to suggest this material was from unstalked comatulid crinoids).

The attached fauna, possibly crinoids, bryozoa and serpulids are, in the absence of firm substrates, likely to be allochthonous. This again suggests current activity. Alternatively, the presence of crinoidal material may be from pseudopelagic forms

(Clarkson, 1993) such as *Pentacrinites fossilis* Blumenbach living attached to floating debris. On death such forms would have scattered ossicles across the sea floor. No woody material was found at this site suggesting that there was no floating debris available for pseudopelagic crinoid attachment. The presence of ophiuroids (Figure 18) suggests a number of environmental possibilities depending on the types present. They can occur as today (Kershaw, 1994) as epifaunal carnivores such as *Palaeocoma egertoni* (Broderip) or filter-feeding crevice dwelling forms (Levinton, 1982).
The numbers of unidentified gastropods in COQI were low (Figure 18, Stratabugs chart for Clipsham Quarry). Similarities in the substrate and environmental conditions suggest that these faunas were derived from the same habitats as the attached fauna. A single *Actaeonina* was also present possibly suggesting the transport of material from nearby lagoonal environments from where this polychaete predator would have originated (Kohn and Arua, 1999; see Figure 29).

The impoverished ostracod fauna of COQI (Figure 18, Stratabugs charts for Clipsham Quarry) is too sparse for confident palaeoenvironmental analysis. Also present are ostracods, these are unidentifiable due to wear possibly due to pre-depositional and diagenetic activity.

The foraminiferal fauna of COQI is too sparse for confident palaeoenvironmental analysis. Brouwer (1969) and Ainsworth *et al.* (1989) consider *Lenticulina muensteri* to be fully marine, Nagy *et al.* (1981), however, report *Lenticulina* from brackish environments. All of those foraminifera present are considered morphologically epifaunal/infaunal with affinities towards fine sandy sediments (Koutsoukos and Hart, 1990).

4.02.2. Lincoln Member (Castle Bytham Beds).

These beds are some 3.2 metres thick. The basal 0.5 metres of which are represented by a visible component of quartz, intraclasts, ironstone and echinoderm fragments (Appendix 1b sheet 1). The presence of quartz may suggest a degree of input from terrestrially derived sources. This may be a result of several factors.

a) A change in terrestrial drainage.

b) A lowering of the sea level.

c) The input of storm derived sediment from landward of the exposure.

The presence of limestone intraclasts and ironstone suggests nearby erosion from an area where they were previously deposited. However, it is possible that this erosive event will be correlated with the erosive event that channelled into the Grantham Formation noted at Cowthick (Figures 11 and 28) and in the Northamptonshire Ironstone as documented by Taylor (1963). The presence of echinoderms and infaunal burrowers suggests that the underlying environmental and depositional conditions of the Castle Bytham Beds were similar to those of the Scottlethorpe Beds.

Figure 28. An eroded contact between Aalenian deposits and the Lincolnshire Limestone Formation sediments discovered in the 1970's at Cowthick Quarry. Seagull for scale.

The overlying biomicrites are topped by sample COQII. The communities of these micritic beds suggest that the substrate was sufficiently competent for an epifauna to become established (Figure 18 and Stratabugs charts for Clipsham Old Quarry). These filter-feeding forms require organic, particulate-rich currents to pass over their filtering structures (Goldring, 1991; Kershaw, 1994). Also abundant are *Bactroptyxis guisei* and *B. cotteswoldiae* some with axial lengths in excess of 100 millimetres. *B. guisei* is considered to be most indicative of the Upper Bajocian / Lower Bathonian Clypeus Grit (Barker, 1976). Barker (1976) cited *B. guisei* as present in the Lower

Lincolnshire Limestone at Castle Bytham (SK9918). At Clipsham, this species occurs in the uppermost Lower Lincolnshire Limestone of Kent (1966), which extends its known range. Algal grazers indicate the development of algal films on the sediment surfaces (Figure 18). This in turn suggests a photic environment with crinoid fragments, bryozoa, and ophiuroids indicating conditions similar to those in the underlying bed.

The ostracod fauna of COQII (Figure 18, Stratabugs charts for Clipsham Old Quarry), is too sparse for confident palaeoenvironmental analysis. The species *Progonocythere cristata* is considered by Morris (1983) to indicate quiet vegetated lagoons.

The foraminiferal fauna is too sparse for confident palaeoenvironmental analysis (Figure 18, Stratabugs charts for Clipsham Old Quarry). *Lenticulina muensteri, Lenticulina quenstedti* and *Lenticulina* var. A are represented, together with *Spirillina infima, Dentalina pseudocommunis, Vaginulina contracta* and *Vaginulina jurassica*. Species of *Dentalina, Vaginulina* and *Epistomina* are considered by Koutsoukos and Hart (1990) to be epifaunal / shallow-infaunal deposit feeders indicative of fine grained sands and muds. This suggests that the substrate was both soft and rich in organic material. The source of material may well have been generated from the detritus produced by algae and sea-grasses as indicated by presence of *Spirillina* (Nagy, 1992; Koutsoukos and Hart, 1990). The organic materials in the sediment had probably not given rise to anoxia, however, as these forms are considered intolerant of reduced oxygenation and/or increased sulphide in the sediment (van der Zwaan *et al.*, 1999). *Spirillina* are considered by Nagy *et al*. (1981) and Copestake (1989) to indicate shallow marine conditions.

The preservation of instars and species of small size suggest that size-sorting may have been operating during deposition (Morris, 1983; Whatley 1988). The foraminiferal fauna however appears to have been less affected than the ostracoda, with adults of both large and small sized species of foraminifera present.

This sample also contains the gastropods described in Appendix 2a. Those present suggest the presence of algal coatings and a degree of transport of sediment from lagoonal environments.

There is an absence of quartz in this sample, suggesting that the source of supply has been redirected or cut off.

The next horizon although fine-grained contains coarse ooids (to 1.5 millimetres) (Appendix 1b sheet 2) suggests proximity to a source where time was sufficient for their growth, which requires shallow and turbulent conditions in a warm photic environment. Despite the overall fine-grained nature of the beds, the ooids, quartz, and broken shell material suggests energetic conditions. The conditions must have also been sufficiently calm to allow the net deposition of fine-grained sediment (probably enhanced by the peloidal input of the fauna and mixing by infaunal burrowers). Infaunal burrowing may have enhanced the formation of broken shell deposits. Although less fossiliferous than the lower bed, it contains trace fossils and both *Bactroptyxis cotteswoldiae* and *B. guisei*. The top 100 millimetres of this bed are made up of comminuted shell material, this being produced by energetic conditions which reduced the shelly material to a finely ground state. The top surface of this bed is marked by an undulating eroded surface, identified as a hardground by Ashton (1977, 1980; see Appendix 1b).

No macrofauna or microfauna were recorded from the sampled horizon COQIII. The undulating nature of the eroded surface suggests that the underlying strata were down-cut prior to deposition of the overlying material. This down cutting probably occurred repeatedly as small-scale (narrow and shallow) channels as suggested by the undulating nature of the surface. Ashton (1977, 1980) considered the interface between the Lincoln and Clipsham Members to be a hardground.

4.02.3. The Clipsham Member.

A bed of decalcified solitary corals, probably equivalent to the Wilsford Coral Beds of Kent (1966) was noted (Appendix 1b sheet 2). This suggests that the interface between the Lincoln Member and the Clipsham Member (Figure 9) was a hard / firm ground (Goldring, 1995). According to Clarkson (1993) the corals required a hard or firm substrate on which to attach especially in current dominated environments, perhaps in a similar way to that cited for the Corallian Stanford Member by Goldring *et al.* (1998).

The presence of corals suggests a post-erosional halt or reduction in deposition as they have a very low tolerance for muddy environments, which interfere with both their filter feeding, and with the settling of their planulae (Clarkson, 1993; Taylor *pers comm.*). Their presence also broadly suggests warm, shallow (photic) conditions, assuming Jurassic corals are comparable to those of today (Clarkson, 1993; Kershaw, 1994). The photic requirement is suggested because many coral species have symbiotic relationships with zooxanthellate algae (Clarkson, 1993).

Above this basal coral bed, the lithology is one of a well-cemented oosparite suggesting high porosity at deposition, probably due to winnowing of the pre-lithified sediment. The first 0.5 metres are well-cemented oosparites. These are followed by cross-bedded oocalcarenites and calcirudites suggestive of deposition under unidirectional flow the source material containing terrestrial quartz.

The succeeding bed consists of finer-grained material, with lower energy conditions. This was colonised by an epifauna, dominated by species of *Modiolus* and gastropods. This fauna suggests a sediment surface either sufficiently consolidated for colonisation by epifaunal organisms or that other hard substrates were available. Depositional rates must have been sufficiently low to allow filter-feeding and the compaction of the sediment. The environmental conditions must have remained sufficiently stable to allow both colonisation and reproduction.

The thin clay sampled as COQIV (Appendix 1b sheet 2) tops this bed. Unidentifiable gastropods, echinoid fragments, and crinoid elements with species of bryozoan and serpulid worms dominated its fauna (Figure 18). Low rates of deposition and current activity may have taken place in order to produce the abrasion observed at the sediment surface. The sediment must also have been sufficiently compact to allow the movement of echinoids across the sediment surface. It is likely that the echinoids were local in origin judging from the good preservation of the fragments. The presence of crinoids indicates a nearby firm substrate in current agitated water with a low inorganic sediment load (assuming the absence of stemless forms). The microfauna of sample COQIV is sparse (Figure 18, Stratabugs charts for Clipsham Quarry).

This impoverished ostracod fauna includes the species *Ektyphocythere triangula* and *Praeschuleridea subtrigona*. These species are considered by Morris (1983) to indicate turbulent and quiet lagoonal habitats respectively. This suggests the mixing of bioclasts (Whatley, 1988).

The foraminiferal fauna is also too sparse for confident palaeoenvironmental analysis (Figure 20, Stratabugs charts for Clipsham Old Quarry). Koutsoukos and Hart (1990) see the foraminifera (except Tetrataxis) as epifaunal/shallow infaunal deposit feeders.

The 5 metres of sediment following COQIV comprise high energy shelly calcirudites. These beds, although too high for safe inspection, pinch and swell as stacked channels. This suggests that hydrodynamic conditions were unchanged for sufficient time for erosion and deposition to occur. Some of the beds are blue-hearted due to the generation of iron pyrites throughout the sediments during diagenesis (Dawn *pers comm.*; Tucker, 1991).

The ratios of ecologically indicative gastropods (Figure 29) are low but suggest that there was post-mortem mixing between environments.

Figure 29. Ecologically indicative gastropods, ratios from Clipsham, Old Quarry. See Figure 27b.

Sample	*Trochus*	*Phasianella*	*Cerithium*	*Rissoina*	*Actaeonina*
COQI	0	0	0	0	0.44%
COQII	0	0.379%	0.758%	0.379%	0.758%
COQIII	0	0	0	0	0
COQIV	0	0	0	0	0

4.03. Copper Hill Quarry, Ancaster, Lincolnshire, (SK 979427).

The Quarry is now disused and mostly cleared of rubble. It exhibits deeper exposures than were available for Ashton (1977). The strata of the quarry are as follows, (see Appendix 1c).

4.03.1. The Greetwell Member.

Due to unsafe exposures, access to this member was restricted. This member constitutes the base of the section, comprising approximately 6.2 metres of fine-grained micritic lithology gradually becoming coarser (more oolitic) through the exposure (ooliths to 1.5 millimetres diameter). These beds may have formed under a number of environmental conditions.

a) The sediment may have been deposited by a storm event or by the re-positioning of the lagoon channel system. This would have brought coarse-grained sediment into lower energy environments. It is unlikely that the ooliths were produced *in situ* as the lithology is fine-grained indicating that depositional turbulence may have been restricted.

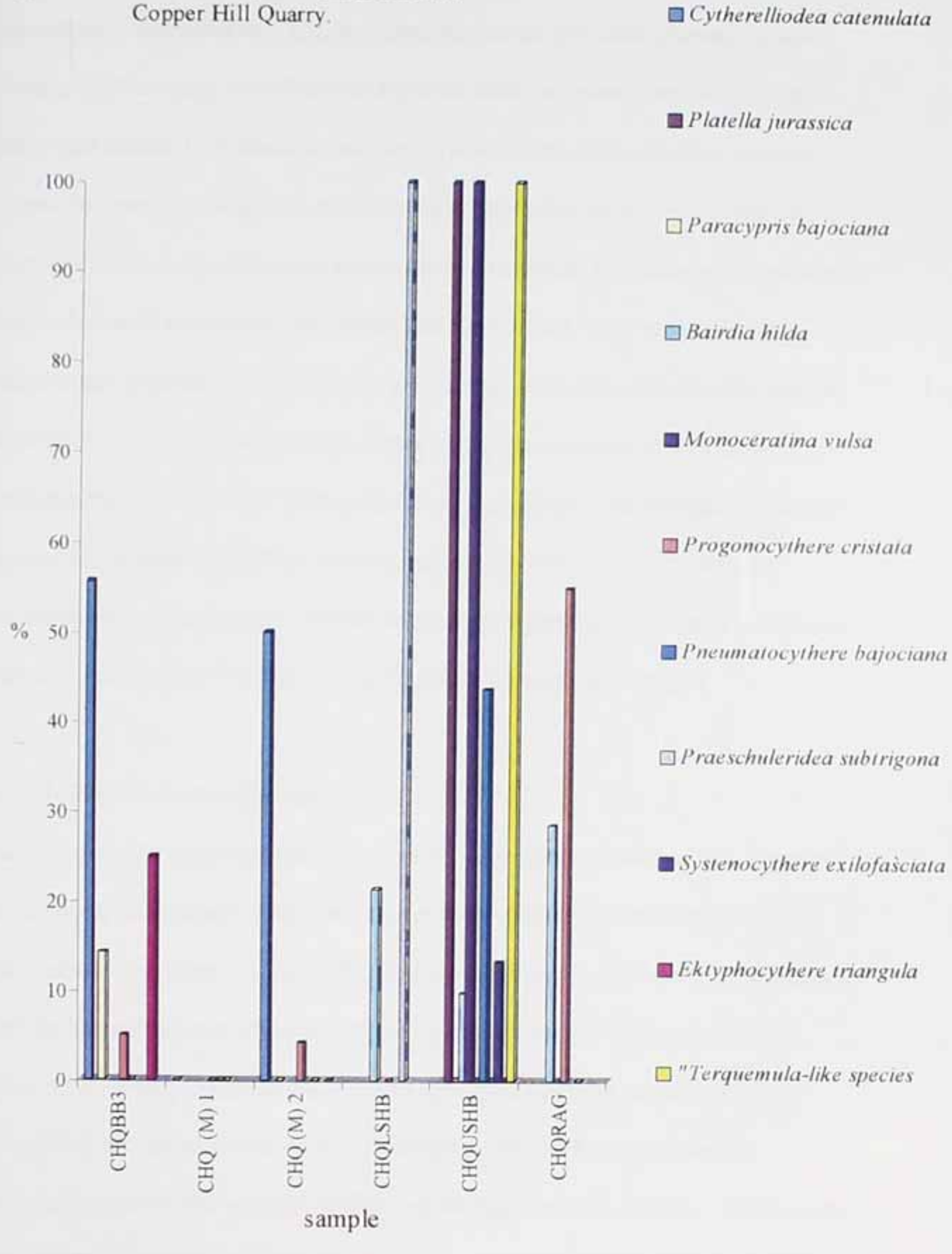
b) An alteration in the hydrodynamics of the lagoon, such as a gradual increase in environmental energy might allow the formation of this structure, causing micrite and ooids to be deposited together. Again because no discrete bed was formed, it is probable that such a change was gradual; the environmental energy remaining insufficient to remove the underlying micrite. It is possible that environmental energy may have been relatively high however, as a Hjulstrom's diagram (Tucker, 1981, p.25, Fig 2.13) illustrates that cohesion of clay-sized particles can increase the energy required for erosion.

Bioturbation by large bivalves, including *Gervillia* and *Pholadomya* (found both whole and fragmentary) is especially heavy at the top of these beds. It is of note, however, that these infaunal bivalves are characteristically size-sorted and found in hydrodynamically stable positions (Brett and Baird, 1986). These features suggest erosion that caused exhumation of the shells, size sorting, and movement into stable positions (Brett and Baird, 1986), indicating current flow. Furthermore, the unimodal orientation suggests unidirectional flow (Kidwell *et al.*, 1986). Unimodal orientation can occur in tidal influenced environments if one tidal current predominates (Tucker, 1981). There are lamina in the non-bioturbated sections, suggesting slow deposition, possibly by settling or precipitation (laminae can form due to high velocity flow according to Tucker (1981) but this usually occurs in coarser sediments).

Fragments of bivalves dominate sample CHQBB3 (Figure 20, Appendix 1c sheet 1, Stratabugs charts for Copper Hill Quarry). Although the degree of fragmentation may be due in part to sieving, the bulk is probably the result of taphonomic wear. The dominance of these bivalve fragments indicate post-mortem movement due to bioturbation and \ or post depositional movement (Brett, 1990; Tucker, 1990). It is possible that the fragments consist of *Gervillia* and *Pholadomya* as these are the major body fossils present in these beds, with the possible inclusion of species mechanically too weak to remain intact through bioturbation. It is notable that only a small percentage of the fauna is made up of echinoid or crinoidal material, suggesting these elements are parautochthonous.

The degree of disarticulation of ostracod carapaces can give an indication of the degree of time averaging which affected them (Whatley, 1988). Time on the sediment surface provided time for the decay of the tissues holding the valves together. *Cytherella fullonica, Progonocythere cristata* and *Cytherelloidea catenulata* occasionally occur as intact carapaces (Figure 30), suggesting a relatively short period prior to burial. The other species present, however, occur as disarticulated valves. The proportion of ostracod fauna unidentifiable due to wear also suggests post-mortem transport, these individuals possibly include non-resident species (Figures 20 and 30, Stratabugs charts for Copper Hill Quarry). Consequently, it is suggested that the resident fauna consisted primarily of *Cytherella fullonica* and *Progonocythere cristata* with *Cytherelloidea catenulata* together with several subordinate species. *Cytherelloidea catenulata* is considered by Morris (1983) to indicate turbulent and non-phytal environments respectively. The large size and lack of instars and juveniles within the microfauna suggests winnowing of the sediment, a feature consistent with a turbulent environment (Morris 1982, 1983).

Figure 30. Ostracod carapace completeness at Copper Hill Quarry.



The foraminiferal fauna of CHQBB3 is dominated by *Lenticulina muensteri* with subordinate *Lenticulina* var. A, *Lenticulina quenstedti*, *Dentalina pseudocommunis*, *Nodosaria fontinensis*, *Frondicularia lignaria*, UnID calcareous benthic A, UnID calcareous benthic C, *Planularia beierana*, *Citharina* sp. A, *Eoguttulina liassica*, *Vaginulina jurassica*, *Vaginulina legumen* and *Vaginulina* sp. A. The occurrence of epifaunal/infaunal deposit feeding foraminifera - *Dentalina*, *Frondicularia*, *Nodosaria*, *Vaginulina* and *Lenticulina* is consistent with fine-grained sandy environments (Koutsoukos and Hart, 1990). This agrees with the small size, high diversity and low abundance of the foraminifera which appear to comprise material from similar environments as indicated by their microfaunal composition. The Greetwell Member appears to represent deposition in a back-barrier lagoon in which turbidity and sediment transport increased over time, resulting in microfaunas indicative of different habitats. Ashton (1977, 1980) did not record this member in this quarry.

4.03.2. The Leadenham Member.

At this quarry the sediments are comprised of bioturbated biomicrites. The 2 metres of sediment contain burrows filled with coarser material than the surrounding matrix, punctuated by clay/marl horizons. The fauna is dominated by algal grazing gastropods and the infaunal bivalves *Pleuromya lirata* (Sowerby) and *Pholadomya uniformis* (Sowerby). This grazing fauna was absent from the underlying member possibly suggesting that the sediment surface had become sufficiently consolidated for colonisation and/or the sediment surface had developed phytal growths. Alternatively, the sediment chemistry may have become conducive to habitation. The burrow fills may arise in two ways.

a) When locally derived shelly material is washed into the still open burrow entrance (Goldring, 1991).

b) When the material is actively selected by a resident organism either as a backfill or a burrow lining (Goldring. 1995; for example, as used by modern tubeworms such as *Lanice* and *Diopatra*, Goldring, 1991).

Regular echinoids and crinoids dominate the fauna of sample CHQ (M) 1 (Figure 20, Stratabugs chart for Copper Hill Quarry) 1 metre from the base of the member. The presence of echinoid fragments alongside algal grazing gastropods again suggests that the sediment/water interface may have been vegetated unlike that of the Greetwell Member. Furthermore, it suggests that the origin of the crinoid fragments may be parautochthonous, a hard/firm substrate probably existing nearby (in the absence of pseudopelagic forms). It must be noted that both echinoid and crinoid skeletons fragment into a large number of elements (Aslin, 1968; Taylor, 1983; Brett and Baird, 1986). The abundance of broken bivalves indicates that the material accumulated on the sediment surface where it was abraded and rolled by the currents. Those same currents possibly winnowed away any fine sediment, perhaps slowing the rate of sediment accumulation. These broken bivalve accumulations might have provided substrates for the crinoidal fauna (Taylor, 1990; Levinton, 1982). The low numbers of rolled gastropods may indicate either that the resident gastropod fauna was restricted, or that it was absent and the material was from another source.

The ostracod fauna is dominated by *Progonocythere cristata*, a species not recorded in similar Cotswold material by Morris (1983). Those species present are, however, largely consistent with Assemblage 2 of Morris (1983). In his material he regarded

Cytherelloidea catenulata and *Praeschuleridea subtrigona* as indicative of quiet lagoonal, non-phytal environments. The proportion of the sample made up of unidentifiable fragments however is high (Figure 30), suggesting a degree of post-mortem movement prior to burial (Whatley, 1988; Wakefield, 1995), as does the absence of articulated ostracod material (Whatley, 1988). This movement may also have resulted in winnowing. The ostracod microfauna consists almost entirely of small adults or instars which may have been winnowed from nearby sources, possibly being deposited around vegetation. A further possibility is that as each ostracod growth stage tends to live separated from the others (Whatley, 1988) the sample may represent a "Nursery-accumulation".

The foraminiferal microfauna of CHC (M) 1 (Figure 20, Stratabugs chart for Copper Hill Quarry) is dominated by *Spirillina infima*. This is consistent with the findings of Morris (1982) who recorded a similar association in contemporaneous deposits in the Cotswolds. *Spirillina* spp. are considered by Copestake (1989) to indicate shallow marine conditions. In modern environments *Spirillina* are recorded from lagoonal environments (Nagy, 1992). Species of *Spirillina* are considered by Koutsoukos and Hart (1990) to have been both epifaunal deposit feeders and semi-attached browsers, possibly suggesting the presence of marine vegetation (Morris, 1982) this being in agreement with the macrofauna. There is a marked drop in *Lenticulina* numbers in this sample, perhaps due to environmental constraints. These constraints may include a reduction in oxygenation or the introduction of brackish water conditions (Brouwer, 1969 and Ainsworth *et al.*, 1989). Nagy *et al.*, (1981) report *Lenticulina* from brackish environments, although Shipp (1989) points out that *Lenticulina* are long-ranging and have a wide range of environmental tolerances. Koutsoukos and Hart

(1990) consider *Lenticulina* species to be at least partially shallow-infaunal. Therefore, the sediment may have been either too consolidated, or chemically unfavourable for colonisation possibly as a result of increasing sulphide levels in the sediment from the decomposition of the algal growths (Gooday and Rathburn, 1999; van der Zwaan *et al.*, 1999). Morris (1983) considers high species dominance alongside low species diversity as a feature of palaeocommunities living at or near the site of deposition. *Ammobaculites* are considered a typical constituent of low diversity estuary deposits (Nagy *et al.* 1995) possibly because these agglutinating benthonic foraminifera are believed to be more tolerant of low oxygen levels and high sedimentation rates (King *et al.*, 1989; Murray, 1991). *Ammobaculites* are considered by Koutsoukos and Hart (1990) to have been infaunal deposit feeders. They suggest *Frondicularia* to have been epifaunal to shallow infaunal deposit feeders. Consequently, it is unlikely that substrate type was the only factor inhibiting *Lenticulina* from flourishing, chemical variables possibly making them less competitive. The physical size distribution of foraminifera in this sample, although dominated by adult forms, is bimodal in that large and small sized species are present (0.25-1 millimetre). This suggests that the material may have been subject to minimal size sorting. Morris (1982) suggested that the *Spirillina* are easily transported between environments. It is unlikely, however, that this process accounts for the high numbers recorded.

The faunas of this environment are considered suggestive of low energy back-barrier deposition with restricted influence from other environments.

4.03.3. The Lincoln Member.

This is represented by 2.8 metres of white biomicrites. The top of the member is characterised by an increase in bioturbation (Appendix 1c sheet 1) and an increase in the numbers of nerinoideans especially *Bactroptyxis cotteswoldiae*. The possibility of their having an infaunal nature was suggested earlier. This member yielded sample CHC (M) 2 (Figure 20, Appendix 1c sheet 1). The macrofauna of the marl CHQ (M) 2 at the base of the member is characterised by the dominance of echinoid fragments and crinoidal elements. Wear, degree of fragmentation and coatings on the gastropods and bivalves suggest these spent some (unknown) time at the sediment surface prior to lithification.

The ostracod microfauna (Figure 20, Stratabugs chart for Copper Hill Quarry) is characterised by the dominance of *Progonocythere cristata*. The ostracod faunas broadly correlate with groups 2 and 3 of Morris (1983), forming a combination of non-phytal and turbulence adapted forms. Unidentified ostracods make up a high proportion of the total ostracod fauna, indicating that pre-depositional abrasion was in operation. Time averaging and winnowing were active processes. The presence of only three intact ostracods in microfauna in this sample (Figure 30) precludes identification of the resident faunas. Although instars are present they are few and belong to both group 2 and 3 species.

The foraminiferal microfauna shows the appearance of *Lenticulina* var. B (Figure 20, Stratabugs chart for Copper Hill Quarry). Otherwise, the fauna of this sample is similar to that of sample CHQ (M) 1, suggesting a similar range of biotic and abiotic conditions. The lithology of these horizons and the sediments between these beds indicates that they may form part of the Ropsley Beds (Ashton, 1977, 1980). Also present are crab fragments (claws), ophiuroid material, and large quantities of sponge spicules. This possibly suggests a rapid deposition of material because the size range of particles (sponge spicules - gastropods) is not consistent with current deposition and winnowing. The ratios of worn to non-worn gastropods and abundance of bivalve fragments are each 8%. The gastropods *Bactroptyxis cotteswoldiae* and *B. guisei* are present. Coral patch reefs up to 0.8 metres across occur at the top of the Lincoln Member. These may be equivalent to the Castle Bytham/Wilsford Coral Beds (Kent, 1966) as identified at Clipsham Old Quarry. The corals at this location are more compound in nature than at Clipsham. These bioherms are tabular in cross-section and flat topped, possibly indicating a reaction to energetic conditions with a low profile growth reducing abrasion by currents. Another possibility is that the low profiles are a post-mortem erosional feature, the corals having been abraded flat. At the base of these coral bioherms, as they wear out of the outcrop, mica flakes can be seen in the limestone. The origin of these flakes may be from an as yet unidentified terrigenous source, where igneous and / or metamorphic material is being eroded, or derived from the erosion of previously deposited sediments. The Grantham Formation (Figure 3) and the Collyweston Slate (Wilson, 1948) represent the most likely candidates for a possible mica source as these are the most mica rich units coeval to the sample. As stated previously the Lincolnshire Limestone Formation is seen to infill channels into the Grantham Formation (Taylor, 1963; own field observations) and the Collyweston Slate (Wilson, 1948). If the Grantham Formation proved to be the source of the mica in the Upper Lincoln Member at Copper Hill Quarry, its presence would be of value in the correlation of the Formation. This environment appears to have been deposited under low energy conditions with influences from more turbid environments.

4.03.4. The Sleaford Member.

Ashton (1977, 1980) identifies Copper Hill as equivalent to the Ancaster Freestone of Richardson (1939). Ashton (1977, 1980) regarded Copper Hill as the type locality for the Sleaford Member. The member is characterised by the coarsening of the lithology and the introduction of dune-cross bedding with ooids and intraclasts becoming a major lithological component (Appendix 1c sheet 2). These features suggest a net increase in environmental energy. This coarsening was the result of the over-riding of the protected lagoons of the Lower \ Middle Lincolnshire Limestone Formation by a barrier bar complex (Ashton, 1977; Tucker, 1985). The "bulk" palaeontology of the member is characterised by the fact that only robust / durable gastropods and bivalves are preserved in an identifiable state. The base of the member consists of the clay sampled as CHC4.

This sample was made up entirely of crinoid and echinoid fragments. A period of instability may be suggested where the environment favoured algal-grazing echinoids over the previously resident fauna. The crinoid material may be allochthonous given the absence of hard/firm substrates, as discussed previously.

Sample CHQLSHB taken some 28 centimetres above CHC4 suggests a shift away from fine-grained environments. Depositional features include cross bedding up to 30 centimetres in height, and bioclast orientation resulting in the formation of small-scale coquinas, (shells of up to 7 millimetres across). The faunal diversity is high in this sample. It includes a diverse gastropod fauna including both soft sediment algal grazers e.g. *Bactroptyxis* spp., (Barker *pers comm.*), and diminutive hard surface grazers similar to modern limpets. The proportion of unidentifiable gastropods, the presence of size sorted material and faunas with little resistance to wear suggests low energy winnowed conditions in which bioclasts were transported in possibly from a wide catchment area.

The ostracod material studied by Morris (1983) in the Cotswolds suggests that *Bairdia* are indicative of coarser, higher energy facies. Distributions of *Bairdia* species in the modern Bahamas (Prothero and Schwab, 1996 p. 264) indicate their greatest abundance on shallow bottoms (less than 6 metres), which support growth of sea-grasses and algae (Kornicker, 1961). Their appearance in the more oolitic, (algally-formed) facies of the Lincolnshire Limestone Formation is consistent with their recent distribution. The increased proportions of unidentifiable ostracods (Figure 20, 30, Stratabugs chart for Copper Hill Quarry) between this and the previous samples is consistent with the suggested increase in environmental energy, as is the scarcity of articulated material and instars. The species *Praeschuleridea subtrigona* and *Bairdia hilda* occasionally appear as entire carapaces possibly suggesting a more local source than the other species recorded (Figure 30).

The foraminiferal fauna (Figure 20, Stratabugs chart for Copper Hill Quarry) indicates a shift in environmental conditions. Koutsoukos and Hart (1990) would consider the majority of the fauna as epifaunal, with the exception of the surviving *Dentalina* fauna and *Ammobaculites agglutinans*, which they consider to be deposit feeders. Koutsoukos and Hart (1990) do not include *Tetrataxis* sp. in their paper. The occurrence of these species supports the suggestion that conditions had become more energetic, giving rise to coarser substrates. This inference is consistent with the work of Morris (1982) in the Cotswolds, who suggests that rotaline faunas are typical of finer-grained lithologies, surmising that they make up a primary-weed fauna.

SAMPLE	*Trochus*	*Phasianella*	*Cerithium*	*Rissoina*	*Actaeonina*
CHQRAG	0.11%	1.035%	0.92%	1.265%	0 %
CHC5	0%	0%	0%	0%	0%
CHQUSHB	0.385%	1.27%	3.18%	2.44%	0.954%
CHQLSHB	0 %	0.116%	1.62%	0.464%	0.464%
CHC(M)2	0%	0%	0%	0%	0%
CHC(M)1	0%	0%	0%	0%	0%
CHQBB3	0%	0%	0%	0%	0%

Figure 31 Ecologically indicative gastropods from Copper Hill Quarry.

(N.B. % = percentage of entire macrofauna of sample).

This faunal type comprises species specialised to phytal (filamentous algal) substrates. The move to coarser sediments appears to have led to a less-specialised weed/sediment fauna, according to Morris (1982). This is consistent with the occurrence of *Bairdia* in the sample. Therefore, it is likely that the introduction of *Bairdia* is due to environmental pressures rather than to evolution. The microfauna of this sample consists of adult forms, with the size range limited to larger sized individuals and species. This is consistent with a degree of winnowing.

This sample is the first at this locality with the gastropod faunas studied shown in Figures 27b and 31. This fauna is consistent with reworking and importing of sediment from a wide catchment, area with both coarse and fine substrate indicators being represented. These include rare forms indicative of back-barrier lagoons. Lithologically identical to CHQLSHB (Appendix 1c), the fauna of CHQUSHB suggests changes in environmental energy. The proportions of the major bioclasts are similar to those of the previous sample (Figure 20). There is, however, increased bivalve abundance and diversity (see Stratabugs charts for Copper Hill Quarry), and a decrease in the abundance and diversity of unidentifiable gastropods, suggesting a reduction in post-mortem movement. There is also an increase in bryozoan diversity (see Stratabugs charts for Copper Hill Quarry), including the introduction of several fragile encrusting forms, indicating that material remained at the sediment surface for sufficient time for bryozoan settling and growth (Taylor, *pers comm.*). Current activity may have been insufficient to destabilise the material or to provide new sites of bryozoan colonisation as encrustations only occur on one side of their substrate (Allen, 1990; Brett and Baird, 1986).

The resident ostracod faunas (Figure 20 and 30, Stratabugs chart for Copper Hill Quarry) appear to have increased in diversity, alternatively the catchment area from which material was transported may have widened. The assemblages are similar to those identified in the previous sample, suggesting that the material deposited was from a similar range of environments (Morris, 1983). The proportion of individuals made up of single valves and instars indicates that the ostracod material was to some extent transported and/or time-averaged: the majority consisted of single valves with only occasional *Bairdia hilda, Platella jurassica, Systenocythere exilofasciata,* *Monoceratina vulsa, Terquemula*-like species and *Pneumatocythere bajociana* appearing intact (Figure 30).

The composition and size characteristics of the foraminifera in the sample remain essentially unchanged from that of CHQLSHB, the only changes being the introduction of *Lenticulina quenstedti, Citharina heteropleura, Vaginulina legumen, Vaginulina* sp. A and UnID calcareous benthonic C.

Sectioning of the micromorphic gastropods showed that several species of nerinoideans were present including *Bactroptyxis cotteswoldiae and B. guisei*, the relevance of which will be discussed later. The gastropod fauna in this sample is similar to that of the previous sample (Figures 27b and 31). This member represents the onset of barrier-bar deposition.

4.03.5. The Clipsham Member.

Ashton (1977, 1980) identified this member at Copper Hill as representing the Ancaster Ragstone of Richardson (1939). Ashton (1977, 1980) describes the top of the Sleaford Member as a hardground (Appendix 1c sheet 2). Unfortunately, this author found no such hardground.

The lithological character of the Clipsham Member is almost identical to that of the preceeding Sleaford Member, the only change being an increase in clay-sized particles (either of depositional or diagenetic origin). These features indicate that although the seabed material continued to be dune-bedded, it may not have been as winnowed to the same extent observed in the Sleaford Member. Perhaps, as is more likely in a dune-building environment, the fine material was diagenetic in origin (Tucker, 1991), having been deposited by precipitation from pore-waters.

The next sample CHQRAG is essentially similar to those from the Sleaford Member. The difference is the reduction in gastropod diversity (Figure 20). The local environmental conditions may have been a combination of either:

1) Remained unchanged from that of the Sleaford Member shell beds, but with the cessation of sediment input from elsewhere.

2) Environmental conditions had altered to encourage those species now present.

These conditions may have occurred from CHQLSHB to the top of the observable sequence (this is difficult to confirm in the absence of sampling due to the poor condition of the site and access to the upper beds).

Over a third of the ostracod microfauna (Figures 20 and 30, Stratabugs charts for Copper Hill Quarry) was unidentifiable due to post-mortem wear (Figure 30). The species *Monoceratina vulsa* and *Praeschuleridea subtrigona* suggest Assemblage 2 of Morris (1982). This suggests that non-phytal lagoonal material was collecting in an otherwise coarse-grained environment of deposition. *Bairdia hilda* and *Progonocythere cristata* are found intact and so may represent part of the most locally derived fauna (Figure 30). The continued occurrence of *Bairdia hilda* indicates that there was a local weed fauna (Morris, 1982). It is unclear whether or not any of the other ostracod species present were part of this weed fauna.

The foraminifera in this sample are essentially identical to that of CHQUSHB. Again the foraminifera (Koutsoukos and Hart, 1990) indicate a substrate relatively unchanged from that of the Sleaford Member shell beds. The additional species possibly represent an exotic fauna, either allochthonous in origin, or perhaps rare members of the shell bed faunas.

The gastropod faunas (Figures 20 and 31) of CHC5 and CHQRAG are similar, with the absence of forms indicative of lagoonal conditions.

4.04. Brauncewell Quarry, Brauncewell, Lincolnshire (TF. 028518).

No studies were made of ostracod completeness at this locality as none of the material was complete.

4.04.1 Lincoln Member (Scottlethorpe Beds) and the Kirton Shale Member.

The basal deposit to 60 centimetres contains banding. These bands may well be of post-depositional and diagenetic in origin as the result of precipitation from pore waters. Alternatively, they may be algal in origin. There is a possibility that BRAUN III may represent an interdigitation of the Kirton Shale Member with the Scottlethorpe Beds, possibly being a response to changes in depositional conditions between different areas of sediment supply. Ashton did not report this occurrence of the Scottlethorpe Beds in either his thesis (Ashton, 1977) or in subsequent papers (Ashton, 1979, 1980); perhaps this material was not exposed during his research. The Kirton Shale is one of the best known beds in the Lincolnshire Limestone Formation with much work having been done on its faunas, especially in terms of ostracods (for example Bate, 1967a and 1967b).

The ostracod fauna of sample BRAUN II is restricted in number limiting its palaeoenvironmental use. The majority of ostracods are unidentifiable (Figure 22, Stratabugs charts for Brauncewell Quarry), suggesting that the ostracod fauna may be partially allochthonous, with wear occurring during transport. Another possibility was that material was deposited slowly, allowing time at the sediment-water interface for bio-erosion and small-scale mechanical breakage (Brett, 1990; Brett and Speyer, 1990). The laminar nature of the bedding of these beds also suggests low rates of deposition and the absence of burrowing organisms. The reduced abundance of infaunal organisms may be due to unfavourable chemical conditions within the sediment (Bottjer and Savrda, 1990) e.g. anoxia.

The foraminifera noted (Figure 22, Stratabugs charts for Brauncewell Quarry) are forms considered by Koutsoukos and Hart (1990) to be partially epifaunal in habit. This suggests that the infauna may have been restricted due to sediment or water chemistry. It is possible however that the limited degree of wear exhibited by the foraminifera indicates that the top few millimetres of sediment may have been habitable. Morris (1982), Koutsoukos and Hart (1999) and van der Zwaan *et al.* (1999) suggest that *Spirillina* may have lived attached to plant material, possibly a nearshore, shallow environment (Copestake, 1989) where current flow was insufficient to remove the attached foraminifera. The dominance of *Spirillina* also equates with the autochthonous community of Morris (1982) (*Spirillina* are easily reworked however). The foraminifera of this sample also appear to have strong associations with Group 1 and 3 of Morris (1982), groups he considered as indicating phytal environments. The occurrence of *Eoguttulina liassica* also suggests deviation from normal marine salinities, possibly indicating lagoonal or shallow marine influences (Packer, 1986) from work on analogies with modern day *Guttulina*. The sample also contains calcitic spines, interpreted here as the sensory / stabilising spines of *Acanthothiris crossi*, and essentially similar to those collected from the Kirton Shale Member at Metheringham. It is possible that these outspread spines may have effectively increased the surface areas of the organism so stabilising it on soft substrates. Also present in this sample are wood fragments and ophiuroid ossicles. These occurrences suggest that although salinities were probably marine, the sediments were deposited in a near-shore environment. The sampled clay may have been deposited on an eroded base possibly associated with a brief shallowing. This sample also contains rounded quartz grains suggesting a nearshore environment or a supply of worn arenaceous sediment.

The majority of the ostracod fauna of BRAUNIII are unidentifiable due to wear suggesting either a degree of allochthonous origin or of time at the sediment surface prior incorporation into the sediment (Kidwell *et al.*, 1986; Kidwell, 1991; Kidwell and Bosence, 1991). The presence of borings (algal and/or fungal), also suggests that this ostracod material spent some time at the sediment surface prior to deposition.

The foraminiferal fauna consists of forms considered by Koutsoukos and Hart (1990) to be semi-infaunal/epifaunal herbivores and detritivores (Figure 22, Stratabugs charts for Brauncewell Quarry). It is possible that the environment of deposition was different from BRAUNII. Not only has the species diversity fallen, but spirillinids have also decreased in abundance. These features may indicate either a reduction in phytal environments or reworking. Occasional encrusting bryozoa occurrences suggest a low rate of deposition. This sample contains quartz grains suggestive of a nearshore environment and/or a supply of arenaceous sediment. Sedimentation may not have been continuous, however, - it may have been episodic, the result of transportation by terrestrial floods. This member may have been deposited under low energy lagoonal/back-barrier conditions.

4.04.2. The Metheringham Member.

Six metres of buff oopelmicrites with varying oolitic and peloidal content represent this member.

The ostracod fauna (Figure 22, Stratabugs chart for Brauncewell Quarry) of BRAUN IV consists almost entirely of worn/unidentifiable individuals. Many exhibit signs of algal/fungal boring, suggesting wear and bio-erosion prior to deposition.
The foraminiferal fauna (Figure 22, Appendix d sheet 1, Stratabugs chart for Brauncewell Quarry) of BRAUNIV is very similar to that of sample BRAUNII, with the exception of the abundance of *Spirillina* sp. Therefore, it is likely that in the absence of a change in preservational characteristics the depositional environment may have been comparable. *Acanthothiris crossi* spines and oyster fragments occur, perhaps suggesting that the sediment was unconsolidated. As suggested previously the spines of this brachiopod may have had a stabilising effect. The oysters however had no such structures. They must therefore have:

1) Been swept in from elsewhere.

2) Been forms that could simply rest on the sediment surface.

3) Have used the accumulated brachiopod spines as a substrate.

It is likely that winnowing was a major influence on the occurrence of oysters. This is consistent with the wear observed on the other bioclasts. *Bactroptyxis implicata, Bactroptyxis cotteswoldiae* are also present.

The ostracod fauna of BRAUNI (Figure 22), is made up almost entirely of unidentifiable individuals indicating that the material remained unburied for some period of time.

The foraminiferal fauna (Figure 22, Stratabugs chart for Brauncewell Quarry) is dominated by *Spirillina infima, S. numisimalis* and *Conicospirillina trochoides* suggesting (as in BRAUNII) the presence of a marine weed fauna (see Morris, 1982; Koutsoukos and Hart, 1990). Furthermore, it is likely that the palaeocommunity was deposited *in-situ,* a conclusion based on the large range in sizes of the different species. The other species present were considered to indicate similar conditions to *Spirillina* (Koutsoukos and Hart, 1990). The species in this sample are considered by Morris (1982) to indicate Groups 1 and 3, suggesting little environmental change since the previous sample. Lithologically, this sample contains large quantities of rounded quartz grains. This suggests a nearshore lagoonal environment with a continuous supply of arenaceous sediment, and/or periodic influxes of terrigenous material, possibly as a result of flooding.

4.04.3. The Blankney Member.

The Blankney Member bivalve infauna includes large bivalves, terebratulids and pectenids indicating soft sediment this is also suggested by the vertical burrows and gastropod infauna including *Bactroptyxis cotteswoldiae* and *B. implicata* (Appendix 1d sheet 2). The presence of ooids suggests that the fine-grained matrix of the member was deposited adjacent to an area of ooid formation.

4.04.4. The Sleaford Member.

The basal 20 centimetres consist of epifaunal bivalves and the gastropods *Bactroptyxis cotteswoldiae* and *B. implicata* as a bioclast-supported accumulation, possibly representing a concentration deposit. The basal 2 metres are cross-bedded with the overlying material cross-bedded in the opposite direction. This accumulation is considered to be a winnowed deposit by the author as none of the fossils are in life position. All the fossils appear to have been moved into hydrodynamically stable positions. The dune scale cross bedding present throughout the rest of the member indicates an increased strength and duration of the currents depositing this barrier-bar material. They also suggest an ample source of sediment. As the attitude of cross-bedding changes, the uni-directional current flow has clearly changed direction, probably as a result of an alteration in local (or regional) current flow.

Chapter 5. A discussion of the palaeoenvironmental regimes of the sections studied.

5.01. Cowthick Quarry, Weldon, north of Kettering, Northamptonshire.

The ratios of mobile to immobile elements comprising each phase are shown in Figure 32. Although the ratios will be influenced to some degree by time averaging (Brett, 1990; Goldring, 1991) and by the faunas of the depositional catchment area (therefore allochthonous input), the ratios broadly agree with those one might expect. Both Phases I and IV show an increase in the proportion of the epifauna made up of mature immobile elements: i.e. bysally-attached forms. The attached fauna often utilised other bioclasts as substrates e.g. serpulid worm and bryozoa encrustations on bivalve shells (Taylor, 1990; Taylor *pers comm.)*.

The lithologies and sedimentary structures also suggest relatively subdued, stable environmental conditions during these phases. Conversely, during Phases II and III these ratios suggest, along with their fauna and taphonomy, that success of the fauna was at least locally dependent on an ability to move. The need for mobility may have been due to the instability of the environment, possibly as a result of local environmental changes.

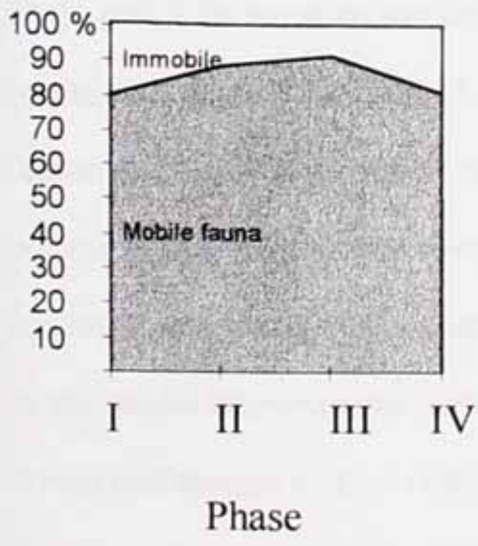
As expected environmental stability and increased substrate grain-size of Phase IV are characterised by an increased diversity in the filter-feeding fauna (Levinton, 1982; Goldring, 1991).

Cowthick quarry has long been considered to be the southern landward edge of the Lincolnshire Limestone Formation, its submarine channels (Figure 11, 28) being relics of water flow between fluvial/brackish and fully marine environments (Marshall and Ashton, 1980). The studied exposure, different to the one described by Marshall and

Ashton (1980) illustrates the cutting into the (Lower?) Lincolnshire Limestone Formation by a later erosive event. Whether this event was locally or regionally uniform remains unclear. It is probable that this erosional interlude was a readjustment of the local hydrodynamic regime. Ashton (1977, 1980) suggests that the Lincolnshire Limestone Formation can be correlated by means of its hardgrounds and/or depositional breaks. It is possible however that these are local responses to variations in environmental conditions, with no further local or regional significance. The overall section is similar to that illustrated by Tucker (1981, p. 152, Fig. 4.57) as a shallowing up limestone sequence, although whether the sequence is indicative of these conditions, or the result of the channel filling is not clear.

Figure 32

The Ratios of mobile/immobile elements at Cowthick Quarry Weldon.



5.01.1. Chronostratigraphy.

As already indicated there is debate on the precise age and correlation of the Lincolnshire Limestone Formation (Chapter 1, Figure 3). The Lincolnshire Limestone Formation was divided into two main parts which were subdivided in different ways by various authors, until Ashton's (1977, 1979, 1980) nine member scheme was published and accepted (Figure 4). Ashton's work however did not include the highly problematic landward (southern) exposures of which Cowthick Quarry is part. Lithologically Phase I with its peloidal Limestones would have been placed in the Lower Lincolnshire Limestone Formation before the 1977 scheme of Ashton. This view would have been supported by the abundance of the nerinoidean gastropod *B. cotteswoldiae* which was considered to be a zonal indicator (Hudleston, 1888) for these horizons. This view would also have supported by to the absence of *A. crossi*, which was considered by Kent (1966) as indicative of the Middle Lincolnshire Limestone Formation.

As the rest of the sequence was deposited after a period of erosion, it was thought to belong to the Upper Lincolnshire Limestone. The entire Middle Lincolnshire Limestone along with sections of the underlying deltaic sequence in some places were believed to have been eroded (Kent, 1966) (Figures 11 and 28). Rhynchonellid faunas, as already stated, were often considered of correlative value in this situation. In Phase IV the species *Microrhynchia barnackensis* (Muir-Wood) and *M. pontonensis* (Muir-Wood) both thought by Kent (1966) to be indicative of the Upper Lincolnshire Limestone. In addition, in Phase IV a single specimen of *A. crossi* was recovered, which in the past was considered the major index fossil for the Middle Lincolnshire Limestone. Therefore, either the stratigraphic range of the species is greater than hitherto recorded, involving diachroneity and facies dependence, or the specimen of *A. crossi* is reworked. Within such a high energy environment, such reworking and derivation appears likely. Nevertheless, the specimen was found in the middle of a low energy horizon in an otherwise apparently allochthonous fauna.

The composition of the fauna is very similar from one phase to the next. This may suggest a geologically brief period of deposition, during which, despite the obvious depositional breaks, the fauna altered little. It is likely that the true depositional environment was a combination of rapid, if periodic, deposition with the constant reworking of material, giving rise to a worn (if not winnowed) time-averaged fauna at least until the onset of Phase IV. At this point, tidally influenced currents appear to have become the major source of sediment redistribution.

5.02. Clipsham Old Quarry, Lincolnshire.

The depositional regime at Clipsham Quarry was made up of two Phases. The first was the Lincoln Member (Scottlethorpe Beds and the Castle Bytham Beds) up to sample COQIII (Figure 9). From the Lincoln Member to the erosive base of the Clipsham Member deposition appears to have been dominated by low energy conditions with fine-grained material deposited. This material, workable by an active infauna, suggests a degree of consolidation in a habitat associated with the development of phytal growths (possibly sea grasses) as indicated by the occurrence of *Spirillina*. Such conditions suggest lagoonal deposition with material being laid down, possibly because of precipitation of calcium carbonate microbial biogenesis and defaecation by a resident community. The sediments were probably partially derived from terrestrial sediments, with beds containing quartz and ironstone fragments. Furthermore, the presence of ooids suggests that although predominantly low-energy, the depositional environment was influenced by nearby shoals. The bed directly below COQII appears to represent the onset of higher energy conditions with increased movement of ooids into a lagoonal environment. With the onset of these conditions, the resident community became more dominated by an epifauna suggesting that conditions were no longer as favourable to infaunal forms (Levinton, 1982; Goldring, 1991). This may be because of greater sediment consolidation and particle size, increased sediment movement because of stronger current activity or a change in the sediment chemistry. Ashton (1977, 1980) and Tucker (1985) suggest that the sediments of the Lincolnshire Limestone were deposited as a barrier bar complex was over-ridden by a complex of lagoons and mudflats. This research has found that the strata of the Scottlethorpe and Castle Bytham Beds are consistent with the over-ridden clay dominated back-barrier lagoonal complexes theory. Phase two represents the coarser grained, cross-bedded material of the barrier bar. The sediments of the barrier at this locality near the top of the sequence are marked by what appear to be stacked channels, these may represent a complex of on-barrier channels.

The evidence provided by Figures 33 and 34 shows a slight alteration in the composition of the foraminiferal fauna with the onset of the barrier facies. With the onset of barrier bar facies agglutinating foraminifera are introduced. This is possibly as a result of slightly reduced levels of free oxygen in the sediment. Many agglutinating foraminifera appear to be better adapted to such conditions than calcareous forms (King *et al.*, 1989).

An erosive period occurred during the deposition of the Clipsham Member at Clipsham Old Quarry. The hardground appears to mark the absence of the Sleaford, Blankney and Metheringham Members. The erosion of this material was significant. Possibly 9 metres of material was removed, the base of which being the hardground at the base of the Clipsham Member. It is probable that at the time of deposition, the Lincoln Member was more extensive than is now apparent. This member has been downcut during this erosive phase. This erosive feature may have been part of a more widespread complex as suggested by Ashton (1977, 1980). Erosive breaks may be of some use in the internal correlation of the Lincolnshire Limestone Formation, possibly including the (as yet uncorrelated) southern-most exposures north of Kettering. Other fieldwork undertaken during this study has traced this erosive phase through Great Ponton, Ropsley and Ancaster. The hardground may be equivalent to part of the Wilsford Coral Beds of Kent (1966). This correlation however would require the coral bed to have been deposited early in the Crossi Beds (Kent (1966) below the Kirton Shale of Ashton (1977, 1980).

Figure 33.

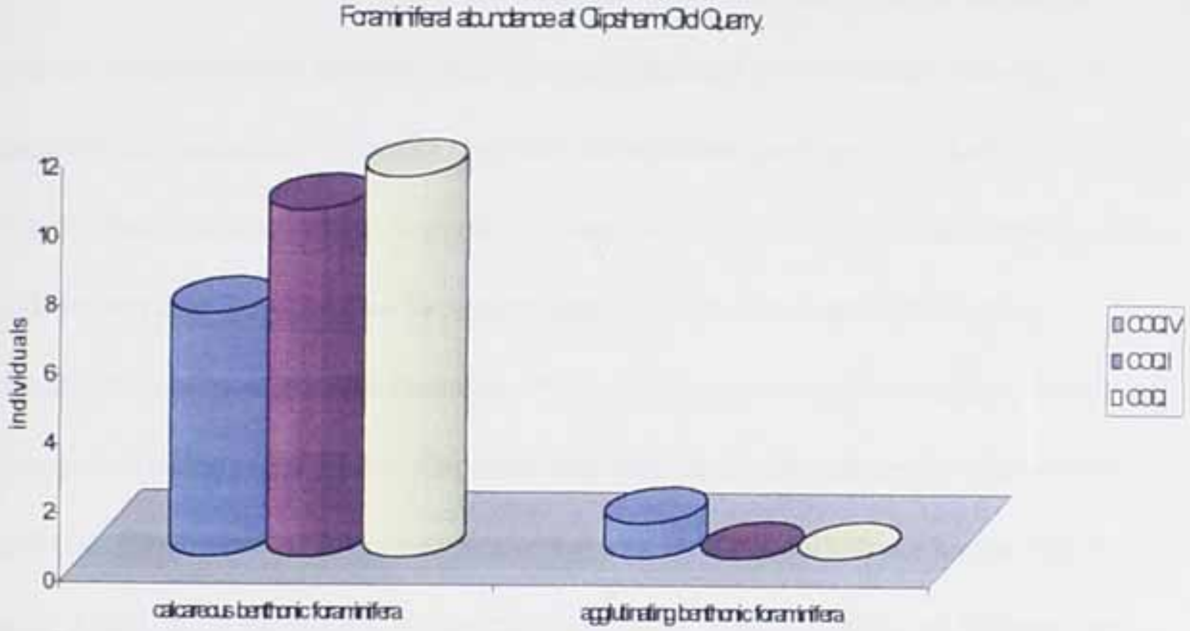
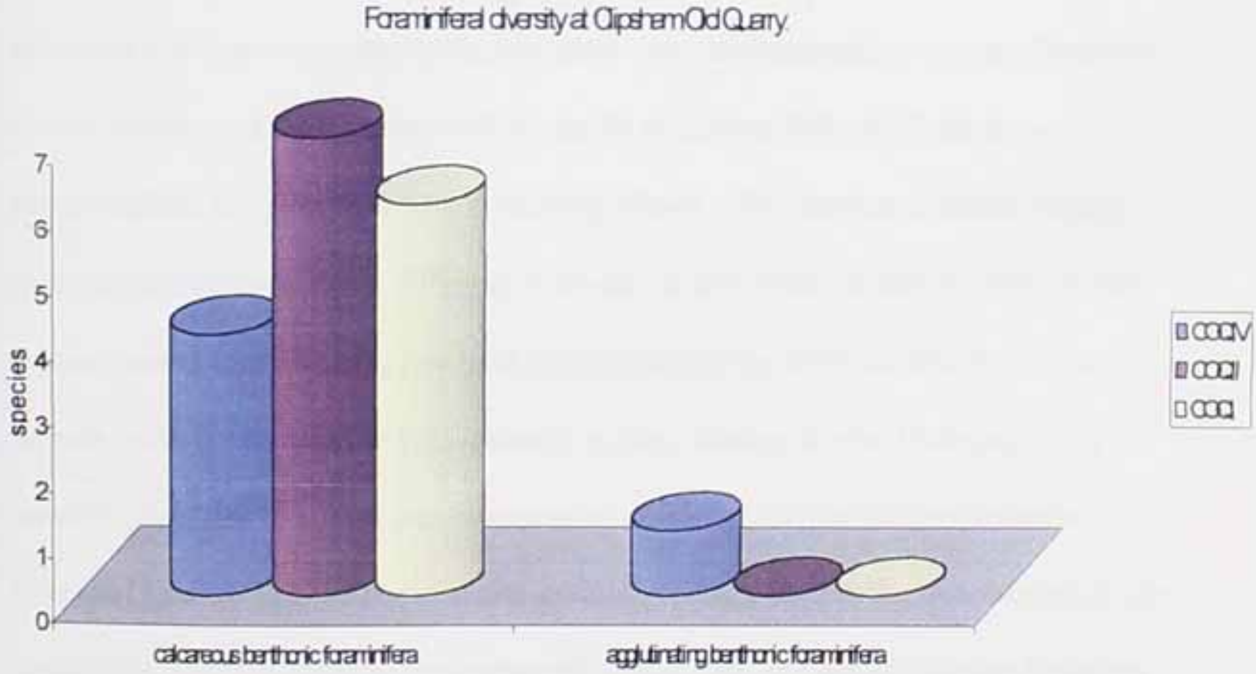


Figure 34



5.03. Copper Hill Quarry, Lincolnshire.

Deposition appears to have occurred in two distinct phases. Phase one extends from the base of the exposure to the base of the Sleaford Member, encompassing the sediments of the Leadenham, Greetwell, and Lincoln Members. These members consist of fine-grained sediment that is bioturbated and of low faunal diversity. The macrofaunas consisted of locally abundant nerinoidean gastropods including *Bactroptyxis cotteswoldiae, B. guisei* and occasional *B. implicata* with colonial corals (the importance of which has been discussed), against a background of often fragmentary bivalve material including *Pholadomya* spp. Phase two on the other hand comprised of the Sleaford and Clipsham Members and is dominated by cross-bedded oolites. These phases of deposition also agree with the theory that a barrier bar over-rode a near shore lagoonal complex (Ashton, 1980; Tucker, 1985), with Phase two representing the barrier bar complex. The sediments lain down during the Sleaford Member suggest currents bringing sediment into the sample area brought in material from a wide catchment region, some of which probably included material eroded from sediments lower in the stratigraphic sequence. An erosive break (or series of erosive breaks) punctuated the deposition of the strata at Copper Hill with both the Metheringham and Blankney Members being absent. This erosion is similar to that recorded at Clipsham, but is different in extent. It also differs in that the base of the erosion occurs immediately prior to the deposition of the Sleaford Member. This erosive break is known to downcut deeply in the Ancaster district (Ashton, 1977) where it gives rise to a thickness in excess of 12 metres for the Sleaford Member at Creeton (Ashton, 1977). There is also evidence to suggest that the downcutting at the base of the Sleaford Member also removed sections of the Lincoln Member including the Scottlethorpe Beds. With the removal of the Scottlethorpe Beds, the position of the mica and coral horizons can be pinpointed with a little more accuracy. The position of the coral horizon differs with the findings of Ashton (1977, 1980) in the Ancaster district. Although the exposure in this study is more complete than that studied by Ashton, his research found that coral beds were confined to the basal horizons of the Lincoln Member. In this study, the coral horizon has been found near the top of that member.

Again, the foraminiferal faunas trace the change from back-barrier lagoonal deposition to barrier facies (Figures 35-36). These figures illustrate the changing abundance and diversity patterns occurring across the transition between Phases 1 and 2. These trace the development of marine vegetation (as indicated by the occurrence of *Bairdia hilda* and *Spirillina*), which gives rise in turn to the greatest microfaunal diversities and abundances. It is notable that alongside this trend the numbers of agglutinating foraminifera increase during the Upper Lincolnshire Limestone. This may be associated with the accumulation and decomposition of organic material from the phytal biomass, altering the sediment chemistry (King *et al.*, 1989). The agglutinating form *Ammobaculites agglutinans* present in the samples is regarded by Nagy *et al.* (1992) to be indicative of low diversity estuaries, suggesting that this species might have a broad range of chemical tolerances so possibly allowing it to live in chemically harsh substrate.

It is also of note that both abundance and diversity fall sharply in sample CHC4 this may be due to an anoxic event. With the accumulation of detritus in the sediment bacterial activity not only uses up oxygen but also increases sulphide levels, these factors in combination are considered fatal to the microfauna (van der Zwaan *et al.*, 1990; Gooday & Rathburn, 1999). This view is further suggested by the lack of infaunal macro-organisms in this sample.

Figure 35.

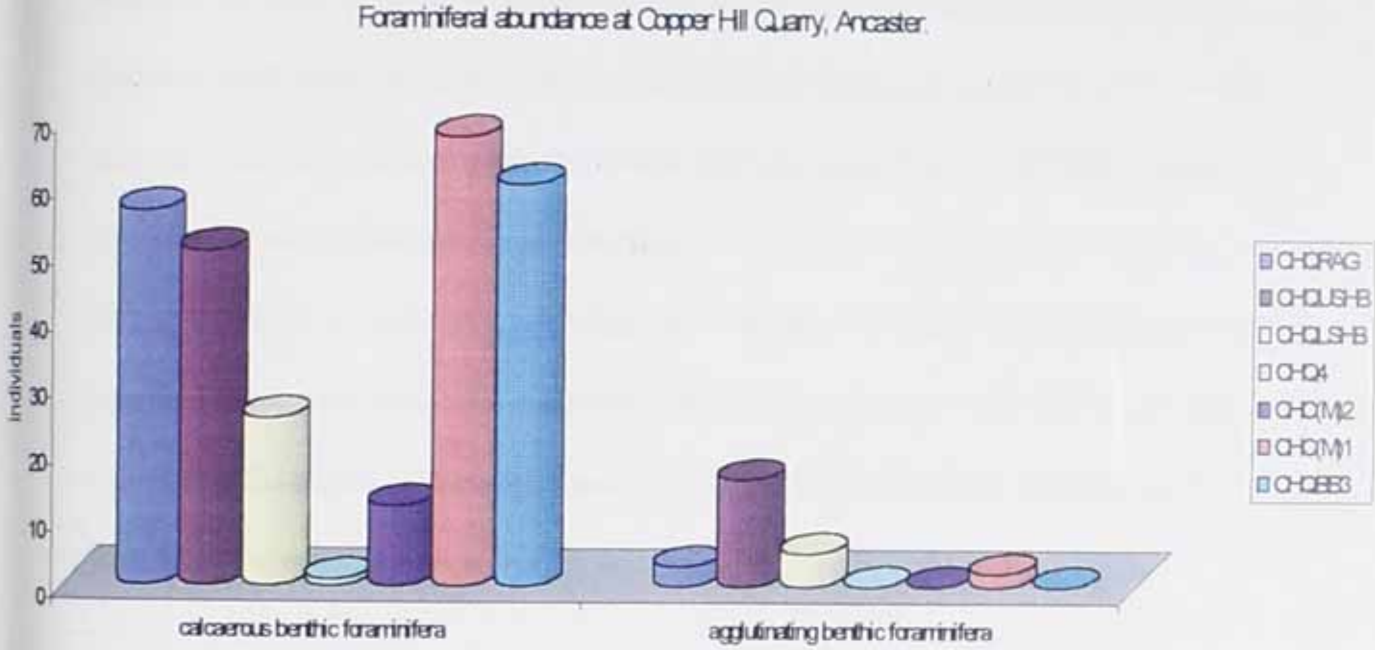
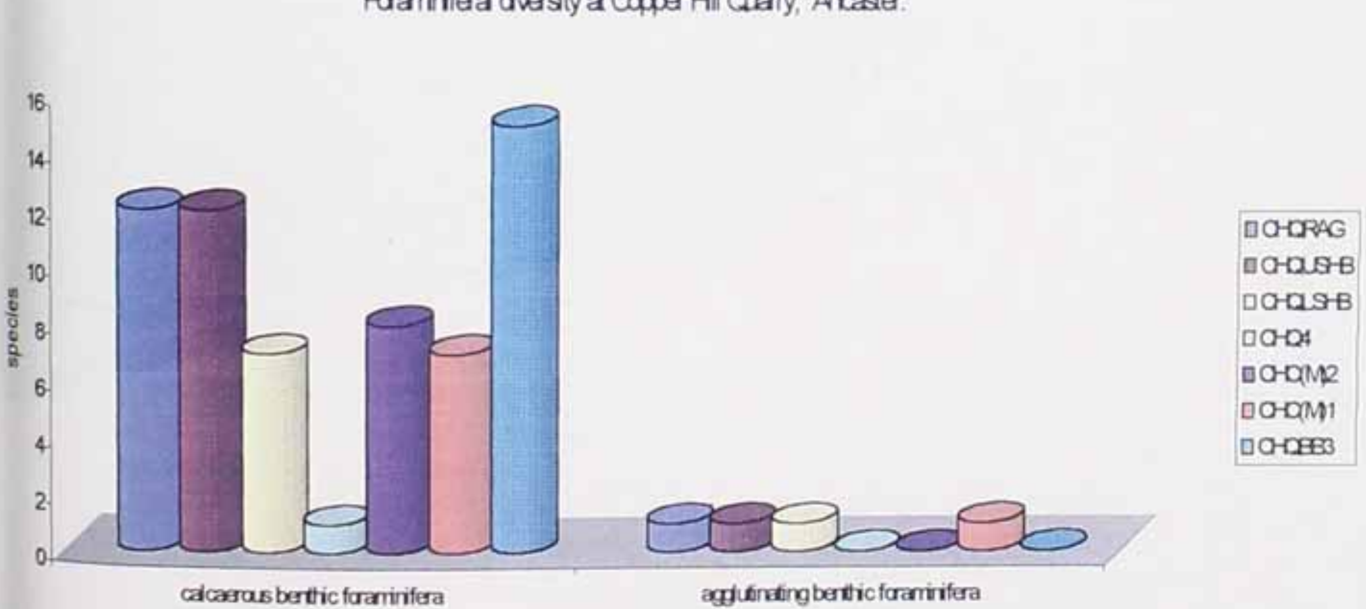


Figure 36



Therefore, the overall palaeoenvironment was similar to that of the Clipsham Old Quarry section. The timings (and possibly the severity) of the erosive episodes, however, appear to have varied. The transition from lagoonal flats to barrier bar can be traced by changes in the foraminiferal fauna with the shift from phytal specialists (primary weed fauna) to generalists (weed /sediment fauna). It is notable that generally with the onset of more energetic conditions, with the exception of CHQBB3, species diversity per sample increases and abundance reduces (see Conclusions). This may well be the result of both the winnowing out of smaller individuals and the transport of tests into the sample from an increasingly wide catchment area. The shift in substrate type is also illustrated by the appearance of *Bairdia hilda,* probably as a result of its phytal and facies associations.

5.04. Brauncewell Quarry, Lincolnshire.

The lithology of the Lincoln Member (Scottlethorpe Beds), Metheringham and Blankney Members at Brauncewell Quarry agree with the hypothesis of mud flats and lagoons becoming over-ridden by a near-shore barrier bar complex (Ashton, 1977, 1980; Tucker, 1985). At this quarry this hypothesis is supported by the presence of significant *Spirillina* and *Conicospirillina* which indicate shallow water conditions (and so perhaps sensitivity to salinity variations), and the presence of marine vegetation (Morris, 1983; Koutsoukos and Hart, 1990). Figures 37 and 38 show that with the onset of the Metheringham Member (BRAUNIII), the calcareous foraminiferal population declines sharply. Sediment chemistry alterations might have affected the largely phytal micro-community.

Figure 37

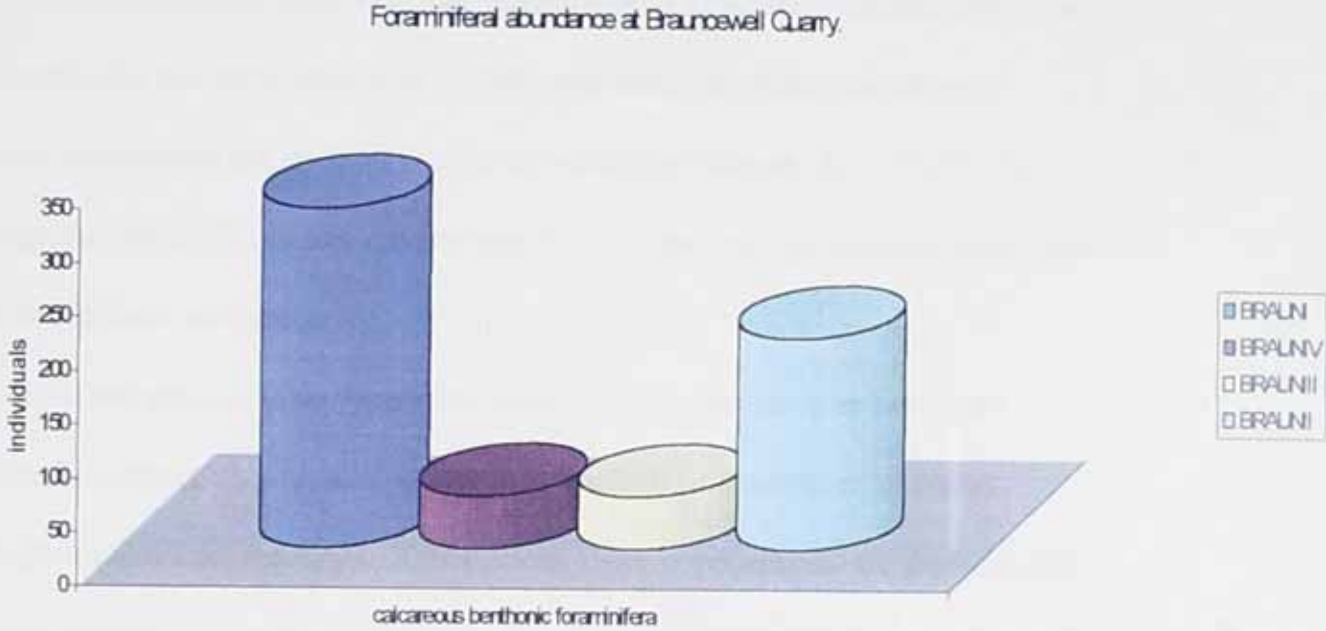
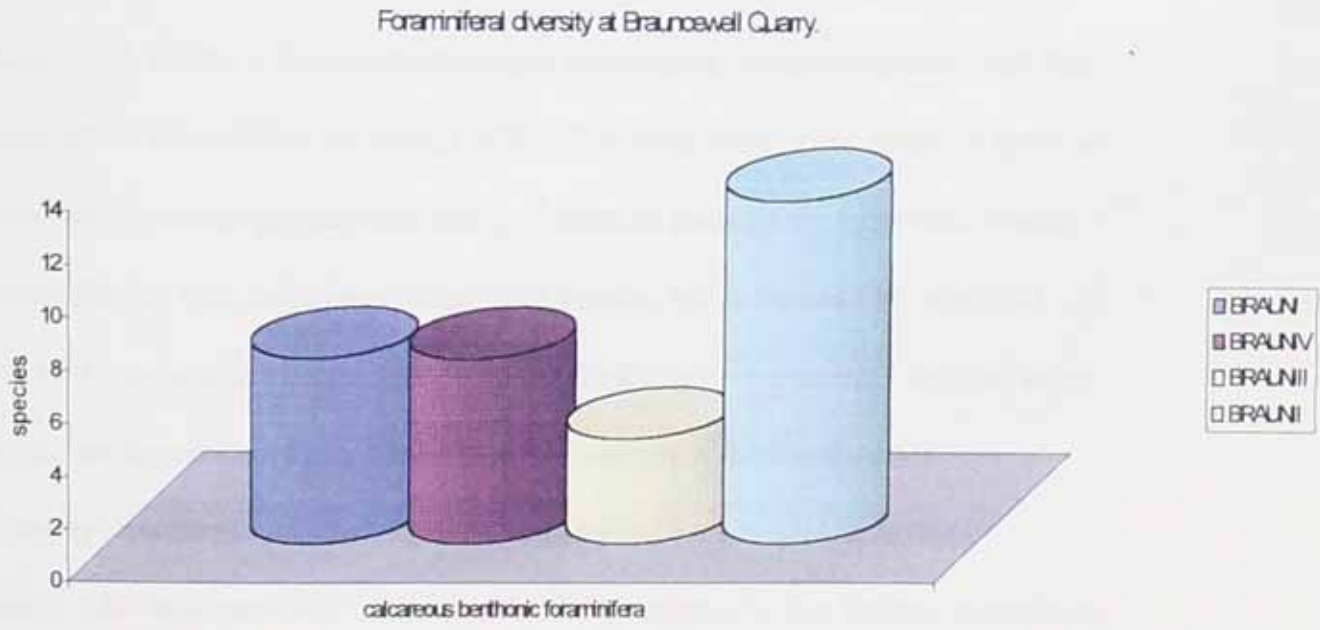


Figure 38.



Seasonal cycles may have affected the vegetation, causing a reduction in the habitat available (Gooday and Rathburn, 1999). This effect might have been heightened as the amount of detritus in the sediment built up resulting in a degree of anoxia. This is in agreement with van der Zwaan *et al.* (1999) who state that under conditions of reduced oxygenation the epifauna is affected before the infauna. It is notable that although the availability of free oxygen may have reduced no agglutinating forms were identified in these sediments.

The depth and nature of this vegetation is not clear. It was likely to have been continually submerged, with little evidence of brackish or freshwater influence, although wood occurs sparingly. Furthermore, there is evidence to suggest that there was little sediment redistribution by current activity due to the high degree of species dominance and low diversity seen amongst the foraminifera (Morris, 1982). The Scottlethorpe Beds, known to interdigitate with the Kirton Shale Member elsewhere (Ashton, 1977, 1980), at Brauncewell contain an ostracod fauna comparable with that recorded in the Kirton Shale by Bate (1967b). The deposition of the lagoonal facies at Brauncewell shows the gradual coarsening of material through the sequence. It also illustrates the fact that the palaeocommunities became less influenced by terrestrial material with perhaps flood-transported quartz declining over time until the final onset of barrier bar deposition. From the onset of deposition of the Sleaford Member sedimentary structures such as dune cross bedding appear (as does intraclastic material). The basal part of the Sleaford Member consists of a thin horizon comprising almost entirely of rolled nerinoideans and bivalves. The rolled nature, coarseness, and disorientation of the material suggests that prior to the deposition of the bulk of the visible member, there was a period of non-deposition and winnowing.

The material sampled, has affinities with the Yons Nab Beds reported by Nagy *et al.* (1981). The basal part of the Yons Nab Beds correlates to somewhere within the base of the Kirton Shale Member (Cope *et al.*, 1980). The Yons Nab material contains a "*Citharina* assemblage" similar to that found in the Metheringham Member.

Chapter 6. A Discussion of the Internal Biotic and Lithostratigraphic Correlation of the Lincolnshire Limestone Formation.

6.01. Ashton's, (1977, 1980), lithological scheme and its use across the study area.

Ashton's (1977, 1980) (Figure 4) correlation scheme works well for the bulk of the of the Lincolnshire Limestone Formation outcrop.

There is no evidence to suggest that the barrier bar (suggested by Ashton 1977, 1980) reached as far south as Cowthick. If the barrier had reached Cowthick, it may be that the exposure studied was part of the barrier bar complex with the earlier material having been removed by erosion.

In the past, the only faunal indicator of the Lower Lincolnshire Limestone has been the presence or absence of *Bactroptyxis cotteswoldiae* (Hudleston, 1888; Barker *pers comm.*). It has been shown by this research that this species reaches as high as the Sleaford and possibly into the Clipsham Member (Upper Lincolnshire Limestone Formation of Ashton, 1977, 1980), hence discounting this species as a correlative tool. In the absence of other established correlative species, others must be sought. No species occurring in both the southern and northern exposures appear to be sufficiently unconstrained by environmental conditions to be applicable. No clear biostratigraphic correlation is possible between the Northamptonshire strata and the rest of the Lincolnshire Limestone Formation as a result.

It may be possible to correlate erosive events with the material they have reworked. For such an approach to succeed, the reworked particle (the tracer) must not occur in the rock into which it is transported. One possible useful example is the erosion of material prior to Cowthick Phase III (Figure 11 and 28), into the Grantham Formation, which is known from fieldwork and from Kent (1966), to be rich in mica. Mica is not common in limestone environments due to its low tolerance of mechanical and chemical abrasion. Mica flakes are found in the study area notably in the Lincoln Member at Copper Hill Quarry, Ancaster, possibly suggesting a link with Phase III at Cowthick. Although a possibility, there is no evidence for this supposition other than occurrence of mica. Without detailed analysis of the mica flakes and/or fragments of ironstone to discount other sources, the relationship between the two units is speculative. The only conclusions that may be made are as follows.

a) The beds of "Aalenian type" intraclasts may be due to deposition as a result of a single erosive episode, if not a single event, because only one deposit was located.

b) The source material for this event came from a regional source (or sources), where such material was present.

Ironstone intraclasts occur in the Castle Bytham Beds (Lincoln Member) of Clipsham Old Quarry. At this locality, there are no mica flakes within the limestone. This might be expected however, as ironstone intraclasts might better survive transportation. Were the Grantham Formation the source of this ironstone the micaceous material might be expected at Clipsham rather than Ancaster, Clipsham being closer to the source area. Any micaceous horizons at Clipsham may have been subsequently eroded.

One erosive event into such material is that documented in Northamptonshire although there is no direct evidence to indicate either the event or source. Therefore the strata of Cowthick quarry remain unconstrained in terms of the Ashton scheme, although there is evidence to suggest that Phase III and IV at Cowthick may be of post Lincoln Member age. It may well require other techniques such as gamma-ray logging (Emery and Dickson, 1991) to constrain further the Northamptonshire deposits, in terms of Ashton's scheme.

The mica may have originated from the Collyweston Slate (Wilson, 1948) at the very base of the Lincolnshire Limestone Formation. The distribution of this micaceous facies is, however, poorly documented. Further work would be required to determine whether this was the source.

6.02. Taphofacies. (See Figure 39).

The taphofacies of the members suggests that although the individual exposures exhibit variation in terms of taphonomic trend (e.g. the exceptional preservation exhibited in the Copper Hill shell beds within the more fragmentary rolled faunas of the Sleaford Member) the members themselves remain essentially similar. This suggests that despite local variations, the energetic regimes altered little between the erosive events and sediment supply changes. The taphonomy of the formation is dominated by the difference between the low energy, mud-dominated infaunas of the Lower and Middle Lincolnshire Limestone Formation, and the more erosive, mobile oolites and rudites of the Upper Lincolnshire Limestone Formation.

The fine-grained material is characterised by the domination of infaunal species, bioclast articulation, absence of sorting, bioturbation and bioclast fragmentation. These characteristics are considered typical of low energy environments, where sediment movement is largely the result of infaunal activity.

The barrier-bar sediments on the other hand are better sorted, have a higher degree of wear (with less fragmentation) and tend to contain a more diverse epifauna.

Figure 39. The effects of taphonomic processes on invertebrate macrofossils in the Lincolnshire Limestone Formation (after Brett and Speyer, 1990).

Member	Biot	Type	Articulation	Frag	Wear	Sorted
Greetwell	Yes	B	Some	Co	Ra	No
Leadenham	Yes	E,C,B	Common	Co (E,C)	Ra	No
Lincoln	Yes	E,C,B,T,Co,G,S	All T, Some B	Co (B,G)	Ra	No
Metheringham	Yes	B, G	Some	Some	Ra	No
Blankney	Yes	B, G	Some	Co	Ra	No
Sleaford	No	E,C,B,T,G,Br,S	Rare	Ra	Cm	Yes
Clipsham	No	E,C,B,T,G,S	Rare	Ra	Cm	Yes

Biot = bioturbation, Type = major skeletal types, Frag \ wear = fragmentation and wear, Skeletal types. E = echinoids, C = crinoids, B = bivalves, T = terebratulids, Co = corals, G = gastropods, Br = bryozoans, S = serpulid worms. Cm = common, Ra = rare.

6.03. Biofacies.

The biofacies of the Lincolnshire Limestone Formation can be divided into two types, lagoonal and barrier. The basal section (the Greetwell Member to the Lincoln Member) is dominated by *in-situ* infaunal bivalves and gastropods and epifaunal echinoids and gastropods together with an allochthonous fauna dominated by crinoids and possibly echinoids. The gastropod fauna though abundant is of low diversity dominated by *Bactroptyxis implicata* and *B. cotteswoldiae*. The barrier facies (Sleaford and Clipsham Members) differs from the lagoonal facies in that the faunas are more diverse. Much of this fauna indicates epifaunal life habits with influences from hard substrate environments e.g. *Capulus rugosus,* crinoids and bryozoa. Inspection of the figures suggests it is clear that no macro-species is restricted to any horizon or member, the fauna appearing stable, though in different proportions. This might be a result of reworking. It is possible that the communities remained largely unchanged throughout each phase (lagoonal or barrier). The only exceptions occur after or during "environmental" events took place that temporarily favoured species different to the indigenous fauna. The transport of "exotic" bioclasts may have influenced faunal compositions. Examples are the temporary increase in diversity in the Cowthick and Copper Hill shell beds, the Copper Hill and Clipsham coral beds and the increase in echinoderm abundance between the Sleaford and Clipsham Members at Copper Hill. There are several possible causes for this apparent lack of faunal change.

a) Although the sedimentology and environmental energy changed during deposition, the palaeocommunities were able to survive the changing conditions whilst *in-situ.*

b) The faunas remained unchanged because of mixing and reworking from adjacent communities.

It is likely that the deposition of the Lincolnshire Limestone Formation sequence occurred more rapidly than the pace of evolution, therefore the few changes in fauna that do occur in the Lincolnshire Limestone Formation are most likely "environmental" in origin: e.g. as a result of changes in substrate.

6.04. Zonal indicators. Several species are considered as zonal indicators due to their restricted occurrence, abundance and ease of identification in the Lincolnshire Limestone Formation, these are set out below.

6.04.1 The ostracods of Bate's correlation scheme (Appendix 2b).

After the work of Bate (1963a, 1963b, 1964, 1967a, 1967b) and Bate and Robinson, (1979), suggested a zonation scheme for ostracod occurrences during the period studied.

The *Kinkenella (Ektyphocythere) triangula* ostracod Zone ranges from *Discites* to the *Laeviuscula* ammonite zones and is defined on the basis of the presence of *Kinkenella (Ektyphocythere) triangula*. This species was found to occur sparingly throughout the studied sections. This zone can be further subdivided into two Subzones.

The *Progonocythere reticulata* Bate ostracod Subzone ranges is within the *Discites* ammonite zone. This is defined on the occurrence of this and associated species including *Tetracytheridea punctata* Bate, *Paraschuleridea* sp., *Pleurocythere* sp., *Praeschuleridea decorata* Bate, *Cytherelloidea eastfieldensis* Bate, *Dolocythere maculosa* Bate and *Cytheropterina comica* Bate. None of these species are represented in any of those samples found to contain ostracods.

The *Pneumatocythere carinata* Bate ostracod Subzone ranges from the *Discites* to *Laeviuscula* ammonite Zones and is defined on the presence of the index species and its associated species. These include *Glyptocythere* sp., *Pneumatocythere bajociana* Bate, *Praeschuleridea subtrigona* (Jones and Sherborn), *Pleurocythere kirtonensis* Bate, *Pleurocythere nodosa* Bate, *Patellacythere vulsa* (Jones and Sherborn), *Paracypris bajociana* Bate and *Eocythere reticulata* Bate. Several of these species have been noted in this study indicating that some strata are of *Laeviuscula* age.

Packer (1986) places the boundary between the ammonite zones (in Humberside) towards the Middle and Upper Kirton Shale based on the occurrence ostracods. In this study, species indicative of the *laeviuscula* Subzone are found as low as the Leadenham Member at Copper Hill, Ancaster.

6.05. Gastropods

6.05.1. *Bactroptyxis cotteswoldiae* (Appendix 2a). This species has been considered in the past to be indicative of the Oolite Marl and Pea Grit of the Cotswolds and the Lower Lincolnshire Limestone Formation (Hudleston, 1888; Barker 1976, Barker *pers comm.*). This view suggests that this species should only occur in the Sproxton, Leadenham, Greetwell, and Lincoln Members. In this study it has been positively identified in thin section from as high as the Sleaford Member at Ancaster and Brauncewell. It is possible that this occurrence is the result of reworking. This occurrence prevents a confident use of this gastropod species as a stratigraphic indicator.

6.05.2. *Bactroptyxis guisei* (Appendix 2a). As already discussed, this species has been considered an Upper Bajocian \ Lower Bathonian species confined mainly to the Clypeus Grit *Parkinsoni / Zigzag* Zone (Hudleston 1888; Barker 1976). Barker (1976) recorded the species from Castle Bytham (SK9918) in the Lower Lincolnshire Limestone of Kent, (1966), *Discites* Zone, (in the Sproxton to Lincoln Members using Ashton's 1977 scheme) see Figures 3 and 4. This research has identified the species from the Upper Shell beds at Copper Hill, Ancaster. Although micromorphic the individuals identified were well preserved in thin section. It is possible that the material was eroded from the underlying Lincoln Member from which individuals in excess of

10 centimetres were extracted at Clipsham Old Quarry and Ropsley, where with *Bactroptyxis cotteswoldiae*, they constituted a discrete horizon. The range of this species can now be extended into the *Ovalis* Subzone and possibly into the *laeviuscula* Subzone of the *Laeviuscula* Zone.

A number of species can be considered as zonal indicators due to their restricted occurrence, abundance and ease of identification in the Lincolnshire Limestone Formation, these include those set out below.

6.06. Foraminifera.

6.06.1. *Tetrataxis* (Appendix 2c). This distinctive species is known to range from the Aalenian *Murchisonae* Zone into the Late Bathonian (Copestake, 1989). Copestake (1989) illustrates a gap in its occurrence from the *Bradfordensis* Subzone to the *Progracilis* Zone. Its occurrence in the Lincolnshire Limestone Formation however goes some way to address this gap as it occurs in the Sleaford and Clipsham Members at Ancaster and Clipsham (*laeviuscula* Subzone) (Figure 3-4). This species appears abruptly, is relatively abundant, is easily identifiable, and can be traced locally across the Ancaster-Clipsham area, and as such may be of use as a local stratigraphic marker.

6.06.2. The *Spirillina* / *Conicospirillina* Assemblage (Appendix 2c).

The members of this assemblage are species of *Spirillina* and *Conicospirillina* and are considered to be common substrate-dependant Jurassic forms. These genera are especially common at Brauncewell Quarry and in the Copper Hill marl horizons. In the Inferior Oolite similar assemblages have been recorded from Humberside (Packer, 1986) and the Cotswolds (Morris, 1982), its occurrence now being confirmed in the

Lincolnshire Limestone Formation. The submarine vegetation with which these genera were associated (Koutsoukos and Hart, 1990; Morris, 1982) was probably restricted with the introduction of mobile oolite facies during the Upper Lincolnshire Limestone (or tests were winnowed away due to their size). This assemblage is considered, due to its degree of substrate dependence, to be indicative of the Greetwell to Metheringham Members of the Lincolnshire Limestone Formation (back-barrier facies as described by Ashton, 1977).

6.07. Ostracoda

6.07.1. *Bairdia hilda* (Appendix 2b) (this species is often large) is restricted to the Sleaford and Clipsham Members at Copper Hill Quarry (Figure 9, Appendix 1c). This species appears abruptly in abundance, often in beds winnowed of all instars (juveniles), in mobile oolite facies. This species has been recorded by Bate (1967 b), in beds now considered as belonging to the Sproxton and Greetwell Members of Ashton (1977). Therefore, its presence in the Sleaford and Clipsham Members is probably due to facies dependence as it appears only in barrier bar facies. This occurrence may be due to the development of shallow-water growths of algae and sea grasses (Kornicker, 1961). There may be other factors responsible for the distribution of this species in south Lincolnshire. Bate (1967b) also recorded this species in the Kirton Shale at Kirton Cement Quarry, Kirton Lindsey, and in clays and marls in north Lincolnshire. These occurrences may represent either vegetated sub-environments with the development of sea-grasses or be allochthonous accumulations. Morris (1983) has also recorded the species from contemporaneous strata in the Cotswolds where he also noted its facies dependence. It is of note that this species is not found in the Upper Lincolnshire Limestone Formation of Clipsham Old Quarry, this is perhaps due to facies constraints. Further sampling would be required to fully assess the value of this species as a zonal indicator.

Chapter 7. Conclusions.

7.01. The correlation of the northern and southern Lincolnshire Limestone Formation.

The internal correlation of these areas of the Lincolnshire Limestone Formation has proved to be very difficult by biostratigraphical means. The depositional environments represented in Northamptonshire (Figures 1-2) (near-shore) comprise lithologies similar to the coarser grained material of the barrier-bar system. As a result (in the absence of change due to evolution) the resident faunas are similar to those encountered in the Upper Lincolnshire Limestone.

Biostratigraphically the only species known to be of correlative use in Lincolnshire and Rutland are absent in the Northamptonshire material. The attempt to use nerinoidean gastropods proved of little use in the biostratigraphic subdivision of the Formation. The individuals recovered either occurred sporadically across the sequence, or were too small for accurate identification. Other gastropod species appeared intermittently throughout the sequence, possibly because of facies dependence or reworking. Neither *Spirillina,* indicative of the lagoonal facies nor *Tetrataxis* from the barrier facies are represented in the sediments at Cowthick.

The possibility of correlation using mica and/or ironstone bioclasts as tracers to correlate channelling in Northamptonshire with the Lincoln Member at Copper Hill requires further research. Only through the identification of the source material and chemical analysis of the tracers can this possibility be assessed.
One method that might aid in correlation is the use of gamma-ray log anomalies as used by Emery and Dickson (1991). Sampling and subsequent analysis of

palynomorphs may lead to correlations both between the members of the Formation, and to other areas of contemporary deposition.

7.02. Correlation of the Lincolnshire Limestone Formation with other areas.

The discovery of microfaunas at several of the sample locations has allowed parallels to be drawn with the faunas of the Yons Nab Beds, Yorkshire. The faunas give rise to a possible correlation between the basal Yons Nab Beds and the Metheringham Member on the basis of their foraminiferal faunas. Other areas with similar microfaunas include the strata of the *laeviuscula-discites* Subzones (Figure 3-4) of Humberside (Packer, 1986) and the *Opalinum? - Scissum* Zone to the *murchisonae* Subzone of the Cotswolds (Morris, 1982, 1983).

7.03. Biostratigraphic indicators.

The species *Bactroptyxis cotteswoldiae* and *B. guisei* previously considered as biostratigraphic indicators are suggested by this research, to be too unconstrained for use. Alternatives are put forward here in place of these species.

The *Spirillina / Conicospirillina* assemblage is indicative of the lagoonal and back-barrier lithologies of the Lower and Middle of the Formation. The presence of *Tetrataxis* sp. is found to be indicative of the mobile barrier-bar facies of the Upper Lincolnshire Limestone Formation (Figure 4). The occurrence of these microfossils is dependent on substrate type and palaeoenvironment. Microfossils have been considered rare in the Lincolnshire Limestone Formation. This apparent paucity, however, is probably the result of a lack of sampling and study.

7.04. Palaeontology, taphonomy and palaeoecology.

This research has concluded that using the "Holistic community concept" of Kauffman and Scott (1976) the Lincolnshire Limestone Formation at the localities studied remains remarkably consistent throughout its thickness, with substrate and turbidity dependence being the major factors in palaeocomminity structure. The palaeoenvironments recorded (using their associated faunas) agree with the depositional environments proposed by Ashton (1977, 1980).

The microfaunas of the Lincolnshire Limestone Formation have been shown to have been supported by algae and possibly sea-grasses, especially during the deposition of the Sleaford and Clipsham Members.

Mixing, fragmentation and coating of bioclasts remained the dominant taphonomic processes throughout the Lincolnshire Limestone Formation in the study area, although this is not considered to have hampered study of the palaeoenvironments.

7.05 Loss of exposures.

The number of exposures and their condition will be a serious constraint to future studies. The decline in the steel industry in Northamptonshire and the gradual decline in limestone quarrying in Lincolnshire has resulted in ever fewer exposures being available for study. Furthermore, in those quarries that are still in use large areas of exposure are left to progressively deteriorate into a dangerous condition as extraction is scaled down.

7.06. Future work.

There is still much scope for future work in this area. Potential avenues for research include the following.

a) Detailed and comprehensive sampling for foraminifera and ostracoda throughout the formation must be undertaken at other localities, especially further north. More data are needed before confident correlations can be made between the microfaunas of other sediments and those of the Lincolnshire Limestone Formation. This sampling must include the deposits around Northamptonshire as microfossils might provide a means of correlation within the Formation.

b) Studies are overdue into the interspecies variation and taxonomy of the various gastropod faunas of the Lincolnshire Limestone Formation. This is especially overdue with respect to the (non-*Bactroptyxis*) nerinoideans. Barker (1976) reviewed the *Bactroptyxis* but no such work has been carried out on the *Nerinella* or *Nerinaea.* Again such work would possibly increase our understanding of the correlation of the Formation.

c) Methods such as gamma-ray logging might be utilised to correlate the material in Northamptonshire with its counterparts in the better understood middle and northern Lincolnshire material.

d) Statistical analysis of the ostracod and foraminiferal faunas might produce detail on the degree to which habitat and substrate dependence influences the individual species.

e) More work needs to be done to create a more comprehensive and accurate zonation scheme for both Middle Jurassic ostracods and foraminifera.

Chapter 8. References.

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Appendix 1

Symbols used on Logs

Gastropoda

Cerithium

Bryozoan

Bactroptyxis

A. crossi

Crinoid

Echinoid

Echinoid fragment

Bivalve

Bivalve fragment

Shell fragments

Terebratulid

Reefs

Rhynchonellids

Coral

Serpulids

Trace fossils

Echinoid spines

Herringbone Crossbedding

Eroded surface

Crossbedding

Channels

Intraclast

Ooids

Pisoliths

Appendix 1a

Cowthick Quarry Logs

Operator: JS

Date: 13/4

Sheet No: 1

Locality & Grid Ref: Contain

Formation/Member: Southern Lincolnshire Limestone Formation

Weather: Hot + Sunny

BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand: f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No
15			Buff Brown	70% Oolites 15% Bio + Intraclasts		
175			Buff Brown	80% Ooliths 20% Shell Fragments	Material Orientated	
1m			Orange / Brown Some blue / heart	50% Bioclasts 15% Spar 10% Intraclasts 25% Ooliths	Top of Bed Crowded With Large Bivalves Material Orientated	
75		OBSCURED		SAND		

Operator: JS
Date: 13/4
Sheet No: 2a

Locality & Grid Ref: Cowthick
Formation/Member: Southern Lincolnshire Limestone Formation

Weather: Hot - Sunny

BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No
2m (200)			Buff Brown	70% Ooliths 15% Bioclasts 15% Intraclasts		
1m (100)			Buff Brown	40% Bivalves 60% Ooliths / Cement	Bivalve Packed Bio-oomicrite Cross Bedded Sampled L2 Bivalves	
248			Buff Brown	25% Intraclasts 25% Ooliths 20% Bioclasts 10% Gastropods 15% Spar 5% Echinoderm Fragments	Material Orientated / 30°	

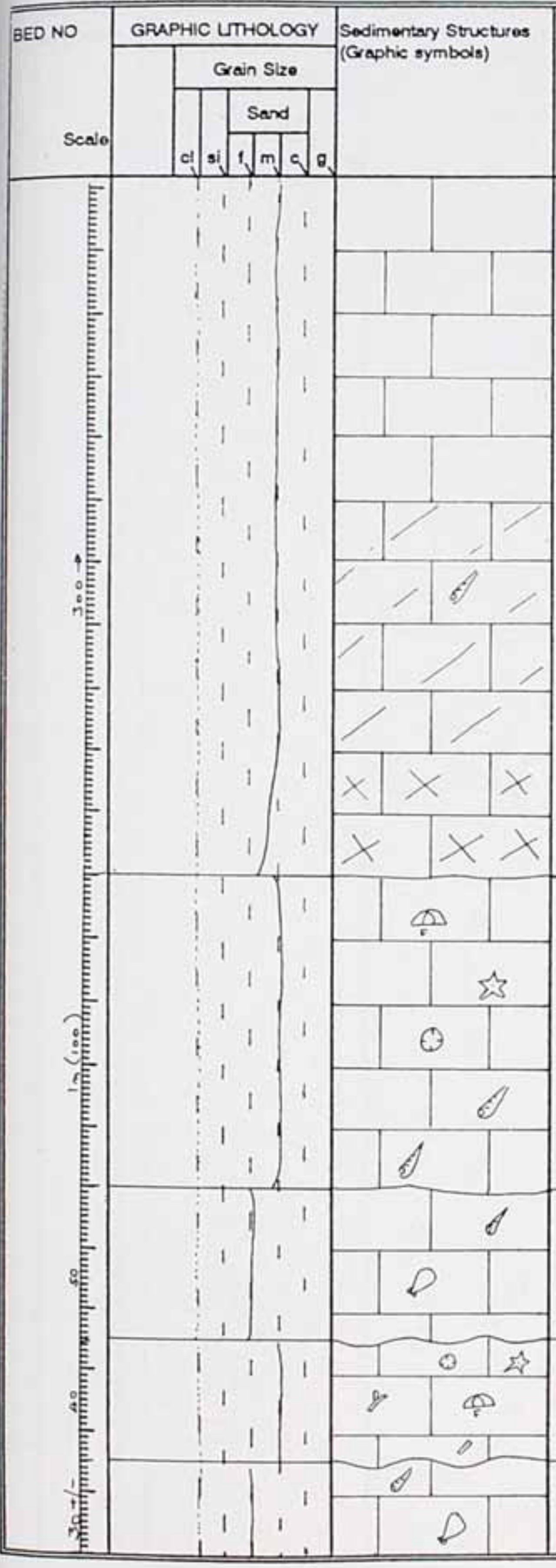
Operator: JS

Locality & Grid Ref.: [illegible]

Date: 13/4

Formation/Member: Southern Lincolnshire Limestone Formation

Sheet No: 26



BED NO	Colour	Fossils (symbols, %)	Additional Notes	Facies No
			Dune Cross/Bedding up to 90cm High Herringbone cross/bedding in fine grained basal material.	
			Very Loosely Cemented No Orientation Sample 28E	
		As Base Bed	As Base Bed Material Orientated =========	
			Very Loosely Cemented No Orientation	
		90% Oolitic/Cement 10% Bioclasts	Very Fine Grained Irregular Surface BB42B1	

Operator: NJ

Date: 13/4

Sheet No: 3

Locality & Grid Ref: Cowthick ... Quarry

Formation/Member: Southern Lincolnshire Limestone Formation

BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No
250			Buff / Brown	70% Ooliths 15% Bioclasts 15% Intraclasts		
120-160			Buff / Brown	60-70% Bioclasts 30-40% Spar O = Oyster/Serpulid "Bioherms"	Sample BVB Dune Cross Bedding Up To 80cm High Bivalve Packed Oo-micrite	
1m (100)			Buff / Brown	45% Fine Cement 20% Ooliths 20% Bioclasts 15% Intraclasts	Hardground on Bivalve shelly base Sample L3B1	
← 160					Obscured	

Operator: JB

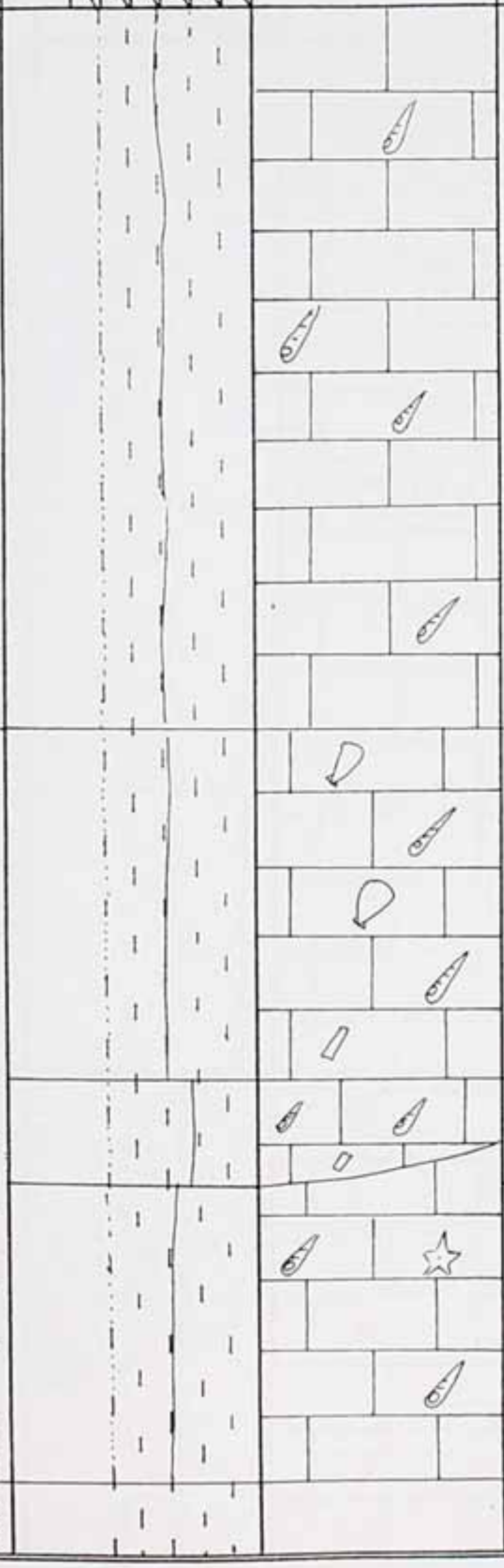
Date: 13/4

Sheet No: 4

Locality & Grid Ref: Cowthick

Weather: [illegible]

Formation/Member: Southern Lincolnshire Limestone Formation



BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand: f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No
3m (300)			Buff / Brown		Rubbly / Platy Limestone	
1m (100)			Buff / Brown	Ooliths = 45% Intraclasts = 30% Bioclasts = 25%	Hard Blue - Hearted Limestone. Material orientated ← flow. Basal 25cm poorly cemented - Sample (Channel) Crumbly Lst	
30			Yellow / Brown		No Orientation Channel 4	
85			Buff / Brown		Fine Grained Limestone Cut at 20° by Channel Base. Sample Base 4	
					Obscured	

Operator: JS

Date: 13/4

Sheet No: 5

Locality & Grid Ref: Cowthick

Formation/Member: Southern Lincolnshire Limestone Fm

Weather: Hot + Sunny

BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand: f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No
			Buff / Brown		Platy Limestone	
			Buff / Brown		Rag - Knolls of Oyster Bivalves and Serpulids	
			Buff / Brown	Base with Corals	Blue Hearted Sparry Limestone	
			Buff / Brown		Same Characteristics and Horizon as Loc 4's Crumbly Limestone	
		CLAY	Buff / Brown		Clay Sampled (L5Clay) Crumbly Limestone Orientated \ 20° Ironstained 4m → L4.	

Operator: JS

Date: 7/5

Sheet No: 6

Locality & Grid Ref: Cowthick

Formation/Member: Southern Lincolnshire Limestone Fm

Weather: Hot → Sunny

BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand: f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No
80cm			Buff / Brown		Platy Limestone	
60cm			Buff / Brown		Oysters Serpulids And Large Bivalves	
40cm			Buff / Brown		Blue Hearted and Well-Cemented	
160cm			Buff / Brown		Bedded Limestone Intraclasts and Spar-Filled Bivalves Disorientated. Sample 1m ↓ Shells Finer and Less Cemented at Base. Sample L6Cou	
60cm			Buff / Brown		Hard / Well Cemented Sparry Limestone	
100cm			Buff / Brown		As Above Hard / Well Cemented Bed Sample L6LB 6m from LS →	

Operator: ..
Date: 7/5 Formation/Member: SOUTHERN LINCOLNSHIRE LIMESTONE Fm
Sheet No: 7

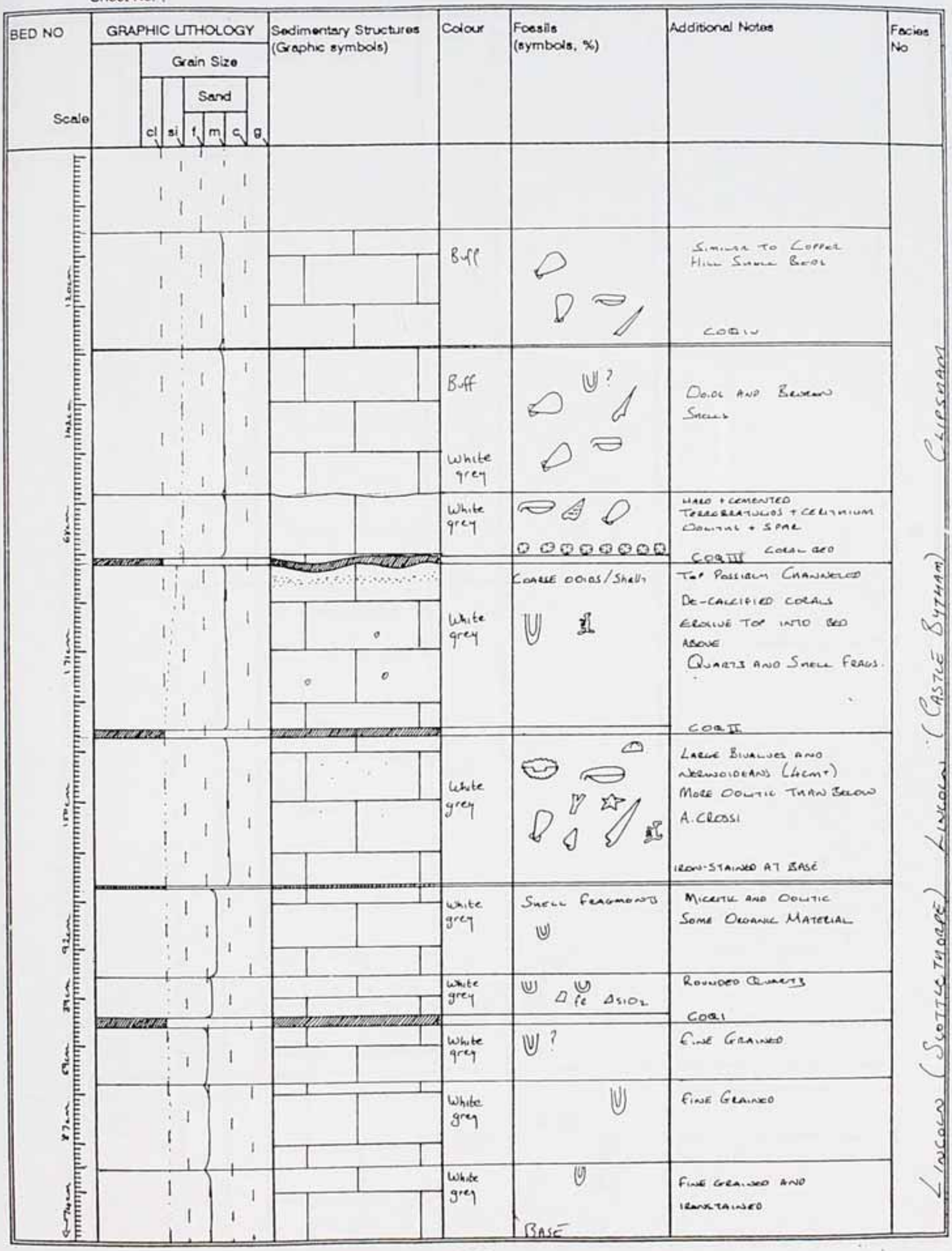
BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No
150cm (1.5m) +			BUFF/ BROWN		PLATY LIMESTONE	
40 cm			BUFF/ BROWN		BIVALVE BED	
140cm			BUFF/ BROWN		CAPPED BY LARGE BIVALVES MERGING INTO BED ABOVE.	
30cm			BUFF/ BROWN		BLUE HEARTED	
90cm			BUFF/ BROWN		CRUMBLY SHELLY (ORIENTATED). SPARRY INTRACLASTS AND ROUNDED BIOCLASTS Sm → SmBGL8 SAMPLE L71 L7CLAY	
80cm			BUFF/ BROWN		HARD BLUE-HEARTED INTRACLASTS AND ROUNDED BIOCLASTS. SPARRY 6m → L6	

Appendix 1b

Clipsham Quarry Logs

Operator: JS
Date: 19/4
Sheet No: 1

Locality & [illegible]: CLIPSHAM OLD QUARRY
Formation/Member: LINCOLNSHIRE LIMESTONE FORMATION



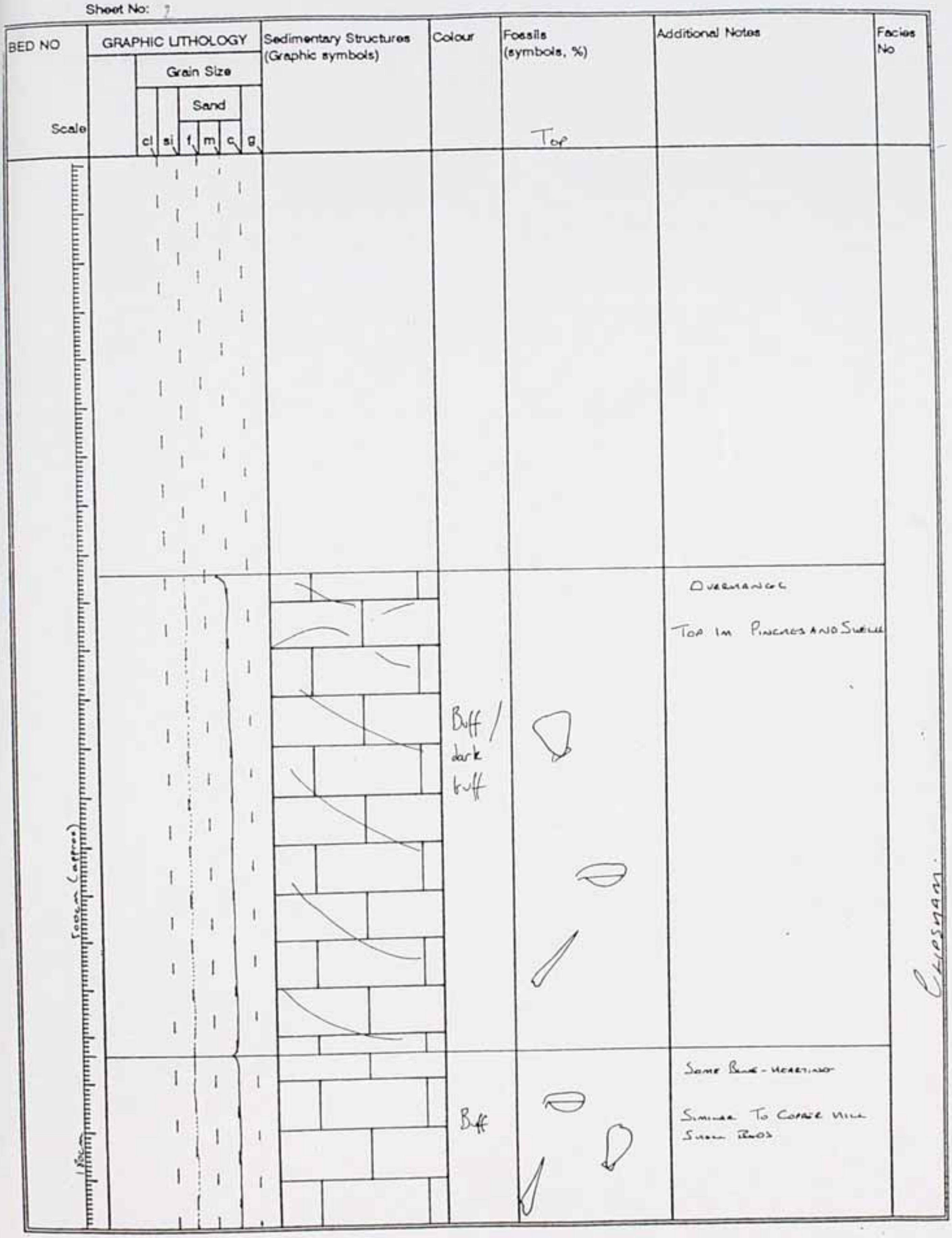
Operator: JB

Date: 19/4

Sheet No: 7

Locality & Grid Ref: Clipsham Old Quarry

Formation/Member: Lincolnshire Limestone Formation



Appendix 1c

Copper Hill Quarry Logs

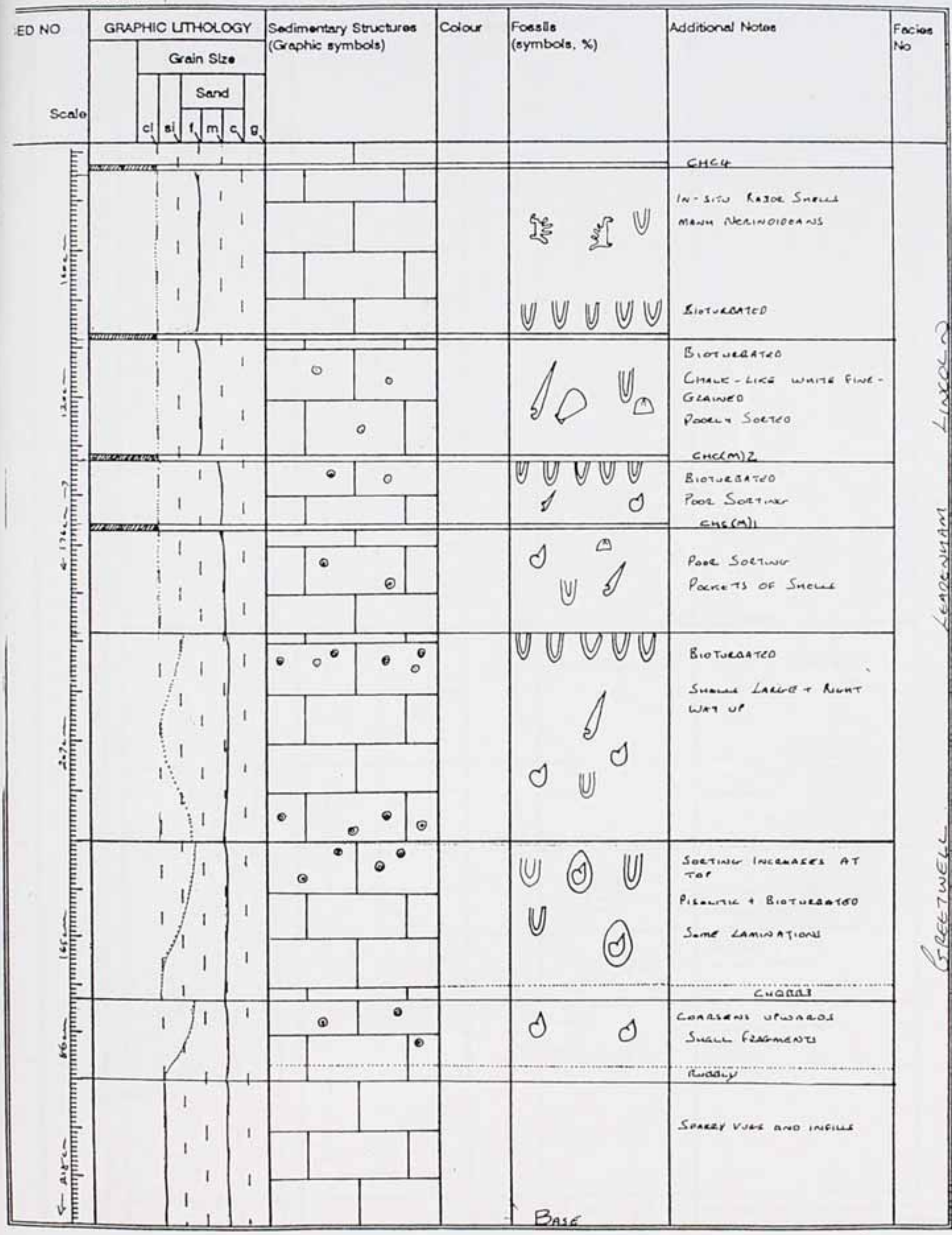
Operator: J

Date: 22/10

Sheet No: 1

Locality & Grid Ref: COPPER HILL, ANCASTER

Formation/Member:



Operator: B

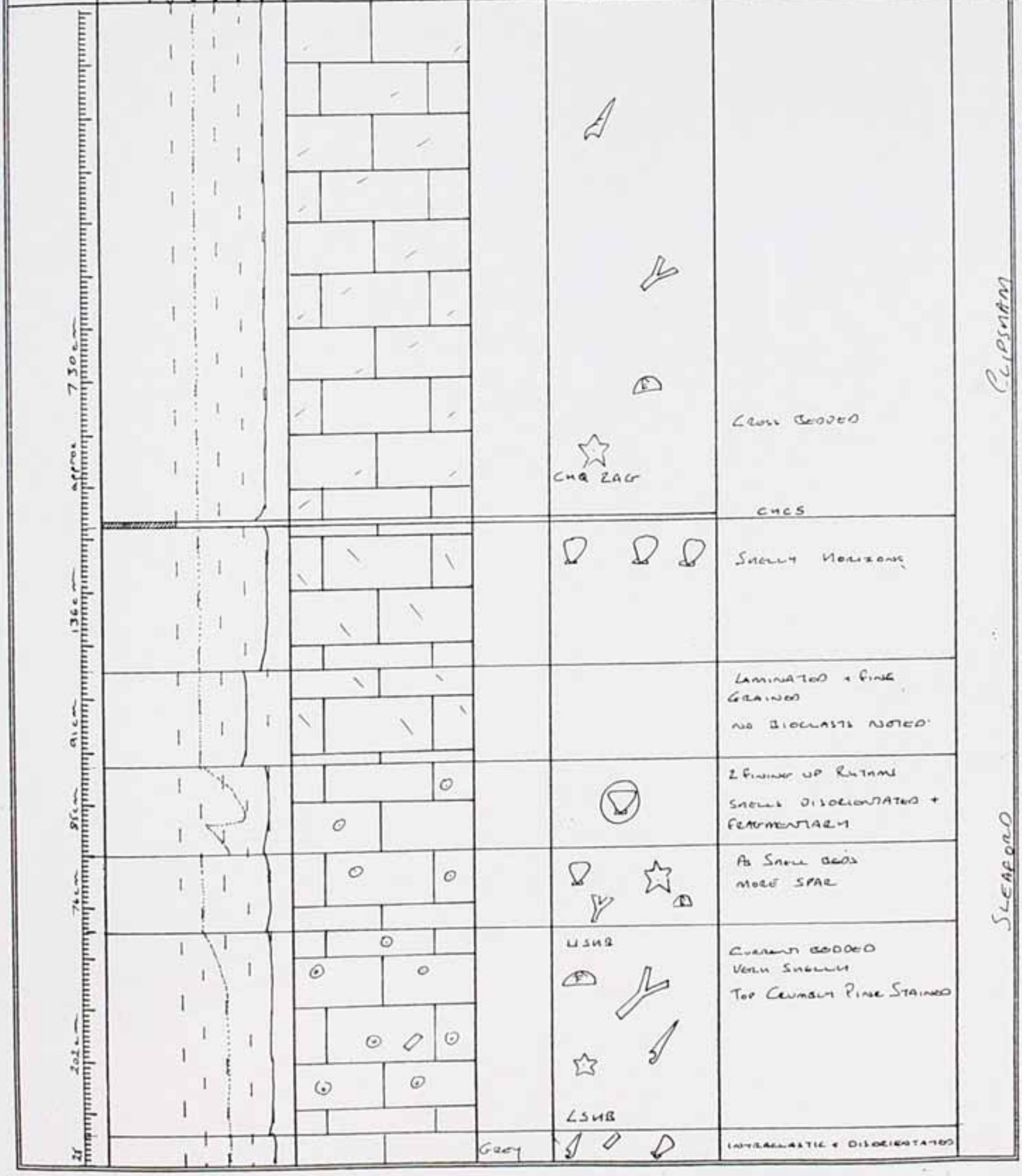
Date: 22/10

Sheet No: 2

Locality & Grid ref: COPPER HILL ANCASTER

Formation/Member: LINCOLNSHIRE LIMESTONE FORMATION

BED NO / Scale	GRAPHIC LITHOLOGY (Grain Size: cl, si, Sand f, m, c, g)	Sedimentary Structures (Graphic symbols)	Colour	Fossils (symbols, %)	Additional Notes	Facies No



Appendix 1d

Brauncewell Quarry Logs

Operator: JB

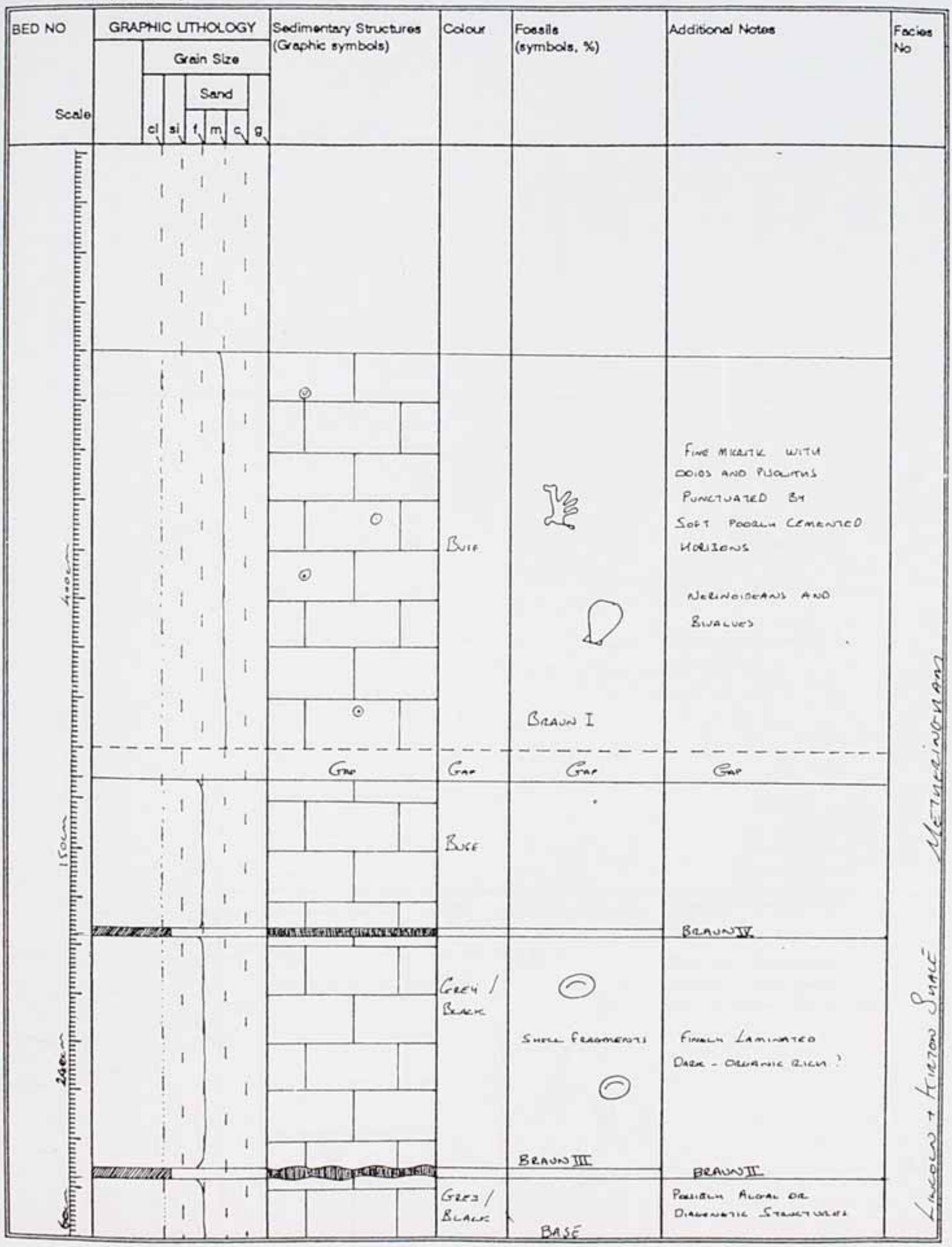
Locality & Grid Ref: BRAUNCEWELL Q

Weather:

Date:

Formation/Member:

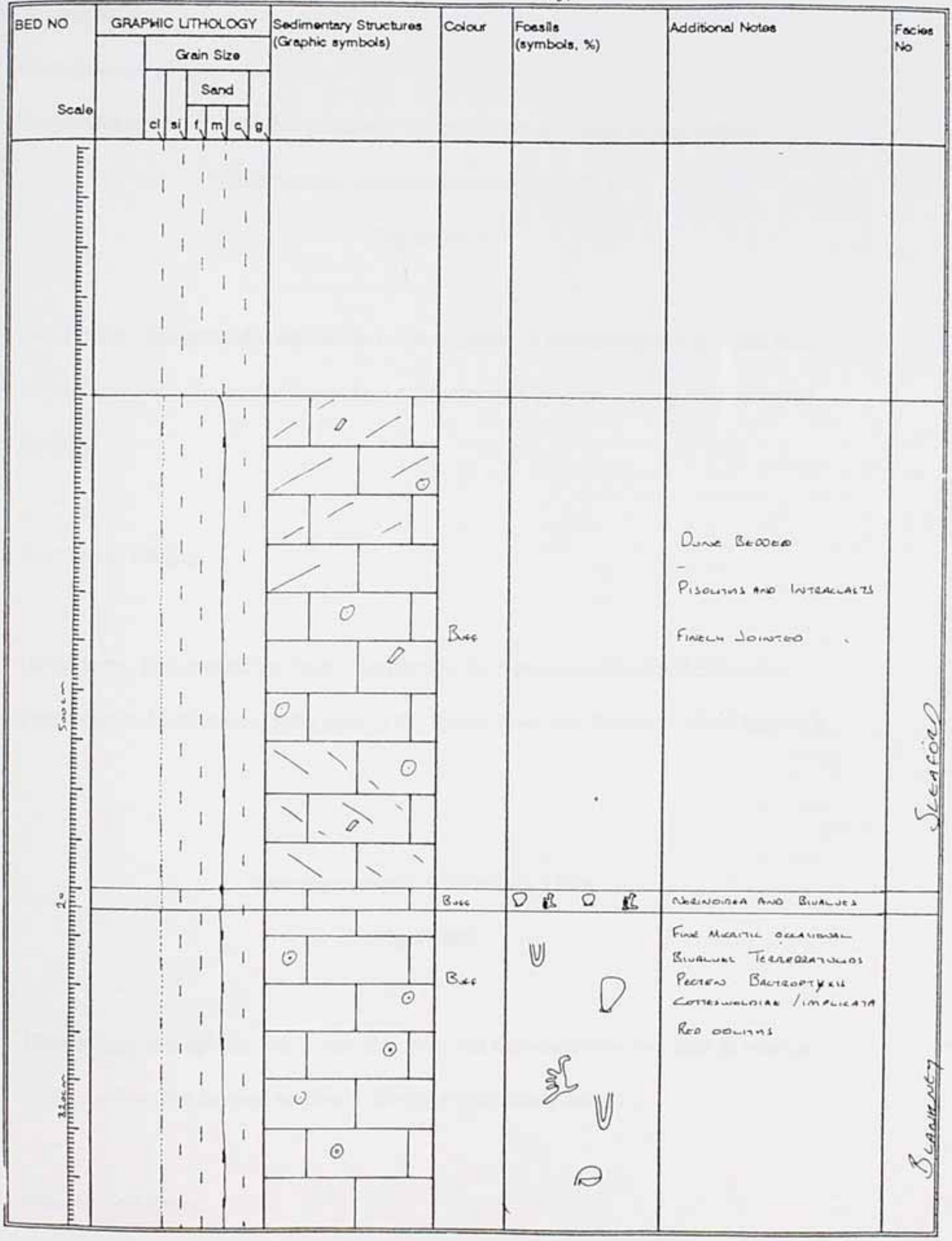
Sheet No: 1



Operator: JS
Date: 27/6
Sheet No: 2

Locality & Grid Ref: Brauncewell Q
Weather:
Formation/Member: Lincolnshire Limestone Formation

Top



Appendix 2

Appendix 2a

Nerinoideans

Only those species considered as zonally indicative are described in this section.

Bactroptyxis cotteswoldiae (Lycett, 1857)

(Figure 40i).

Description: The internal cross-section of this species is very distinctive as it has three columellar folds. Externally the surface is ornamented by faint slanting unidirectional grooves.

Size: Up to 100mm.

Occurrence: This species has been described in the Lower Lincolnshire Limestone Formation by Hudleston (1888) Plate XVI, figures 3a-d, and Barker (1976) Figure 2.8.

Bactroptyxis guisei (Witchell, 1880)

Figure 40ii

Description: This species has an acicular spire and the whorls are very high in relation to their width. The internal section is elongate with simple folds.

Size: Up to 100mm.

Occurrence: This species was considered representative of the Clypeus Grit and Lower Lincolnshire Limestone Formation by Hudleston (1888) Plate XV Figures1a-c, and Barker (1976) Figure 2.8.

Nerinoideans

Figures include internal outlines of some of the species recorded during this research.

For scale see descriptions in previous section.

Figure 40

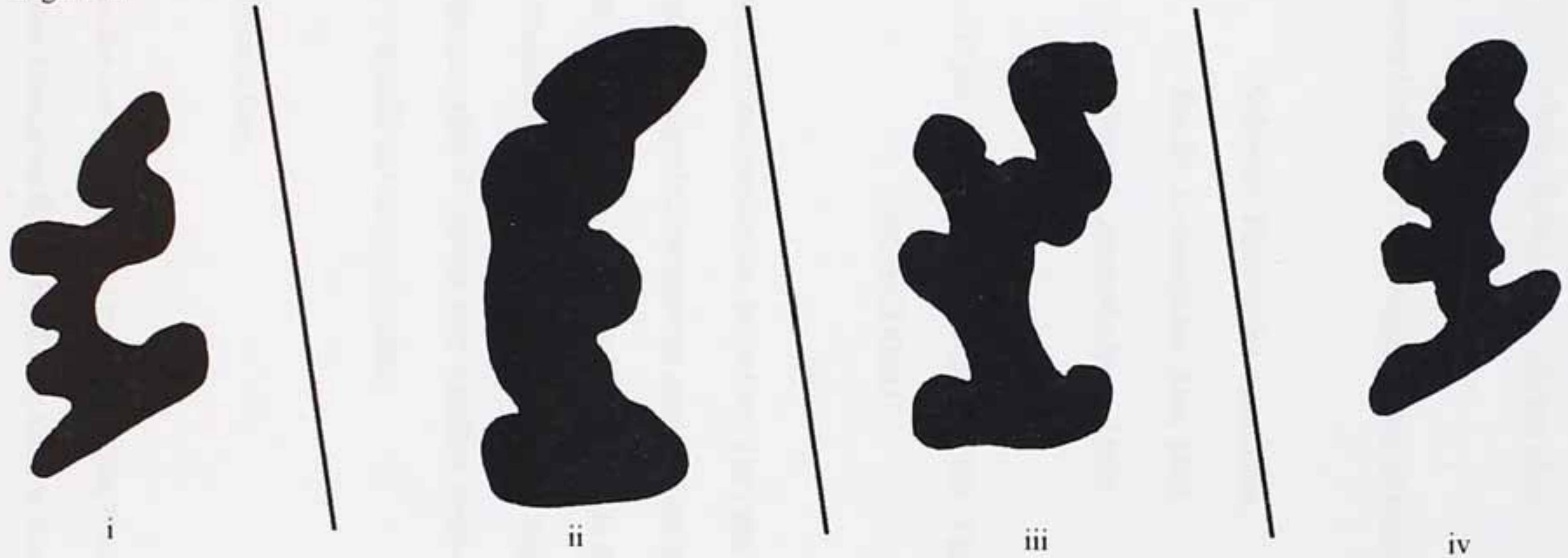
i. *Bactroptyxis cotteswoldiae* (Lycett, 1857).

ii. *Bactroptyxis guisei* (Witchell, 1880).

iii. *Bactroptyxis implicata* (d'Orbigny, 1854).

iv. *Bactroptyxis pisolitica* (Witchell, 1887).

Figure 40



Appendix 2b Ostracod Systematics

Subclass: Ostracoda Latrielle, 1806.

Order: Podocopida Muller, 1894.

(The University College of Northampton holds all reference material).

Suborder: Platycopina Sars, 1866.

Family: Cytherellidae Sars, 1866.

Genus: *Cytherella* Jones, 1849.

Cytherella fullonica Jones and Sherborn, 1888 (Figure 41i).

Type: JBCOQIIO1

Description: This species is sub-rectangular in outline. The right valve is larger than the left overlapping it on all sides bar the anterior margin. This species is longest through its mid point, highest in the anterior third and widest in the posterior third. The anterior and posterior are broadly rounded (the posterior being rounded more obliquely). The carapace surface is smooth with a shallow dorso-median depression marking the position internally of the muscle scars.

Size: Up to 0.6 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 1 Figures 1-2) from the Middle Lincolnshire Limestone Formation Kirton Shale at Kirton in Lindsey and the Lower Lincolnshire Limestone Formation at Greetwell Quarry near Lincoln. Bate

(1967b) records this species from the Lower Lincolnshire Limestone Formation at Greetwell Quarry, Lincolnshire, in Lincoln and the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey. Packer (1986; Plate 1 Figure 2) also records this species from the Lincolnshire Limestone Formation at Kirton in Lindsey.

Genus: *Cytherelloidea* Alexander, 1929

Cytherelloidea catenulata (Jones & Sherborn, 1948) (Figure 41ii.).

Type: JBCHQM2O2

Description: The carapace of this species is sub-rectangular in outline with a posterior swelling shaped like a question mark. The carapace surface is marked by a reticulate tracery of fine ridges. This species reaches its greatest length through the midpoint, the greatest height in the anterior or posterior thirds and the greatest width in the posterior third. The dorsal margins of both valves are slightly concave in the anterior half becoming strongly convex behind the valve middle. The right valve overlaps the left except around the anterior margin where the right valve simply over-reaches the left. A dorso-median depression marks the position of the muscle scars.

Size: Up to 0.6 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 1 Figures 3-6) from the Middle Lincolnshire Limestone Formation around Kirton in Lindsey and Lower Lincolnshire Limestone Formation around Lincoln. Bate (1967b) records this species from the Lower Lincolnshire Limestone Formation of Lincoln (Greetwell Quarry, Lincolnshire) and the Middle Lincolnshire Limestone Formation Kirton Shale at Kirton in Lindsey. Bate (1967b) also records this species from the Bajocian Cave Oolite of Yorkshire and Whitwell Oolite. Morris (1983) records this species from the Lower Inferior Oolite of the Cotswolds (Plate IV Figures 4-6 and 9).

Genus: *Platella* Coryell & Fields, 1937.

Platella jurassica Bate, 1963 (Figure 41iii).

Type: JBCHQUSHBO3

Description: This species is ovoid in outline with arched dorsal and concave ventral margins. The broadly rounded anterior has a narrow compressed rim which is obliquely rounded at the posterior end. The carapace is ornamented with reticulate small pits in rows that parallel the carapace sides. The greatest length is around the mid-point, the greatest height in the anterior third and the maximum width just behind the valve centre. The right valve overlaps the lert except around the anterior and posterior margins. A dorso-median pit marks the position of the muscle scars.

Size: Up to 0.4 millimetres long.

Occurrence this species was recorded by Bate (1963a; Plate 1 Figures 7-10 and 1967b) in the Middle Lincolnshire Limestone Formation of Kirton in Lindsey. Bate (1967b) also records this species from the Lower Lincolnshire Limestone Formation at Greetwell Quarry, Lincolnshire.

Suborder: Podocopina Sars, 1866.

Superfamily: Cypridacaea Baird, 1845.

Family: Paracyprididae Sars, 1923.

Genus: *Paracypris* Sars, 1866.

Paracypris bajociana Bate, 1963 (Figure 41iv).

Type: JBCHQM1O4

Description: the carapace is smooth, sub-reniform in outline and elongate. The anterior is rounded and the posterior tapering. The anterior has a short anterio-dorsal slope, posterially the slope is longer and steeper. The greatest height and width are in the anterior third, the maximum length being below the mid-point. The left valve overlaps the right.

Size: Up to 0.4 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 2 Figure 1-8) in the Middle Jurassic sediments of Lincolnshire and Yorkshire. Bate (1967b) records this species from the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey. Morris (1983; Plate IV Figures 15-19) has recorded this species from the

Lower Inferior Oolite of the Cotswolds. Packer (1986; Plate 1 Figure 3) has identified this species from the Lincolnshire Limestone Formation of Kirton in Lindsey.

Superfamily: Bairdiacea Sars, 1888.

Family: Bairdiidae Sars, 1888.

Genus: *Bairdia* McCoy, 1844.

Bairdia hilda Jones, 1884 (Figure 41v).

Type: JBCHQLSHBO5

Description: The carapace of this species is sub-deltoid in outline with a smooth surface. The left valve overlaps the right strongly overlapping it , along the dorsal margin and midventrally. There is no overlap anteriorly and there is a slight overreach along the posteriorventral margin. The anterior is rounded with a anterodorsal slope which is straight or slightly convex in the left valve, concave in the right. The posterodorsal margin is straight becoming upturned at the posterior (this is most pronounced in the right valve).

Size: Up to 1 millimetre.

Occurrence: This species has been recorded by Bate (1963a; Plate 2 Figures 9-12 and Plate 3 Figures 1-4) from the Middle Lincolnshire Limestone Formation at Kirton in Lindsey (Kirton Shale) and the Lower Lincolnshire Limestone Formation around Lincoln. Bate (1967b;) identifies this species from the Middle Lincolnshire Limestone

Formation of Kirton in Lindsey (Kirton Shale) and the Middle Lincolnshire Limestone Formation of Greetwell Quarry, Lincolnshire he also records it from the Bajocian Cave Oolite of Yorkshire. Morris (1983; Plate IV Figures 11-14) records this species from the Lower Inferior Oolite of the Cotswolds. Packer (1986; Plate 1 Figure 5) discovered this species in the Lincolnshire Limestone Formation strata around Kirton in Lindsey.

Superfamily: Cytheracea Baird, 1850.

Family: Bythocytheridae Sars, 1926.

Genus: *Monoceratina* Roth, 1928.

Monoceratina vulsa (Jones & Sherborn, 1938). (Figure 41vi).

Description: This species is subquatrate in side view, the postventral border is broad. In dorsal view this species is almost parallel sided with a slight divergence towards the posterior. Bate (1963a) suggests that elongate individuals (possibly males) may be the result of sexual dimorphism. The hinge is straight, ending in a node similar to an eye swelling. The ventral margin is slightly convex. The anterior is rounded and the posterior is acuminate produced by a long oblique (convex) posteroventral slope and a short (concave) posterodorsal slope. The carapace is markedly convex and is divided by a vertical median sulcus. In dorsal view the anterior lobe is smaller than the dorsal lobe. The greatest height is just behind the valve middle, the maximum width below and behind the median sulcus. The left valve slightly overlaps the right. There is a distinct postventral keel, and surface ornamentation in the form of pits and ridges, giving a wrinkled appearance.

Occurrence: This species has been recorded by Bate (1963a; Plate 3 Figures 5-12) in the Lower Lincolnshire Limestone Formation at Greetwell Quarry, Lincolnshire and the Middle Lincolnshire Limestone Formation (Kirton Shale) of Kirton in Lindsey. Bate (1967b) and Morris (1983; Plate V Figures 18-20) records this species from the Inferior Oolite of the Cotswolds.

Monoceratina cf. *scrobiculata* Triebel & Bartenstein, 1938. (Figure 41vii).

Description: The carapace is elongate and quadrate. The dorsal margin is long and straight the ventral margin is short, paralleling the dorsal margin. The posterior and anterior margins are compressed. At the posteroventral border of each valve there is an inflated projection pointing back and down. The maximum length is dorsal of mid-point, the greatest width is in the posterior third. On the ventral surface a "V" shaped flattening is present.

Occurrence: This species has been recorded by Bate (1963a; Plate 4 Figures 1-4 and 1967b) in the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey. Morris (1983; Plate V Figures 10-11) has recorded this species from the Inferior Oolite of the Cotswolds.

Family: Progonocytheridae Sylvester-Bradley, 1948.

Subfamily: Progonocytherinae Sylvester-Bradley, 1948.

Genus: *Progonocythere* Sylvester-Bradley, 1948.

Progonocythere cristata Bate, 1963 (Figure 41viii).

Type: JBCHQM2O8

Description: This species is oval in outline with slight swelling medially. Bate (1963a) suggests that elongate individuals may be males. The dorsal margin is mildly convex and slopes to the posterior. The ventral margin is convex, the anterior margin being rounded, the posterior is triangular with concave posterodorsal and convex posteroventral slopes. There is a keel. The shell surface is smooth to punctate. Three longitudinal ribs ornament the ventral surface. The left valve is larger than the right. The greatest length is through the midpoint, the maximum height in the anterior third and the greatest width just posterior of valve centre.

Size: Up to 0.3 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 4 Figures 5-15 and Plate 5 figures 1-6) from the Lower Lincolnshire Limestone Formation of Greetwell Quarry, Lincolnshire and the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey. Bate (1967b) records this species from the Lower Lincolnshire Limestone Formation at Greetwell Quarry, Lincolnshire the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey and the Bajocian Whitwell

Oolite and Yons Nab Beds of Yorkshire. Nagy *et al.* (1981) also describes this species from the Yons Nab Beds of Yorkshire.

Genus: *Pneumatocythere* Bate, 1963.

Pneumatocythere bajociana Bate, 1963 (Figure 41ix).

Type: JBCHQBB3O9

Description: The outline is oval with some elongated forms (Bate (1963a) calling these males). The maximum length is through the mid-point the maximum height being in the central area. There is a degree of inflation of the carapace especially around the valve centre. The ventrolateral border of each valve is convex, projecting below the ventral, particularly the mid-ventral, surface. The marginal borders are compressed. The carapace surface has weakly developed longitudinal ridges. The left valve overreaches the right, overreaching it along the dorsal and anterior margins. Posterially the right valve overreaches the left. The anterior is rounded and the posterior triangular with strongly concave posterodorsal and convex posterodorsal slopes.

Size: Up to 0.35 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 5 Figures 7-10 and Plate 6 Figures 1-10) throughout the Lincolnshire Limestone Formation and Yons Nab Beds of Yorkshire. Packer (1986; Plate 1 Figure 8) has recorded this species from the

Lincolnshire Limestone Formation of Kirton in Lindsey and Nagy *et al.* (1981) from the Yons Nab Beds of Yorkshire.

Genus: *Acanthocythere* Sylvester-Bradley, 1948.

Subgenus: *Protoacanthocythere* Bate, 1963

Acanthocythere (Protoacanthocythere) faveolata Bate, 1963 (Figure 41x).

Type: JBCHQM1O10

Description: In outline, this species is sub-rectangular to sub-quadrate. Bate (1963a) suggests that the most elongate individuals might represent males. The anterior is rounded, slightly oblique dorsally with a short anterodorsal slope which ends with an eye tubercle. The posterior is rounded in the left valve with a short concave posterodorsal slope in the right valve. The dorsal margin is straight, the ventral margin being concave anteromedially and convex posteriomedially. The lateral posteroventral margin is swollen and overhangs the ventral margin. A thickened marginal keel is developed around the anterior and posterior margins along the ventral margin almost reaching the midpoint. Although the left valve is the largest it hardly overhangs around anterior or along the dorsal margin. Ornamentation is present this gives rise to the development of small spines at the ridge intersections.

Size: Up to 0.45 millimetres long.

Occurrence: Individuals have been described by Bate (1963a; Plate 7 Figures 5-13 and Plate 8 Figures 1-5) as common throughout the Kirton Shale and parts of the Lincolnshire Limestone Formation. Bate (1967b) has recorded this species from the Lower Lincolnshire Limestone Formation of Greetwell Quarry and the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey. Packer (1986; Plate 1 Figure 7) records this species from the Lincolnshire Limestone Formation of Kirton in Lindsey.

Genus: *Aulacocythere* Bate, 1963.

Aulacocythere punctata Bate, 1963 (Figure 41xi).

Type: JBCHQUSHBO11

Description: This species is inflated and sub-rectangular in outline. Bate (1963a) suggests that males of this species are more elongate and less inflated than females. The dorsal margins are straight. The cardinal angles are swollen in the left valve but are indistinct in the right. The anterior is rounded and slightly oblique dorsally in the right valve. The posterior is narrowly rounded in the left valve, tapering in the right becoming somewhat triangular. The left valve is largest overreaching the right valve totally. The anterior and posterior marginal areas are compressed, distinct from the convex part of the valve. The shell surface is ornamented by puncta, which cover the entire lateral part of the valve. Ventrally the puncta are less noticeable as here ornamentation is in the form of 3-4 longitudinal ridges. There is also a characteristic horseshoe shaped swelling.

Size: Up to 0.35 millimetres long.

Occurrence: Bate (1963a; Plate 9 Figures 4-9) describes this species from the Middle Lincolnshire Limestone Formation Kirton Shale at Kirton in Lindsey as does Bate (1967b). Bate (1967b) also recorded this species from the Lower Lincolnshire Limestone Formation of Greetwell Quarry and in the Cave Oolite of Yorkshire.

Subfamily: Pleurocytherinae Mandelstam, 1960.

Genus: *Pleurocythere* Triebel, 1951.

Pleurocythere kirtonensis Bate, 1963 (Figure 42i).

Type: JBCHQRAGO12

The outline of the carapace is anteriorly rounded and acuminate- triangular posteriorly. The dorsal margin is straight to slightly concave in the right valve, the left valve being convex. Apart for the dorsal keel ornamentation is identical between valves. Of the three longitudinal ridges the two on the ventrolateral border are best developed. The oblique median ridge (uppermost of the three) is short in this species, to the rear of this is a short posterodorsal ridge typical of the genus. The shell surface is coarsely reticulate. The left valve overlaps the right midventrally and overreaches it dorsally.

Size: Up to 0.3 millimetres long

Occurrence: Individuals have been recorded by Bate (1963a; Plate 10 Figures 14-18 and Plate 11 Figures 1-5) in the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey as did Bate (1967b) and Packer (1986; Plate 2 Figure 1). Bate (1967b) also records this species from the Cave and Whitwell Oolites of Yorkshire. Morris (1983; Plate VIII Figures 1-3 and 7) records this species from the Inferior Oolite of the Cotswolds.

Family: Schulerideidae Mandelstam, 1959.

Subfamily: Schulerideinae Mandelstam, 1959.

Genus: *Praeschuleridea* Bate, 1963.

Praeschuleridea subtrigona (Jones and Sherborn, 1888) (Figure 42ii).

Type: JBCHQM2O13

Description: This species is oval-subtrigonal in outline, strongly convex with its greatest width behind the valve centre. Bate (1963a) presumes that the elongate individuals are males. There is a narrow anterior marginal border on each valve. The left valve overlaps the right valve, which is the more elongate. The maximum length is along the midline, the greatest height for the left valve is at valve centre and for the right valve is in front of centre. There is a slight swelling with oblique furrow on the right valve beneath the anterior cardinal angle, this has been interpreted by Bate (1963a) as possible eye swelling.

Size: Up to 0.4 millimetres long.

Occurrence: This species is recorded by Bate (1963a; Plate 12 Figures 12-16 and Plate 13 Figures 1-9) from the Fullers Earth Clay, Midford, Bath. Bate (1963a) also discovered this species in the Middle Lincolnshire Limestone Formation Kirton Shale at Kirton in Lindsey, describing the species as common in the Lower Lincolnshire Limestone Formation. Bate (1967b) identified the species in the Lower Lincolnshire Limestone Formation of Greetwell Quarry, Lincolnshire and the Middle Lincolnshire Limestone Formation Kirton Shale at Kirton in Lindsey. Bate (1967b) also described this species from strata of the Cave Oolite and Hydraulic Limestone of Yorkshire. Morris (1983; Plate XI Figures 7-9 and 12) has identified this species in the Lower Inferior Oolite of the Cotswolds and Packer (1986; Plate 2 Figure 5) from the Lincolnshire Limestone Formation of Kirton in Lindsey.

Family: Protocytheridae Ljubimova, 1955.

Subfamily: Kirtonellinae Bate, 1963

Genus: *Kirtonella* Bate, 1963.

Kirtonella plicata Bate, 1963 (Figure 42iii).

Type: JBCUQM1O14

Description: The outline of this species is subquatrate to subtriangular. Bate (1963a) believes elongated forms to be males and shorter subtriangular forms to be females. In the latter the dorsal margin is more strongly arched. The anterior portion of both sexes is rounded with the posterior being more triangular. The left valve is largest overlapping the right slightly along the ventral margin, elsewhere the left valve overreaches the right. A groove stretches round the anterior margin producing a raised "rim". The ventral surface is ornamented by 3 or 4 longitudinal ridges, and laterally by circular pits. The greatest length is through the midpoint, the greatest height at the anterior cardinal angle, and the maximum width just behind and above the midpoint.

Size: Up to 0.3 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 13 Figures 10-19 and Plate 14 Figures 1-6, 11-12) in the Lower Lincolnshire Limestone Formation of Greetwell Quarry, Lincolnshire. Bate (1967b) also found this species in the Middle Lincolnshire Limestone Formation Kirton Shale of Kirton in Lindsey as did Packer (1986; Plate 2 Figure 9).

Genus: *Systenocythere* Bate, 1963

Systenocythere exilofasciata Bate, 1963 (Figure 42iv).

Type: JBCHQUSHBO15

Description: The carapace is strongly dimorphic (Bate, 1963a) the female being sub-quadrate with a short, tapered posterior; the male more elongate, the posterior being drawn out and acuminate. The maximum length is below the midpoint in both sexes, the greatest height, although in the anterior third is closer to the midpoint in the male. The greatest width is in the posterior third. The dorsal margin is straight and slopes to the posterior at around 45 degrees. The anterodorsal slope is slightly convex (and is much longer in the male) whereas the posterodorsal slope is slightly concave. The posteroventral part of the shell is swollen. Ornamentation is weak with longitudinal ridges following the carapaces ventral outline. The ventral surface of each valve is strongly ornamented by 4 longitudinal ridges. The left valve is the larger.

Size: Up to 0.8 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 14 Figures 7-10, 13-17 and Plate 15 Figures 1-4) in the Middle Lincolnshire Limestone Formation of Kirton in Lindsey and in the strata of the Cave Oolite. Bate (1967b) recorded this species from the Lower Lincolnshire Limestone Formation at Greetwell Quarry, Lincolnshire and in the Cave Oolite, Whitwell Oolite and Yons Nab Beds of Yorkshire. Nagy *et al.* (1981) also record this species from the Yons Nab Beds.

Genus: *Ektyphocythere* Bate, 1963.

Ektyphocythere triangula (Brand, 1961) (Figure 42v).

Type: JBCHQM2O16

Description: The outline of this species is subtriangular to subquatrate, in dorsal view the carapace is strongly convex. The greatest length is through the midpoint, the greatest height is slightly anterior of middle. The maximum width in adults is in the posterior third whereas in instars is more centrally placed. 3-4 ridges ornament the shell surface, these are sited obliquely through the anterodorsal and anteroventral parts these continue ventrolaterally as longitudinal ridges. At the centre of this triangular arrangement the ridges may break up into reticulations. The valve margins are compressed into a thickened rim. Dorsally the right valve overreaches the left.

Size: Up to 0.5 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 15 Figures 5-18) in the Middle Lincolnshire Limestone Formation Kirton Shale at Kirton in Lindsey as does Bate (1967b) and Packer (1986: Plate 2 Figure 10). Bate (1967b) also records this species from the Lower Lincolnshire Limestone Formation of Greetwell Quarry, Lincolnshire the Cave Oolites and the Yons Nab Beds of Yorkshire. Nagy *et al.* (1981) recorded this species from the Yons Nab Beds. Morris (1983; Plate VIII Figures 3-6) recorded this species in the Lower Inferior Oolite of the Cotswolds.

Family: Loxoconchidae Sars, 1925.

Genus: *Cytheremorpha* Hirschmann, 1909.

Cytheremorpha greetwellensis Bate, 1963 (Figure 42vi).

Type: JBCHQLSHBO17

Description: The carapace of this species is although sub-rectangular in outline tapers to the posterior. The greatest length extends through the midpoint, the greatest height at the anterior cardinal angle and the maximum width is through the posterior third.

Dorsally the species is slender and parallel-sided with slight median constriction. The ventral margin is medially flattened with a tendency to be mildly concave, but convex anteroventrally and posteroventrally. The anterior is high and rounded, the posterior is triangular with a short, straight, steeply angled posterodorsal slope and, a short slightly convex posteroventral slope. There is a low swelling along the ventrolateral part of the carapace. The shell surface is ornamented uniformly by an almost reticulate cover of small pits. This species is almost equivalve with the left valve being only slightly larger than the right.

Size: Up to 0.35 millimetres long.

Occurrence: This species has been recorded by Bate (1963a; Plate 15 Figures 19-21) in the Lower Lincolnshire Limestone Formation at Greetwell Quarry, Lincolnshire and the Middle Lincolnshire Limestone Formation Kirton Shale at Kirton in Lindsey. Packer (1986; Plate 2 Figure 11) also discovered this species at Kirton in Lindsey.

"*Terquemula*-like" species (Figure 46i).

Type: JBCHQUSHBO18

Description: This species is sub-rectangular in outline which tapers to the anterior end. The greatest length is through the midpoint and the maximum thickness is in the posterior third. The most distinctive feature of this species is its ornamentation, each valve is crossed by three continuous longitudinal ridges. Between these ridges are small square reticulations.

Size: Up to 0.35 millimetres long.

Ostracods.

For scale see descriptions in previous section.
Figure 41.

i. *Cytherella fullonica* Jones and Sherborn.
ii. *Cytherelloidea catenulata* (Jones and Sherborn).
iii. *Platella jurassica* Bate.
iv. *Paracypris bajociana* , Bate.
v. *Bairdia hilda,* Jones.
vi. *Monoceratina vulsa* (Jones and Sherborn).
vii. *M. scrobiculata*, Triebel and Barnstein.
viii. *Progonocythere cristata* Bate.
ix. *Pneumatocythere bajociana* Bate.
x. *Acanthocythere (Protoacanthocythere) faveolata* Bate.
xi. *Aulacocythere punctata* Bate.

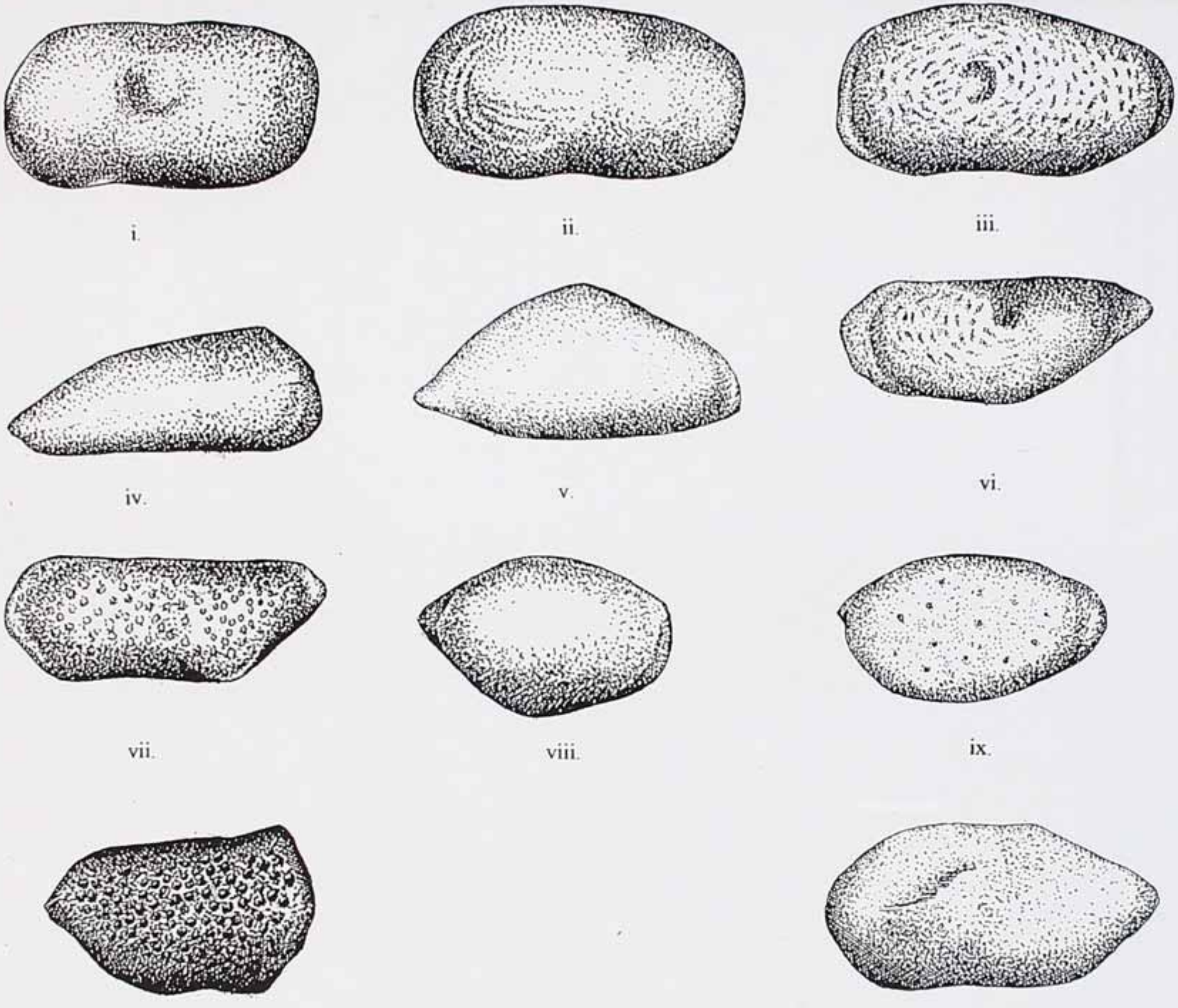
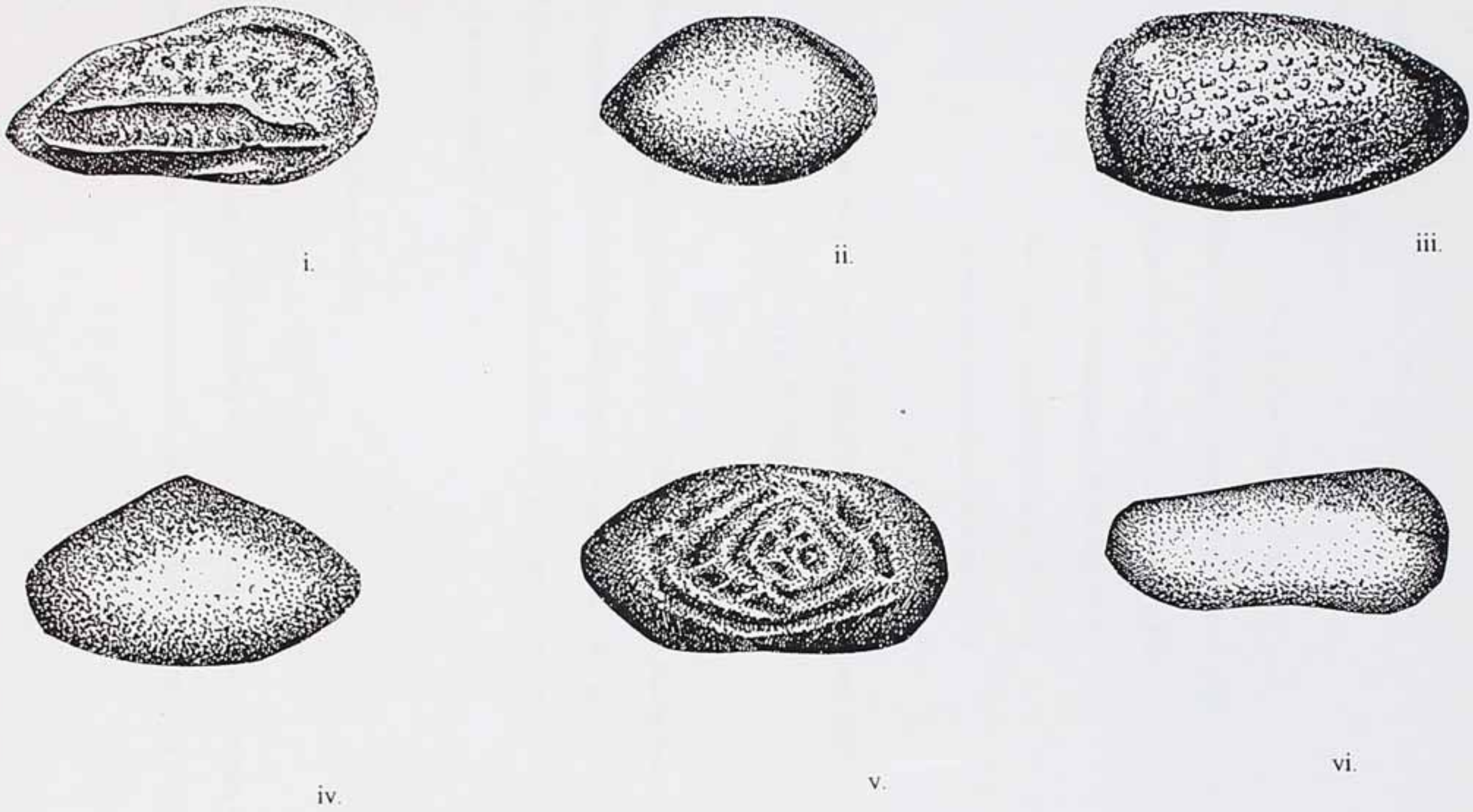


Figure 41

Figure.42
For scale see descriptions in previous section.

i. *Pleurocythere kirtonensis* Bate
ii. *Praeschuleridea subtrigona* (Jones and Sherborn). Bate.
iii. *Kirtonella plicata* Bate.
iv. *Systenocythere exilofasciata* Bate.
v. *Ektyphocythere triangula*, (Brand).
vi. *Cytheremorpha greetwellensis*, Bate.

Figure 42



Appendix 2 c.

Systematics: Foraminifera.

Superorder: Foraminifera.

Suborder: Textulariina Delange and Hérouard, 1896

Superfamily: Ammodisicacea Reuss, 1862

Family: Lituloidae de Blainville, 1825

Subfamily Lituolinae de Blainville, 1825

Genus: *Ammobaculites* Cushman, 1910

Ammobaculites agglutinans (d'Orbigny, 1846) (Figure 43i).

Type JBCHQUSHBF1

Description: An agglutinating foraminifera. The early portion is planispirally coiled the later becoming rectilinear and circular in cross section. The coil is generally composed of four chambers followed by 5-6 similarly sized globular chambers none of which being wider than the coil.

Size: Up to 0.4 millimetres long.

Occurrence: Copestake (1989; Plate 6.3.6. Figure 1) considers this a common Jurassic species that does not become an important part of the fauna until the Late Bathonian.

Suborder: Fusilinina Wedekind, 1837

Superfamily: Endothyracea Brady, 1884

Family: Tetrataxidae Galloway 1933

Genus: *Tetrataxis* Ehrenberg, 1854

Tetrataxis sp. Coleman, 1978. (Figure 43ii).

Type: JBCHQRAGF2

Description: The test of this species is calcareous and granular. The chambers are arranged in a trochoid spiral, 4 to a whorl in the early portion, 3 in those formed later. The sutures are flush.

Size: Up to 0.8 millimetres long.

Occurrence: Copestake (1989) regards the range of this species to be Aalenian to Late Bathonian (Plate 6.3.6. Figure 7).

Superfamily: Miliolacea Ehrenberg, 1839

Family: Nubeculariidae Jones, 1875

Subfamily: Opthalmidiinae Wiesner, 1920

Genus: *Opthalmidium* Kübler and Zwingli, 1870

Opthalmidium cf. *strumosum* (Gümbel, 1862) (Figure 43iii).

Type: JBCHQBB3F3

Description: The test comprises a smooth compressed planispiral that is ovoid in outline. There are 2-5 visible chambers each being ½ whorl long and swollen at the proximal end.

Size: Up to 0.25 millimetres long.

Occurrence: Morris (1982) discovered this species in the Lower Inferior Oolite of the Cotswolds. This species is believed to range from the Aalenian to Callovian by Copestake, (1989; Plates 6.3.6. Figure 13 and 6.4.1. Figures 13-14).

Suborder: Rotaliina Delange and Hérouard, 1896

Superfamily: Nodosariacea Ehrenberg, 1938

Nodosariid? Sp. A (Figure 43iv).

Type: JBCHQRAGF4

Description: This species is too poorly preserved for any reliable identification to be made. The test has an elongated "teardrop" in outline with a very coarsely textured surface.

Family: Nodosariidae Ehrenberg, 1838

Subfamily: Nodosariinae Ehrenberg, 1838

Genus: *Nodosaria* Lamarck, 1812.

Nodosaria sp. A (Figure 43v).

Type: JBCOQIVF5

Description: This species is too poorly preserved for accurate identification. It has linearly stacked chambers (the chambers are not always clearly visible) that gradually reduce in size to give a tapering outline. The surface of the test is finely textured.

Size: Up to 0.7 millimetres long.

Nodosaria fontinensis Terquem, 1870 (Figure 43vi).

Type: JBCHQBB3F6

Description: The test is uniserial and rectilinear, comprising of 6-9 chambers that are broader than high. The final chamber may be inflated. This species is ornamented with 8 broad ribs that run the length of the test these being equally spaced.

Size: Up to 0.7 millimetres long.

Occurrence: Described in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 5 Figure 1).

Size: Up to 0.7 millimetres long.

Genus: *Citharina* d'Orbigny, 1834.

Citharina clathrata (Terquem, 1864) (Figure 43vii).

Type: JBCHQRAGF7

Description: Test large, robust and variable with subtriangular outline. Test ornamented by coarse longitudinal ribs (6-19 in juveniles, more than 20 in adults). Microspheric forms are considered similar to *Vaginulina* (Copestake, 1989).

Size: Up to 1.1 millimetres long

Occurrence:

Nagy *et al.* (1981; Plate 1, Figure 15) recorded this species from the Yons Nab Beds. This species has been recorded from the Aalenian into the Bathonian according to Copestake (1989; Plate 6.3.2. Figure 5 and Plate 6.3.9. Figure 18).

Citharina aff. *flabellata.* (Gümbel, 1862) (Figure 43viii).

Type: JBCHQUSHBF8.

Description: This species is identified with a degree of caution as it occurs as fragments. These fragments are too elongated in relation to their width, have a prominent neck and have ribbing which remains unbroken along the test these characteristics being unlike any of the *Citharina* described by other authors. It is therefore considered that this species most closely resembles *Citharina flabellata* as described by Coleman (1989) although there are similarities to *Citharina aff. inconstans* as figured by Nagy *et al*. (1981).

Size: Fragments to 2 millimetres long.

Occurrence: The species *C. flabellata* is considered (Coleman, 1989) to be Callovian and restricted to the *jason* and *athleta* Zones.

Citharina heteropleura (Terquem, 1868) (Figure 43ix).

Type: JBCHQUSHBF9

Description: Broad fan-like test. Five evolute chambers follow an oval proloculus. The dorsal margin is curved. The chambers are slightly bulbous, these being marked by fine ribbing that crosses the sutures unlike the ornamentation of *Citharina colliezi*. Examples of this species tended to be fragmented and uncommon.

Size: Up to 0.45 millimetres long.

Occurrence: Recorded in the Lower and Middle Lincolnshire Limestone Formation of Kirton in Lindsey by Packer (1986; Plate 4, Fig 8).

Citharina aff. *incostans* (Terquem, 1868) (Figure 43x).

Type: JBBRAUNIVF10

Description: This calcareous benthonic foraminifera has 5-10 chambers and a narrow streamlined test. The length of the test is approximately double its height. Fine ribbing that is continuous along the length of the shell ornaments the test.

Size: Up to 0.45 millimetres long.

Occurrence: This species has been recorded in the Yons Nab Beds by Nagy *et al.* (1981).

Citharina species A. (Figure 43xi).

Type: JBCHQRAGF11

Description: This calcareous benthonic foraminifera is dissimilar to the *Citharina* figured from the Aalenian, Bajocian and Bathonian although it is similar in outline to *Citharina clathrata* (Terquem) (Nagy *et al.* (1981) Plate 1 Figure 15).
The test of this species is short and broad (the length being 1 1/3 times its height) unbroken ribs span the 8 chambers.

Size: Up to 0.7 millimetres long.

Genus: *Dentalina* Risso, 1826.

Dentalina nuda Franke, 1936 (Figure 44i).

Type: JBCHQUSHBF12

Description: Test smooth and slightly arcuate with 7 to 10 chambers. Chamber breadth increases with growth as does chamber height in the later chambers, the final chamber becoming distinctly broader. The sutures are straight and slightly depressed.

Size: Up to 1 millimetre.

Occurrence: Noted in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 4; Figure 6).

Dentalina pseudocommunis Franke, 1936 (Figure 44ii).

Type: JBBRAUNII F13

Description: Test is smooth, long and slender, with 6 to 9 chambers which are higher than they are broad. The sutures are oblique and flush in early chambers becoming increasingly constricted. The early chambers are slightly overlapped by those formed later.

Size: Fragments to 0.4 millimetres long.

Occurrence: This species has been identified in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 4, Figure 2). This species is considered a very common Jurassic species by Copestake (1989; Plate 6.3.7. Figure 5).

Genus: *Frondicularia* Defrance, 1862.

Frondicularia lignaria? Terquem, 1862 (Figure 44iii).

Type: JBBRAUNIIF14

Description: Test flattened with a small rounded proloculus followed by 8 chevron shaped variably sized chambers. The sutures are strongly arched and depressed.

Size: Fragments to 0.3 millimetres long.

Occurrence: Recorded in the Lower Inferior Oolite Of the Cotswolds by Morris (1982) and in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 5 Figure 6,7). This species is also described by Copestake (1989; Plate 6.3.3. Figure 2 and Plate 6.3.8. Figure 5) in the strata of the Aalenian to the Bathonian.

Frondicularia terquemi /nympha (Figure 44iv).

(*Frondicularia terquemi* d'Orbigny, 1849).

(*Frondicularia nympha* Kopik, 1969).

Type: JBCHQM1F15

Description: This species of calcareous benthonic foraminifera has a compressed uniserially arranged test, occasionally seen with raised sutures. It is difficult to identify this foraminifera with more confidence as it is only found as small fragments, which do not satisfactorily fit in to a single documented species.

Size: Fragments to 0.3 millimetres long.

Genus: *Lagena* Walker and Jacob, 1798.

Lagena? sp. (Walker and Jacob, 1798) (Figure 44v).

Type: JBBRAUNIIF16

Description: Test small, single chambered and ovate.

Size: Up to 0.2 millimetres long.

Occurrence: Described in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986) Plate 5 Figure 8.

Genus: *Lenticulina* Lamarck, 1804.

Lenticulina var. A (Figure 44vi).

Type: JBCOQIIF17

Description: This species is typical of the *Lenticulina* in all aspects but suture form. The sutures are marked by a deeply incised crescent shaped groove. This feature makes this species most similar to *Lenticulina varians* (Bournemann) as figured by Nagy *et al.* (1981; Plate 1 Figures 20-21) from the Yons Nab Beds.

Size: Up to 0.45 millimetres long.

Lenticulina var. B (Figure 44vii).

Type :JBCOQIIF18

Description: This species possibly represents either a variation, a more mature form or environmentally produced form of *Lenticulina* var. A. The only difference between the two variants is that this one is far more elongated at the apertural end.

Size: Up to 0.45 millimetres long.

Lenticulina exgalatea Dieni, 1985. (Figure 44viii).

Type: JBCHQM2F19

Description: Chambers slightly involute, biconvex and planispiral. The sutures are deeply depresses with strong ribs along the margin, reaching to the keel.

Size: Up to 0.3 millimetres long.

Occurrence: Known from the Aalenian to the Late Bathonian (being most common in the Lower Fullers Earth Clay and Fullers Earth Rock) according to Copestake (1989; Plate 6.3.8. Figure 8).

Lenticulina muensteri (Roemer, 1834) (Figure 44ix).

Type: JBCHQBB320

Description: Test biumbonate, lenticular with 6-9 planispirally arranged chambers. The sutural ribs are curved and tend to depress in the later stages. Not as distinctly keeled as *L. subalata*. Possesses a distinct umbilical boss.

Size: Up to 0.75 millimetres long

Occurrence: A very common Mesozoic form according to Copestake (1989; Plate 6.3.4. Figures 1-4 and Plate 6.4.2. Figures 11-12). The species has been recorded in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 3 Figure 8).

Lenticulina quenstedti (Gümbel, 1862) (Figure 44x).

Type: JBCHQBB321

Description: The test is a biconvex, involute planispiral with chambers gradually increasing in size. Sharp ribs mark the sutures. These ribs merge with a circular umbilical rib. The keel is well developed.

Size: Up to 0.75 millimetres long.

Occurrence: Noted from the Late Bajocian to the Early Bathonian by Copestake (1989; Plates 6.2.4. Figure 5 and 6.3.8. Figure 12). This species has also been discovered in the Yons Nab Beds by Nagy *et al.* (1981; Plate 1 Figure 22).

Genus: *Planularia* Defrance, 1824.

Planularia beierana (Gümbel, 1862). (Figure 45i).

Type: JBCHQBB3F22

Description: The test is small and transparent with up to 11 chambers, the first 3 or 4 being loosely coiled, the rest are arranged in a gently curved series.

Size: Up to 0.2 millimetres long.

Occurrence: Considered a common Middle Jurassic species, recorded in the Yons Nab Beds by Nagy *et al.* (1981; Plate 1 Figures 23-24) and in the Lower and Middle

Lincolnshire Limestone Formation by Packer (1986; Plate 5 Figure 5). This species is present in the Late Jurassic (often being found in the Oxford Clay) Copestake (1989; Plate 6.3.9. Figure 10).

Genus: *Vaginulina* d'Orbigny, 1826.

Vaginulina sp. (Figure 45ii).

Type: JBCHQM2F23

Description: This species is very similar to *Vaginulina legumen* it is too small however and too straight in outline to be positively identified as such.

Size: Up to 0.2 millimetres long

Vaginulina sp. A . (Figure 45iii).

Type: JBCHQBB3F24

Description: This variety occurs only as single apertural chambers, these are however dissimilar in shape to similar chambers found on the other *Vaginulina* in the samples. In side profile the test has a tapered outline

Size: Up to 0.2 millimetres long

Vaginulina contracta (Terquem, 1868) (Figure 45iv).

Type: JBCOQIIF25

Description: The test of this species is smooth and uniserial with an ovoid cross-section its outline being generally straight. This species is similar to *Vaginulina legumen* however its sutures are more curved, giving the impression that the test is wider.

Size: Up to 0.4 millimetres long.

Occurrence: This species has been noted in the Yons Nab Beds by Nagy *et al.* (1981; Plate 2 Figures 7-8).

Vaginulina jurassica (Gümbel) (Figure 45v).

Type: JBCOQIIF26

Description: This species is smooth and uniserial with chambers which quickly decrease in size with maturity. Furthermore, the most recently formed chambers after the first four become increasingly bent away from the tests previously straight sided outline.

Size: Up to 0.5 millimetres long

Occurrence: This species has been noted in the Lower and Middle Lincolnshire

Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 4 Figure 1).

Vaginulina legumen (Linne, 1758) (Figure 45vi).

Type: JBBRAUNIIF27

Description: The test of this species is smooth, large and uniserial with an oval cross-section, its outline can be straight or curved in outline. The sutures start flush but become increasingly depressed. Individuals of this species are often juvenile and /or fragmentary, therefore some of the identifications may be questionable.

Size: Up to 0.33 millimetres long.

Occurrence: This species has been recorded in the Yons Nab Beds by Nagy *et al.* (1981; Plate 2 Figures 1-2 and 5). This species has also been recorded in the Lower and Middle Lincolnshire Limestone Formation of Kirton in Lindsey by Packer (1986; Plate 3 Figure 11). Copestake (1989; Plate 6.3.9. Figure 20) describes this species from the Middle Jurassic.

Superfamily: Polymorphinacea.

Family: Polymorphinidae.

Genus: *Eoguttulina* Cushman and Ozawa, 1930.

Eoguttulina liassica (Strickland, 1846) (Figure 45vii).

Type: JBBRAUNIIF28

Description: Test small and centrally broad with 4-5 chambers, the test being oval in cross-section. The chambers are arranged spirally each being further from the base than the last.

Size: Up to 0.2 millimetres long.

Occurrence: Described in the Yons Nab Beds by Nagy *et al.* (1981; Plate 2 Figures 10-12) and in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 6 Figure 4). Copestake (1989; Plate 6.2.2. Figure 16) considers this species to range from the Rhaetian to the Kimmeridgian (this species being particularly abundant in the Boreal Lower Jurassic).

Superfamily: Spirillinacea Reuss 1862

Family: Spirillinidae 1862

Subfamily: Spirillininae Reuss 1862

Genus: *Spirillina* Ehrenberg, 1843.

Spirillina infima (Strickland, 1846) (Figure 45viii).

Type: JBBRAUNIF29

Description: The test is planispiral with up to 9 tubular chambers, which generally expand in height. This species differs from *Spirillina numismalis* in that this species is generally larger, the pores are easier to see and there is a greater increase in height

Size: Up to 0.3 millimetres long.

Occurrence: A common Jurassic species, described in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 16 Figure 6). Copestake (1989; Plate 6.3.5. Figure 11) considers this a long ranging Jurassic species.

Spirillina numismalis Terquem and Berthelin, 1875 (Figure 45ix).

Type: JBBRAUNIF30

Description: Test planispiral with 7-9- tubular chambers. Differs from *S. infima* in that the whorls show little increase in height, the sutures are less well defined and the pores are hard to see. *S. numismalis* is generally smaller.

Size: Up to 0.25 millimetres long

Occurrence: Described in the Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey by Packer (1986; Plate 6 Figures 7-8).

Genus: *Conicospirillina* Cushman, 1927.

Conicospirillina trochoides (Berthelin, 1879) (Figure 45x).

Type: JBBRAUNIIF31

Description: Test small, domed spirally wound, with 5 to 6 whorls visible on the dorsal side. The ventral side is slightly involute to flat. The test surface is coarsely perforated.

Size: Up to 0.25 millimetres long

Occurrence: This species is described by Packer (1986; Plate 6, Figure 10) who identifies this species from Lower and Middle Lincolnshire Limestone Formation at Kirton in Lindsey. Copestake (1989: Plate 6.3.2. Figure 7) considers this is a common Lower and Middle Jurassic species.

Superfamily: Robertinacea Reuss, 1850

Family: Ceratobuliminidae Cushmann, 1927

Subfamily: Epistomininae Wedekind, 1937

Genus: *Epistomina* Terquem, 1883

Epistomina sp. (Figure 45xi).

Type: JBCHQUSHBF32

Description: This calcareous benthonic biconvex trochoid foraminifera has 5-7 chambers which are difficult to make out due to their small size and irregular nature.

Size: Up to 0.2 millimetres long.

UnID calcareous benthonic A (Figure 46iv).

Type: JBBRAUNIIF33

Description: This species occurs as up to 7 obliquely stacked smooth chambers with straight sutures. Although increasing in size, the ventral surface nearest the aperture remains flattened. This species may represent a variety of *Dentalina*.

Size: Up to 0.2 millimetres long.

UnID calcareous benthonic B (Figure 46vii).

TypeJBCHQUSHBF34

Description: This species is often small and is identified on internal characteristics (which are visible through a transparent exterior). The test is shield shaped and is approximately twice as tall as it is wide. The test is split by a central suture from which chambers are attached at an angle from both sides of the central line, this giving rise to a chevron like arrangement of sutures split by a central line.

Size: Up to 0.2 millimetres long.

UnID calcareous benthonic C (Figure 46vi).

Type:JBCHQUSHBF35

Description: This species is smoothly textured with a grey colouration. The test is elongated giving the test a "teardrop" shape, no chambers or sutures are visible, the only ornamentation visible being in the form of pits that run intermittently along the length of the test.

Size: Up to 0.18 millimetres long.

UnID calcareous benthonic D (Figure 46viii).

Type: JBBRAUNIIF36

Description: The test of this species is gently curved and is composed of a series of obliquely arranged chambers with curved sutures.

Size: Up to 0.2 millimetres long.

Foraminifera.

For scale see descriptions in previous section.

Figure 43.

i. *Ammobaculites agglutinans* d'Orbigny.
ii. *Tetrataxis* sp. Coleman.
iii. *Opthalmidium strumosum* (Gümbel).
iv. Nodosariid? sp. A?
v. Nodosaria sp. A
vi. *Nodosaria fontinensis* Terquem.
vii. *Citharina clathrata* (Terquem).
viii. Citharina aff. *flabellata* (Gümbel).
ix. *Citharina heteropleura* (Terquem).
x. *Citharina* aff. *incostans* (Terquem).
xi. *Citharina* sp. A.

Figure 43

i

ii

iii

iv

v

vi

vii

viii

ix

x

xi

Figure 44
For scale see descriptions in previous section.

i. *Dentalina nuda* Franke.
ii. *Dentalina pseudocommunis* Franke.
iii. *Frondicularia lignaria* Terquem.
iv. *Frondicularia terquemi / nympha*.
v. *Lagena*? sp. (Walker and Jacob).
vi. *Lenticulina* var. A.
vii. *Lenticulina* var. B.
viii. Lenticulina exgalatea Dieni.
ix. *Lenticulina muensteri* (Roemer).
x. *Lenticulina quenstedti* Gümbel.

Figure 44

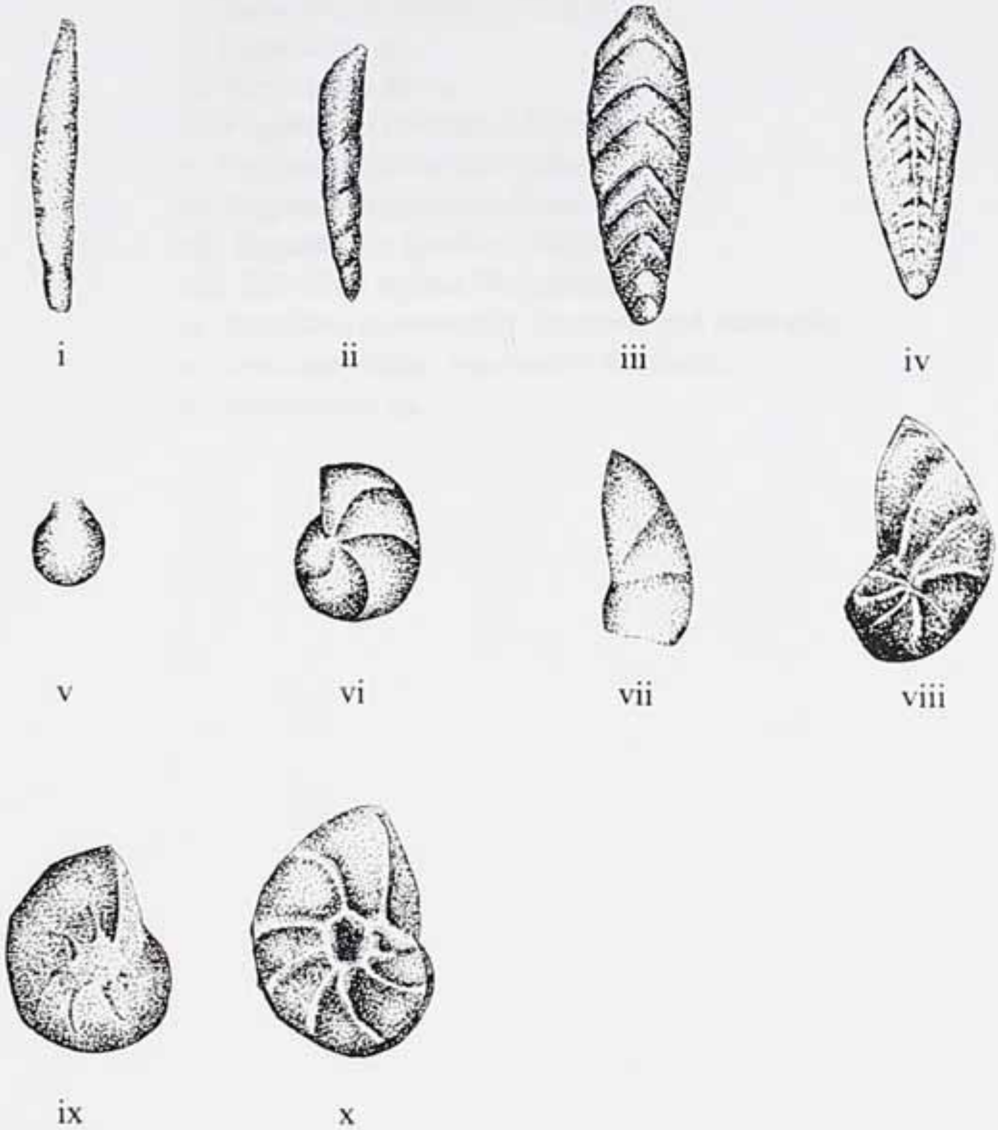
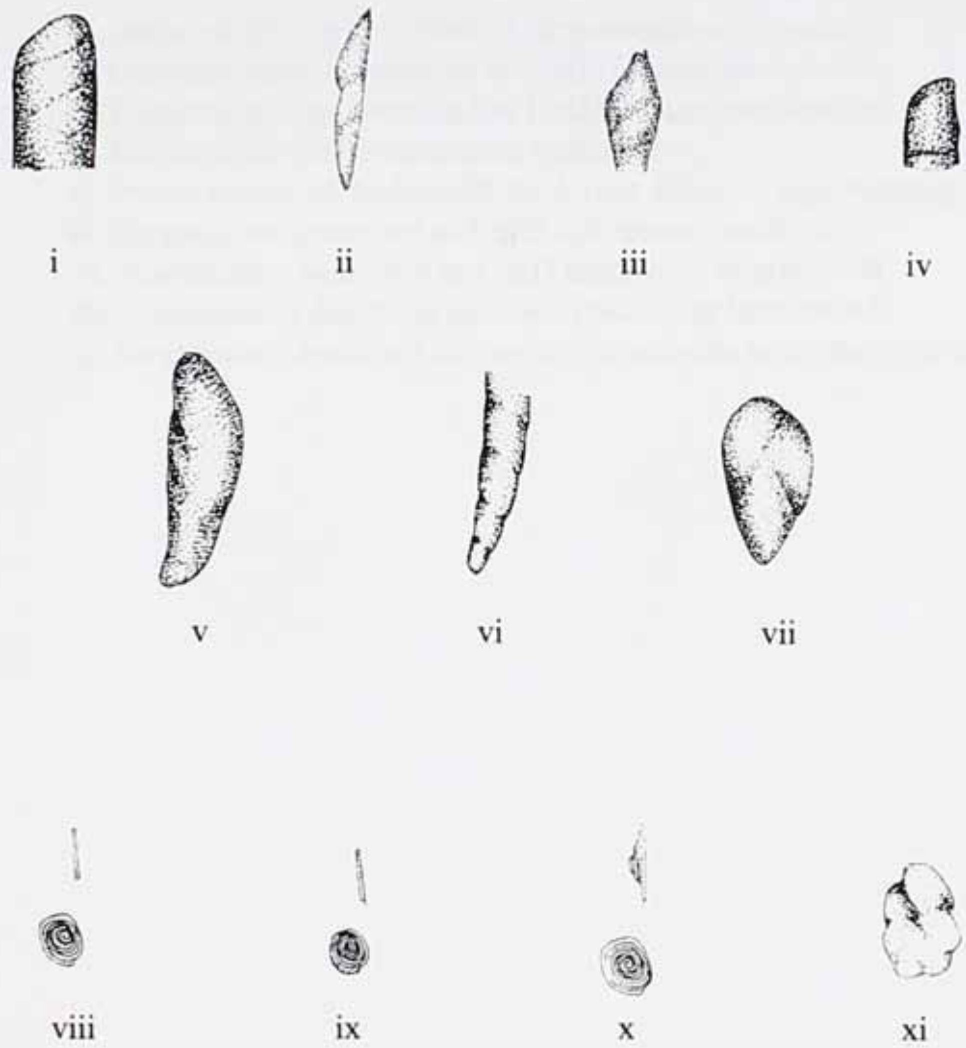


Figure 45
For scale see descriptions in previous section.

i. *Planularia beierana* (Gümbel).
ii. *Vaginulina* sp.
iii. *Vaginulina* sp. A.
iv. *Vaginulina contracta* (Terquem).
v. *Vaginulina jurassica* (Gümbel).
vi. *Vaginulina legumen* (Linne).
vii. *Eoguttulina liassica* (Strickland).
viii. *Spirillina infima* (Strickland).
ix. *Spirillina numismalis* Terquem and Berthelin.
x. *Conicospirillina trochoides* Berthelin.
xi. *Epistomina* sp.

Figure 45

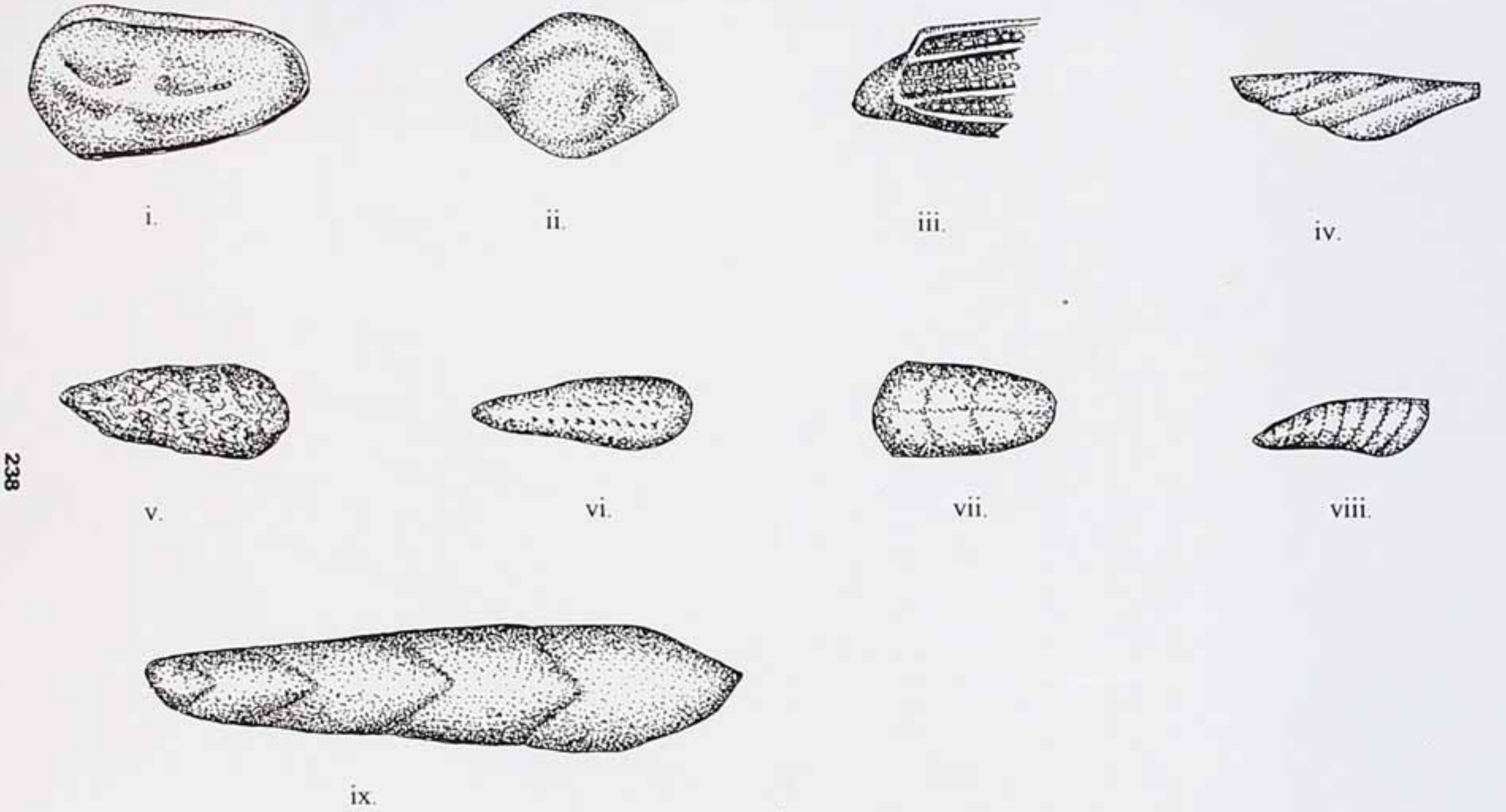


Miscellaneous microfossils

Figure 46
For scale see descriptions in previous section.

i. Ostracod species described as *Terquemula*-like species.
ii. Ostracod species described as UnID Ornamented species.
iii. Ostracod species described as UnID Ornamented species.
iv. Foraminifera UnID calcareous benthonic A
v. Poorly preserved nodosariid sp. A (see 43iv), or agglutinating form.
vi. Foraminifera described as UnID calcareous benthonic C
vii. Foraminifera described as UnID calcareous benthonic B
viii. Foraminifera described as UnID calcareous benthonic D
ix. Foraminifera described as species *Frondicularia terquemi/nympha*.

Figure 46

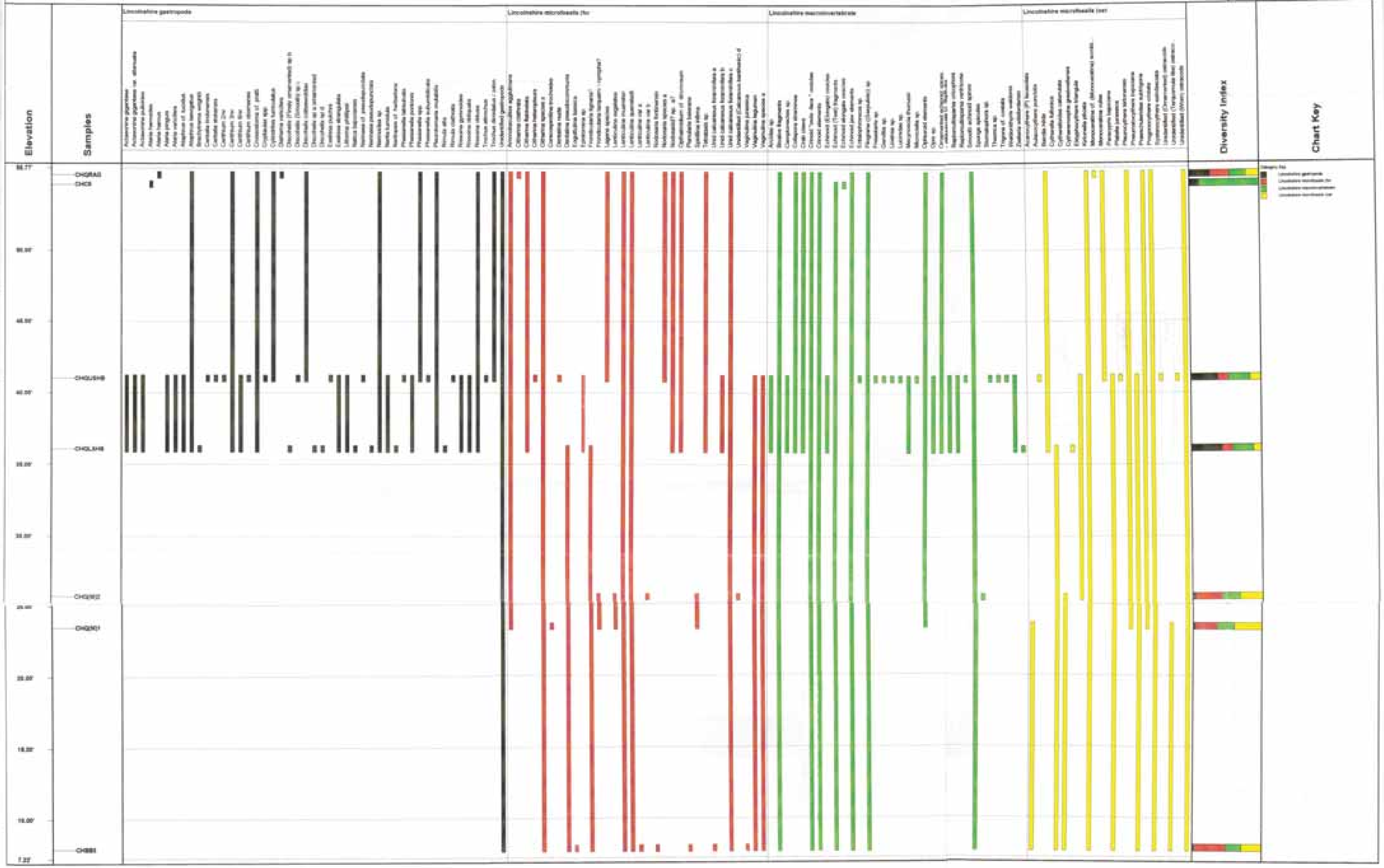


Section : Lincolnshire Limestone

Code : LINCOLNSHIRELIMESTONE
Interval : 58.77 - 7.22
Scale : 1:50
Date : 7-July-2000

Copper Hill Quarry
Style : Stratigraphic Range
Author : John Barker

StrataBugs
Evaluation

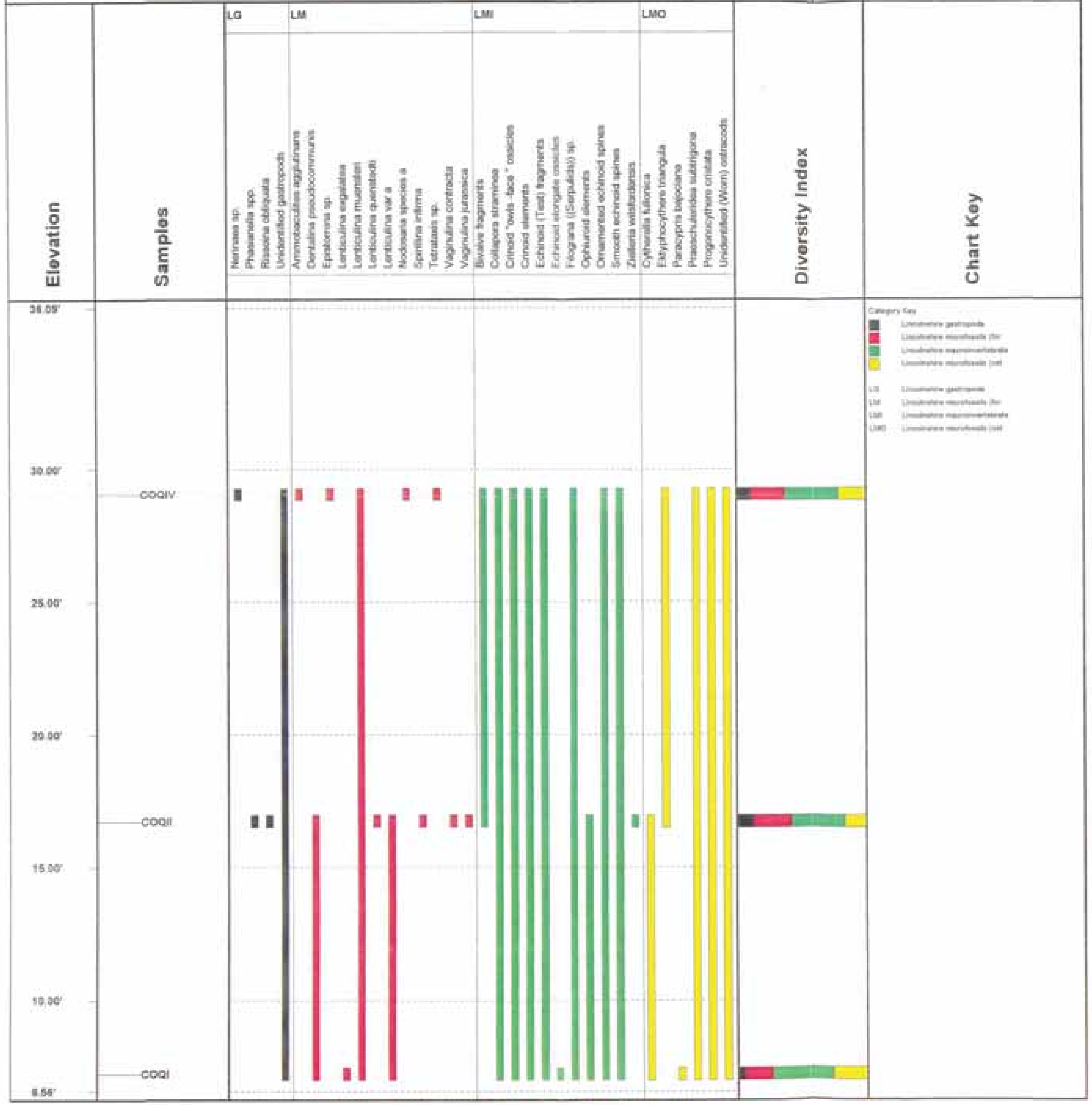


Section : Lincolnshire Limestone

Code : LINCOLNSHIRELIMESTONE
Interval : 36.09' - 6.56'
Scale : 1:50
Date : 7-July-2000
Micropaleontology Distribution Chart

Clipsham Quarry
Style : Stratigraphic Range
Author : John Barker

StrataBugs
Evaluation



Section : Lincolnshire Limestone

Code : LINCOLNSHIRELIMESTONE
Interval : 21.98' - 1.64'
Scale : 1:50
Date : 7-July-2000

Brauncewell Quarry
Style : Stratigraphic Range
Author : John Barker

StrataBugs
Evaluation