AGGLUTINATED BRACKISH WATER FORAMINIFERA AND ARCELLACEANS FROM THE UPPER CARBONIFEROUS, COAL-BEARING STRATA OF THE SYDNEY BASIN, NOVA SCOTIA: TAXONOMIC DESCRIPTIONS, ASSEMBLAGES, AND ENVIRONMENTS OF DEPOSITION.

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The undersigned herby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled: "AGGLUTINATED BRACKISH WATER FORAMINIFERA AND ARCELLACEANS FROM THE UPPER CARBONIFEROUS, COAL-BEARING STRATA OF THE SYDNEY BASIN, NOVA SCOTIA: TAXONOMIC DESCRIPTIONS, ASSEMBLAGES, AND ENVIRONMENTS OF DEPOSITION" by Shelley Ann Thibaudeau in partial fulfilment of the requirements for the degree of Master of Science.

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In dedication to my family and friends....

'By telling you anything at all, I'm at least believing in you,

I believe you're there, I believe you into existence.

I tell, therefore you are.'

from *The Handmaid's Tale* (1985), Margaret Atwood

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Abstract

Representative taxa from 10 genera of agglutinated foraminifera, and 3 genera of arcellacea are described from the Upper Pennsylvanian (Westphalian D), coal-bearing strata of the Sydney Mines Formation, Cape Breton Island, Nova Scotia. Detailed taxonomic study resulted in the identification of the following foraminiferal genera: *Ammobaculites*, *Ammomarginulina*, *Ammotium* (2 forms), ?*Buccicrenata* (2 forms), *Haplophragmoides*, *Miliammina*, *Sorosphaera*, ?*Textularia*, *Trochammina* (4 forms), and *Trochamminita*. The following genera represent the arcellacea: *Difflugia* (3 forms), *Heleopora*, and ?*Paranebela*. Specimens of the polychaete worm genus *Spirorbis*, a branchiopod crustacean ?*Limnestheria sp.*, and a ?nepionic nautiloidean cephalopod are also described.

Agglutinated foraminifera are present in 8, of the 9 separate lithologic units, and this presence provides positive evidence for marine influence in the environments of deposition. Carboniferous microfossil assemblages are compiled, and compared to foraminiferal-arcellacean assemblages that characterise Recent fresh water through transitional-marine and saline environments. A salinity range, and an environment of deposition are interpreted, for each unit, based mainly on the generic diversity of the protistan assemblage. The marine-influenced environments of deposition include: nearshore to abandoned delta lobe, inter-distributary bay through levee-crevasse splay, lower estuarine to transitional marine, and low to middle marsh. One fresh water, lacustrine or upper estuarine-riverine setting is identified.

The diversity of the representative agglutinated taxa of brackish water foraminiferal-arcellacean assemblages remains stable after more than 300 million years. The co-occurrent finds of agglutinated brackish water foraminifera and other fossil biota infer a tolerance to salinity fluctuations by the other organisms. An euryhaline-marine, rather than fresh water, habitat for these biota is also indicated by this relationship. Protistan assemblages are used to positively differentiate fresh water from marine-influenced coastal deposits, and to delimit cyclic sedimentary sequences that are due to sea-level fluctuations.

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Chapter 1. Introduction

1.1 General Introduction

After more than three centuries of coal extraction, and more than one century of commercial mining, the energy demands of industry continue to be met with coal from the Sydney Mines Formation strata (Gregory, Richardson and Bisson, 1978; Calder, 1985). The projected resource demands for energy generation and industrial purposes, compounded with environmental issues and human health concerns, necessitate a requirement for precise palaeoecological and palaeoenvironmental reconstructions of the formative environments of coal-bearing strata. Previous mapping, stratigraphic and palaeontologic studies on the Sydney Mines Formation strata concentrate on estimating the resource quality and quantity for economic purposes (Hacquebard and Donaldson, 1969; Hacquebard, 1972, 1979). Several different interpretations for the environment of deposition of the Sydney Mines Formation are contained within these reports.

Environmental issues such as global warming (the greenhouse effect) and acid rain, are temporal and spatial effects attributed directly to industrial emissions into the atmosphere. Total industrial emission volumes are nearly equivalent to natural emissions. However, industries, that are situated in the northern hemisphere, release as much as 95% of the man-made emissions directly into the atmosphere (Watson *et al.* 1990; Howells, 1991).

Atmospheric releases of up to 5 x 10^9 tons/year (Gt/yr) of greenhouse gasses, including; water vapour, hydrocarbons [primarily methane (CH_4)], oxides of sulphur, and carbon dioxide [CO_2; 5.5 x 10^6 tons /year (Mt/yr)], result directly from mining and burning fossil fuels (WMO, 1987; IPIECA, 1991). Electricity generation, by combustion, is identified as the largest industrial source of CO_2 emissions (IPIECA, 1991). Coal-mine ventilation, and degassing of coal during transport release in excess of 34 Mt/yr of CH_4 directly into the atmosphere from (Watson *et al.*, 1990). Approximately 50% of industrial emissions accumulate in the atmosphere annually. The projected cumulative effect of the build-up of CO_2 in the atmosphere includes a rise in eustatic sea-level which will be sufficient to drown many of the densely populated lowlands in the world.

The generation of thermal electric power is the primary industrial use for coal (IPIECA, 1991). Some of the by-products from the combustion of sulphur enriched coals are sulphur oxide compounds. In turn, these compounds combine with atmospheric water vapour, the most common greenhouse gas, and form a dilute solution of sulphuric acid (H_2SO_4) which precipitates to the earth as 'acid rain' (SMA, 1984). Alterations in trophic communities, and substantive declines in fish populations are documented from many acidified fresh-water lakes, especially in regions where the bedrock has no natural buffering capacity (Shilts and Kettles, 1989; Curren, 1991). Also reported is an increase in the concentrations of toxic heavy metals from acidified bodies of water. This effect is attributed to acid leaching. The impact of the accumulation of toxic heavy metals in the food chain, and ultimately on human health, has yet to be determined (SMA, 1984).

Many coals and peats with medium to high total sulphur contents formed in a marine-influenced environment (McCabe, 1984; Shimoyama, 1984; Teichmüller, 1989; Price and Casagrande, 1991). Elemental sulphur, organic sulphur, and pyrite are the more common sulphur compounds present in marine influenced (paralic) coals and peats. The total sulphur content within marine influenced coals and peats varies considerably, both vertically and laterally. The total sulphur content tends to increase in the direction of marine influence (Williams and Keith, 1963; Hacquebard and Donaldson, 1969; Horne *et al*, 1978; Hunt and Hobday, 1984; McCabe, 1984; Shimoyama, 1984; Casagrande, 1987; Teichmüller, 1989; Price and Casagrande, 1991).

The coals from the Westphalian C to Stephanian-aged (?Cantabrian; Zodrow, 1985; Zodrow and Cleal, 1985) strata of the Sydney Mines Formation, Upper Morien Group (Pictou equivalent) of the Sydney Basin coalfield, Nova Scotia, are enriched with sulphur compounds (Hacquebard and Donaldson, 1969; Zodrow, 1987; Gibling *et al*, 1986; Gibling *et al*, 1989).

The average total sulphur content of these coals fall within the 2 to 6.5% range (Hacquebard and Donaldson, 1969; Rust *et al.* 1987; Hacquebard, 1993). Local sulphur contents reach accumulations of 12.9% (Zodrow, 1987). Finely disseminated syngenetic pyrite is common within these coals. In-seam sulphur distributions are vertically and laterally variable, and in general the concentration of these compounds decreases toward the middle of the seam (Hacquebard and Donaldson, 1969; Zodrow, 1987). Sulphur isotope ($_{\delta}{}^{32}$S:$_{\delta}{}^{34}$S) studies support both a syngenetic marine source for the sulphur compounds in the coals and an epigenetic sulphur enrichment for cleat and interbed pyritic accumulations (Gibling *et al.*, 1986; Gibling *et al.*, 1989). Reports of brackish-water foraminifera from selected horizons of the Sydney Mines Formation indicate marine influence, as well as provide a simple explanation for the presence of sulphur compounds in the coals (Thibaudeau and Medioli, 1986; Thibaudeau 1987; Thibaudeau, Medioli and Scott, 1987, 1988; Wightman *et al.*, 1992, 1993).

Foraminifera are invaluable tools for stratigraphic correlation and palaeoecological interpretation because these protists are excellent palaeoenvironmental indicators. Geologic references support the usefulness of foraminifera for these purposes. Assemblages of Carboniferous brackish-water foraminifera and arcellaceans are useful for interpreting palaeoenvironments of deposition. Thus, facilitating more accurate assessments of the reserve quantity, quality, and areal extent of the resource in the Sydney Basin, and other coalfields.

1.2 Aim and scope of this study.

The purposes of this study are:

1) to present detailed taxonomic descriptions for the genera of agglutinated brackish-water foraminifera and arcellaceans extracted from restricted horizons in the study area;
2) to construct biotic assemblages that consist of the protists, as well as the other fauna present in these units; and
3) to use the biotic assemblages and sedimentary structures to interpret

environments of deposition for the units in this study.

1.3 Kingdom Protista

1.3.1 General introduction to the protists

Protists are an extremely diverse group of eukaryotic organisms that have only one feature in common; they are all unicellular. Many of the approximately 50,000 species in this heterogeneous and largely microscopic group are free-living, solitary forms that have cosmopolitan distributions. In general, protists live in any environment where moisture is present (Barnes, 1980; Lipps, 1987). Two orders of protists, the arcellaceans and the foraminifera, are central to this study. The following sections provide pertinent information about the general biology, ecology and the distributions of each group, as well as address some of the common systemic problems associated with these groups.

1.3.2 Order Arcellinda

The Arcellinida (Namurian, Pennsylvanian (this study), Cretaceous to Recent) are amoeboid rhizopods that construct an unilocular test (shell) with a single aperture. The compound test wall is composed of a resistant autogenous matrix (cement) and agglutinated idio- or xeno-somes (Loeblich and Tappan, 1964; Ogden and Hedley, 1980; Medioli and Scott, 1983; Ogden and Ellison, 1988). Recent arcellaceans are predominantly fresh water inhabitants and the tests from these amoebas are found mainly in lacustrine and paludal environments. Many of the genera and species have cosmopolitan distributions (Haman, 1983; Schafer and Cole, 1988; Medioli, Scott, Collins and McCarthy, 1990; Lewis and Thibaudeau, 1992). Low numbers of these tests are also reported from marine-influenced, coastal environments (Loeblich and Tappan, 1964; Hiltermann and Haman, 1985; Scott, Suter and Kosters, 1991; F. Cole, pers. comm., 1992). The testate remains of arcellinids are valuable for interpreting fresh water influence in the environment of deposition for Cenozoic and Upper Mesozoic aged strata (Loeblich and Tappan, 1964; Medioli and Scott, 1983; Scott, and Medioli, 1983; Patterson, 1987; Fuchs and Schreiber, 1988; Medioli and Scott, 1988; Collins, McCarthy, Medioli, Scott and Honig, 1990; Medioli, Scott, Collins and Wall, 1990). However, the documented occurrences of fossil arcellaceans in lower Mesozoic and Palaeozoic aged deposits are rare (Vasicek and Ruzicka, 1957; Thibaudeau and Medioli, 1986; Thibaudeau, 1987; Thibaudeau, Medioli and Scott, 1987, 1988). This deficiency in reporting may introduce limitations for current use of these fossils as palaeoenvironmental indicators (Medioli, Scott, Collins and McCarthy, 1990).

1.3.3 Order Foraminiferida

Foraminifera (Early Cambrian to Recent) are exclusively marine members of the Phylum Protista. These single celled organisms produce a multichambered test of variable form and composition. To date, there are descriptions for nearly 4,000 genera of foraminifera that exist in all marine-influenced environments and in many continental saline environments (Loeblich and Tappan, 1964, 1988; Culver, 1987). The recent and fossil tests of foraminifera are important tools for stratigraphic zonation, as well as for palaeoclimatological and palaeoecological studies.

The generic lineages for some agglutinated taxa extend well back into the Paleozoic (Lipps, 1987; Tappan and Loeblich, 1988; Loeblich and Tappan, 1964; 1988). Many of these genera are frequently and improperly referred to as the more 'primitive' forms. Several reports describe and identify agglutinated foraminifera from acid insoluble residues (Brady, 1876; Conkin and Conkin, 1968, Conkin and Ciesileski, 1973; Conkin, Conkin and Thurmin, 1979; Conkin, Conkin and Canis, 1968 Cushman and Waters, 1928; Harlton, 1927; Ireland, 1939, 1956, 1960, 1966; Waters, 1927a, 1927b). The basis for the Palaeozoic stratigraphic succession is fusulinid foraminifera, conodonts and an assortment of invertebrate taxa. Complementary stratigraphic sequences exist for Palaeozoic strata and the foundation of these successions is lineages of agglutinated foraminifera. Much of this information and the work is ignored (Conkin and Conkin, 1964, 1970, 1977, 1979; Cummings, 1955, 1956; Loeblich and Tappan, 1964, 1988; Tappan and Loeblich, 1988).

Foraminifera are grouped, perhaps artificially, by visible differences in the structure of the test wall. Like most foraminifera, the agglutinates produce a single or multichambered test but unlike their predominantly calcareous relatives, they construct a compound test wall. The components of an agglutinated test wall include an autogenous cement member which is calcareous, ferruginous or siliceous in content, and an agglutinate member of variable density and ornamentation by xenosomes. Again, relatively little is known about the biology of the agglutinated foraminifera. More discussion about this fact is provided in an upcoming section.

Agglutinated foraminifera that inhabit recent coastal, marine influenced and brackish water environments are central to this study. Inconspicuous populations of specific groups of agglutinated foraminifera thrive in high stress marginal marine environments. Extremes in environmental parameters, such as; salinity fluctuations, temperature variations, reduced calcium carbonate availability due to lower pH and higher organic matter, restricted nutrient availability, and low oxygen contents, normally restrict both the diversity and distribution of most organisms (Buzas, 1969; Phleger, 1970; Gibson and Buzas, 1973; Murray, 1973; Boltovskoy and Wright, 1976; Steineck and Bergstein, 1979; Boltovskoy, Scott and Medioli, 1991). The density of agglutinated foraminifera in more stable marine environments is subdued. This may be due to competitive suppression by the more conspicuously abundant benthic and planktic calcareous tests.

1.3.4 The species concept versus protists and the fossil record

By definition a species is; ‘groups of interbreeding natural populations reproductively isolated from other such groups’ (Mayr, 1963). Therefore, objective observation is the basis for species level identification of living organisms. In general, the application of the ‘species’ concept, as defined, becomes complicated for groups of living organisms, such as protists, where sexual reproduction is neither the norm nor the only reproductive strategy identified in their life cycles. An attempt at applying the ‘species’ concept shall be for the documented reproductive strategies of the Arcellaceans and Foraminifera.

The results of little scientific research provide next to no knowledge about the reproductive biology of arcellaceans. Consequently arcellinida are a relatively unknown group of organisms. Reports containing qualitative observations from both culture-cloned and natural protistan populations identify considerable morphological variation in test form (Wallich, 1864; Hedley, Ogden and Krafft, 1974; Medioli and Scott, 1983; Medioli, Scott and Abbott, 1987; Culver, 1987; Ogden and Ellison, 1988). Arcellinids reproduce by equal binary fission and they basically have a 'simple' life cycle. Since sexual reproduction is unknown for these organisms the practice of identifying 'type' variation using 'species' specific characteristics, as per the definition is in essence a *moot* point for arcellaceans.

In contrast, foraminiferids are one of the most frequently documented groups of biologic organisms. Although sexual reproduction is generally considered to be pervasive in these organisms conspicuously few documented studies address the biology of these organisms. In fact, studies verifying sexual reproduction in the foraminifera exist for fewer than 0.1% of the nearly 10,000 described living species. Also documented is an asexual reproductive phase that usually occurs in alternation with the sexual reproductive generation for selected foraminifera (Loeblich and Tappan, 1964; Culver, 1987). The species concept, as defined, may or may not apply to foraminifera.

A repetitious expression of identifiably inherent morphological characteristics is a requisite for both the designation of 'species' specific variability and the extension of a species-level lineage over time. Few biotic representatives survived the mass extinction which characterises the close of the Palaeozoic era. More than two-thirds of the genera of Palaeozoic foraminifera became extinct by the close of the Permian. A second major extinction event commenced in the latest Cretaceous and continued through to the end of the Mesozoic. The estimated losses approach nearly 50% of the total foraminiferal diversity at that time (Tappan and Loeblich, 1988). Therefore, practical value of applying actualistic, 'species' specific, biotic information to organisms having indirect lineages is at best questionable (Gibson and Buzas, 1973; Scott, *et al.* 1983; Wall, 1983a; Meyen, 1987; Traverse, 1988; Medioli, Scott, Collins and Wall, 1990). Notably, the objective base associated with the living species concept is lost in studies on fossil organisms. In practise, proving 'sameness' in the genetic sense (objectivity) is impossible due to the preservation bias of the fossil record. Thus the 'species' concept, when applied as defined, is basically invalid for both the living and fossil representatives of these 2 protistan orders.

1.3.5 Fossil protists and the assemblage concept

The fossilised hard parts of protistan micro-organisms are the fundamental tools for stratigraphic correlation and palaeoenvironmental reconstructions (Lipps, 1987; Ross and Ross, 1987, 1988; Haq, Hardenbol and Vail, 1988). Thus, relative change in geologic time and in palaeoenvironment is, for the most part, interpreted from qualitative and quantitative observations of 'species' specific variation in the fossil tests. Indirect, supraspecific evolutionary lineages (clades) are proposed for many groups of organisms because few direct evolutionary lineages survived from the Palaeozoic to the Recent (Loeblich and Tappan, 1964; Loeblich and Tappan, 1988; Tappan and Loeblich, 1988; Ross and Haman, 1989).

Scott *et al.* (1983) constructed a model for use in palaeobathymetric studies. The model uses genera and species of recent agglutinated foraminifera that characterise five (5) relatively inclusive, modern marine, depth discernible niches. The five (5) modern niches are subdivided into 15 depth related zones. Comparative analysis at the species level with species from fossil assemblages of various ages (Cretaceous through Palaeogene) suggested little or no relationship. Using genus-level as the base for comparison and reapplying the model indicated little variation in the generic composition of assemblages of agglutinated foraminifera over time.

Agglutinated brackish water foraminifera are studied in many coastal, marine influenced environments around the world. The geographic distribution of the dominant genera and species that inhabit brackish water environments is cosmopolitan. Much of the preliminary work in these environments was done by Phleger and others, and this work is summarised in Daiber (1982). Numerous comprehensive studies positively identify a vertical zonation of assemblages of agglutinated foraminifera that correlate directly with salinity, elevation above mean sea level, and more generally with macrophyte assemblages (Cushman and Brönnimann, 1948a, 1948b; Phleger and Bradshaw, 1966; Scott and Medioli, 1978, 1980; Scott, and Martini, 1982; Petrucci *et al.* 1983; Hiltermann and Haman, 1985; Brönnimann and Keij, 1986; Ellison and Murray, 1987; Scott, Suter, and Kosters, 1991). Also identified is a latitudinal distribution gradient for assemblages of brackish water foraminifera which is influenced by temperature. This distribution gradient is mirrored north and south of the equator (Scott *et al.*, 1990).

Assemblages of brackish water agglutinated foraminifera are reported from Cretaceous and Jurassic deposits. The generic lineages for many of the agglutinated foraminiferal taxa, identified in this study are continuous from the Lower Cretaceous through the Recent (Wall and Singh, 1975; Wall, 1977, 1983 a, b; McLean, and Wall, 1981; Mattison and Wall, 1993). Fossil tests of arcellaceans and foraminifera occur in restricted units of the Upper Morien Group strata in the Sydney Basin (Thibaudeau and Medioli, 1986; Thibaudeau, 1987; Thibaudeau, Medioli and Scott, 1987, 1988; Wightman, *et al.*, 1992, 1993). Preliminary reports of assemblages are also documented from the same Carboniferous aged strata (Thibaudeau, Medioli and Scott, 1987; Wightman *et al.*, 1992, 1993). The longer ranging taxa are valuable indicators for palaeoenvironmental studies. Thus, the marginal marine to upper marsh portion of this salinity and depth model shall be expanded to include agglutinated taxa known to characterise estuarine-marine through fresh water environments. Salinity zones and broad water depths shall be interpreted for the Carboniferous assemblages using this expanded model. In turn, this information is combined with sedimentological data and environments of deposition for the Carboniferous lithologic units are interpreted.

1.4 Geologic Background

1.4.1 General background

Uniformitarianism (actualism), seismic and cyclic stratigraphy, sedimentology (facies models), tectonic history, Darwinian evolutionary concepts, and sea-level change models have been used in numerous attempts to reconstruct the palaeoecological and palaeoenvironmental, conditions for coal-forming environments of the Sydney Basin. Interpreting the environment of deposition for the Upper Morien strata remains problematic, despite the application of these guides.

The rigid application of actualism resulted in the delimitation of paralic (marine influenced) and non-marine (fresh water) coal-forming environments with a thin, impermeable line. Negative evidence, in the form of the absence of conspicuous fossiliferous marine beds, was the criterion used to discern non-marine from paralic coal-forming environments (White, 1925), thus establishing a conceptual and largely indirect association between organic accumulations and freshwater environments.

This inherently negative association evolved into a precept that reads more or less as follows; organic material cannot accumulate in marine influenced environments, and therefore all organic accumulations are from fresh water environments. In turn, this concept continues to be manifested in current geologically and biologically oriented investigations in coastal wetland environments. For example, numerous intensive investigations, undertaken in the search for a modern analogue to coal forming environments, automatically presume that the organic accumulations (peaty material) are freshwater deposits. No analyses of sample material are performed to determine whether positive environmental indicators, namely foraminifera and arcellaceans, are present (Cohen and Spackman, 1972; Kosters and Bailey, 1983; McCabe, 1984; Tye and Kosters, 1986; Cameron, Esterle, and Palmer, 1989; Moore, 1989; Cohen, *et al.*, 1989; Price and Casagrande, 1991).

In general, the 'marine or non-marine' concept may be applicable for abiotic structures and features. However, it is fundamentally flawed for biotic applications and especially for those organisms that live in transitional marine to freshwater environments. The most important deduction that can be made from the presence of any organism found living in a brackish-water environment is that the physiological adaptations necessary for osmoregulation, and ultimately reproduction, have evolved (Beerbower, 1985). Further to this, most organisms have retained an inherent (genetic) ability to tolerate fluctuations in salinity (Thorpe and Covich, 1991). The duration, frequency and intensity of the fluctuations, as well as the ability to compete successfully for nutrition are probably the determinant factors for survival (Price, 1980; Thorpe and Covich, 1991).

The fact that organisms are loosely termed as either marine or freshwater (emergent terrestrial and continental flora included), has also aided in the propagation of this precept. Historically, the term 'nonmarine' (literally translated means 'marine influence absent') has been used inappropriately to dismiss the potential for marine influence that is suggested by the presence of biotic indicators extracted from Carboniferous coal-bearing strata. The references for this are numerous, and shall not be listed.

Coastal environments are extremely complex and contain variable abiotic and biotic components from marine, marginal marine and continental systems. Sediment accumulations provide a record of static and non-static physical parameters. Many of these features are non-genetic and should not be used, in exclusion, to interpret the genetic environment of deposition (Terwindt, 1988). In contrast, the pervasiveness of marine influence or the source of the salt, and some physical parameters (temperature, water depth) are directly reflected by the biotic communities and assemblages that inhabit these environments. No physical / chemical analysis or combination of these analyses can provide, with accuracy, the precise information gained from the physical presence of indicator microfossil assemblages in deposits that are considered to be *in situ*. Moreover, the combined results of multidisciplinary geologic and micropalaeontologic studies in recent coastal environments are proving that the non-marine precept is erroneous (Nichols, Johnson and Peebles, 1991; Boyd and Honig, 1992). Marine influence extending 50 to 100 km inland has been documented from several modern coastal environments. The pervasiveness of the marine influence, and consequently the source of the salt, has been verified by the presence of agglutinated foraminifera (Haman, 1983; Woodroff, Thom and Chappell, 1985; Scott, Suter and Kosters, 1991; Dalrymple *et al.*, 1992).

1.4.2 Definition of fresh water, brackish water and marine

Conspicuously absent from many recent studies is a definition of what is actually meant by the term fresh water. The average global salinity content (water hardness) for fresh water rivers and lake environments is less than 1.5‰ (Wetzel, 1983). For the purposes of this study the term fresh water shall mean waters where the average salinity does not exceed 2.0‰, and where the source of the salinity cannot be traced to concurrent marine influence.

Similarly, brackish water shall mean waters with a fluctuating salinity content which falls within the 0 to 35‰ range, and where the source of the salinity can be determined as from concurrent marine influence. The Normal marine waters have an average salinity of 35‰.

1.5 Geologic Setting.

1.5.1 Tectonic activity and palaeogeography.

The Palaeozoic sedimentary strata of Eastern Canada unconformably overlie deformed, crystalline basement and metamorphic rocks of Late Proterozoic-Palaeozoic age (Howie and Barss, 1975; Bradley, 1982; Dunning *et al.*, 1990; Keppie *et al.*, 1990). Lower Palaeozoic (Ordovician - Devonian) palaeogeographic reconstructions suggest that Laurentia maintained an equatorial to low southern palaeolatitude position, while Gondwana drifted long distances, at times rapidly, in a north-south direction (Van der Voo, 1988). During the Late Ordovician to Middle Devonian there were two collision events between the pan-African Armorica (Avalon and Meguma Terranes), and North American Laurentia (Humber Terrane) (Van der Voo, 1988; Van der Voo *et al.*, 1991). Extensive regional metamorphism, igneous plutonism, and volcanic activity resulted from the Taconic and Acadian Orogenies. After-effects of this activity continued into the Carboniferous (Dunning *et al.*, 1990; Keppie *et al.*, 1990; Van der Voo, *et al.*, 1991).

The North American craton (Laurentia) remained at a relatively stable palaeolatitude throughout the Palaeozoic. During the Middle to Late Carboniferous the Atlantic Region of Canada occupied an equatorial to low southern latitude (Frakes, 1979; Habicht, 1979; Veevers and Powell, 1987). Until recently the palaeogeographic reconstructions for the Middle to Upper Carboniferous proposed that the continental margins of Laurentia and Gondwana overlapped. However, more recent paleogeographic reconstructions suggest the presence of a narrow, equatorially situated, oceanic body of water between Gondwana and Laurentia (Ross and Ross, 1987; 1988). For the purposes of this study the approximate palaeolatitude grids, the glacial ice sheets and the coal deposits for the Carboniferous are compiled on a recent world map (Figure 1).

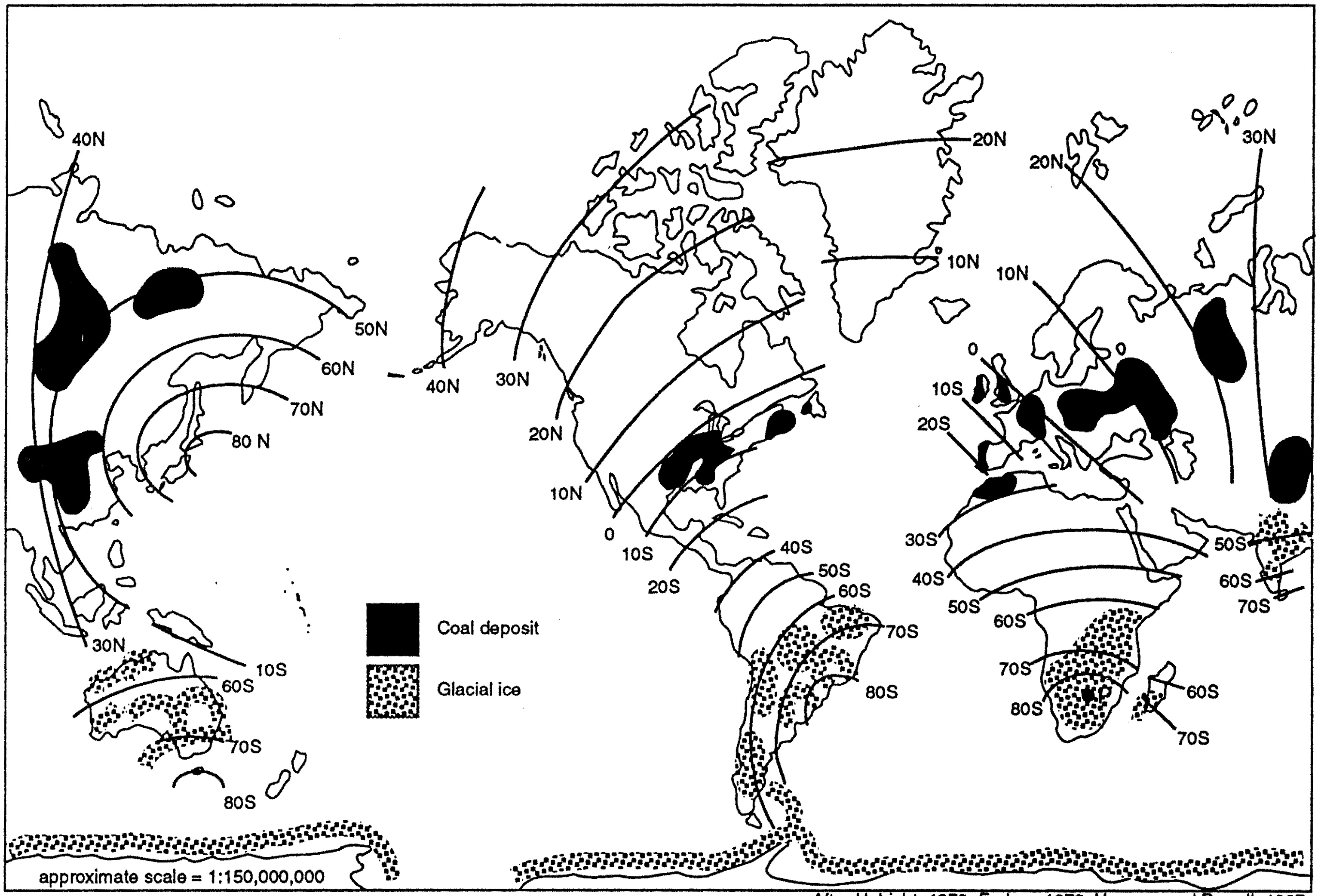
1.5.2 Palaeoclimatology, Eustasy and Palaeoecology

Three separate episodes of glaciation occurred on the Gondwanan continent during the late Palaeozoic. The third and most extensive episode of glaciation commenced in the Namurian and continued through to the close of the Permian. The Westphalian to Stephanian was the period of maximum ice volume (Figure 2) (Veevers and Powell, 1987). The estimated areal extent of glacial ice coverage during the Pennsylvanian is illustrated in Figure 1.

Limited palaeoclimatic information can be extracted from fossil plant communities. The absence of growth rings in the plant fossils suggests an equable climate. An equable, warm climate is also indicated by an equatorial to subtropical palaeolatitude. A general curve for availability of moisture (Figure 2) during the Pennsylvanian is proposed from combined coal resource abundance and vegetation data. Five climatic intervals are apparent for the Pennsylvanian (Phillips and DiMichele, 1981; DiMichele *et al.*, 1985). Sediments were deposited in the study area during the interval of maximum regional transgression (the second wet interval).

Detailed curves for eustatic sea level fluctuations that identify as many as 60 rise/fall couplets during the Carboniferous were compiled from combined micropalaeontological and

Figure 1. A composite map to show the relative palaeolatitudes of the Carboniferous coal-bearing basins of the world, as well as to illustrate the extent of glacial ice coverage during the Late Carboniferous (after Frakes, 1979; Habicht, 1979; Veevers and Powell, 1987).



After Habicht, 1979; Frakes, 1979; Veevers and Powell, 1987.

Figure 1

biogeographic data by Ross and Ross (1987, 1988). A generalized high- and low-stand curve (2nd order) for the Pennsylvanian is illustrated in Figure 2. No magnitude values other than +/- have been assigned to the curves for the purposes of this study. Estimated magnitudes of sea level change during this time range from 200 m to 100 m and between 40 and 160 m (Ross and Ross, 1987; 1988; Heckel, 1986; Klein and Willard, 1989, respectively). The curves indicate an increase in the magnitude of sea level change during the Westphalian and Stephanian. As much as 70% of the sea level change, during this time, is attributed to glacial eustasy (Klein and Willard, 1989).

A correlation of these independent data curves suggests that the Westphalian to Stephanian aged Euramerican Coal Measures formed during a time when relatively large fluctuations in eustatic sea level resulted in multiple regional marine transgressions in coastal lowlands. Maximum accumulations of glacial ice and an increase in relative moisture availabilities are also proposed (Figure 2).

1.5.3 Regional Geology and Stratigraphy

A complete stratigraphic sedimentary record, Late Devonian to Permian, has been correlated from the post-Acadian orogenic margin of Laurentia (Howie and Barss, 1975; Bradley, 1982). Continuous regionalised sediment deposition is proposed for the Atlantic Region during this time. Areally, the record is fragmented and locally deposition is frequently interrupted by unconformities. Ten depositional basins are identified in the Atlantic Region (Bradley, 1982). These post-orogenic basins formed by thermal extension and rifting due to sediment loading (Bradley, 1982; Gibling, Boehner, and Rust, 1987). No single basin is known to contain a complete lithologic record for the Late Devonian - Early Carboniferous through Permian. Tectonically, the mid- to late Carboniferous in the Atlantic region was relatively quiescent (Hacquebard, 1986; Grant, in press).

The Sydney Basin is the second largest coal-bearing basin in the Atlantic region. As much as 95% of the estimated 36000^2 km areal extent of the Sydney Basin is now submarine

Figure 2: A composite stratigraphic figure to illustrate the relative ages of the lithostratigraphic groups that comprise the Carboniferous succession in the Sydney Basin strata (after Boehner and Giles, 1986). The absolute age through to the European Carboniferous succession columns are after Harland, *et al.* (1990). Generalised palaeoclimatological and palaeoecological data curves are presented in the form of an inferred moisture availability curve (after Phillips and DiMichele, 1981; DiMichele, *et al*, 1985); a simplified 2nd order of magnitude sea level fluctuation curve (after Ross and Ross, 1987, 1988); and an estimated glacial-ice volume curve (after Veevers and Powell, 1987) to graphically illustrate the complex nature of the Upper Carboniferous palaeoclimate and palaeoecology.

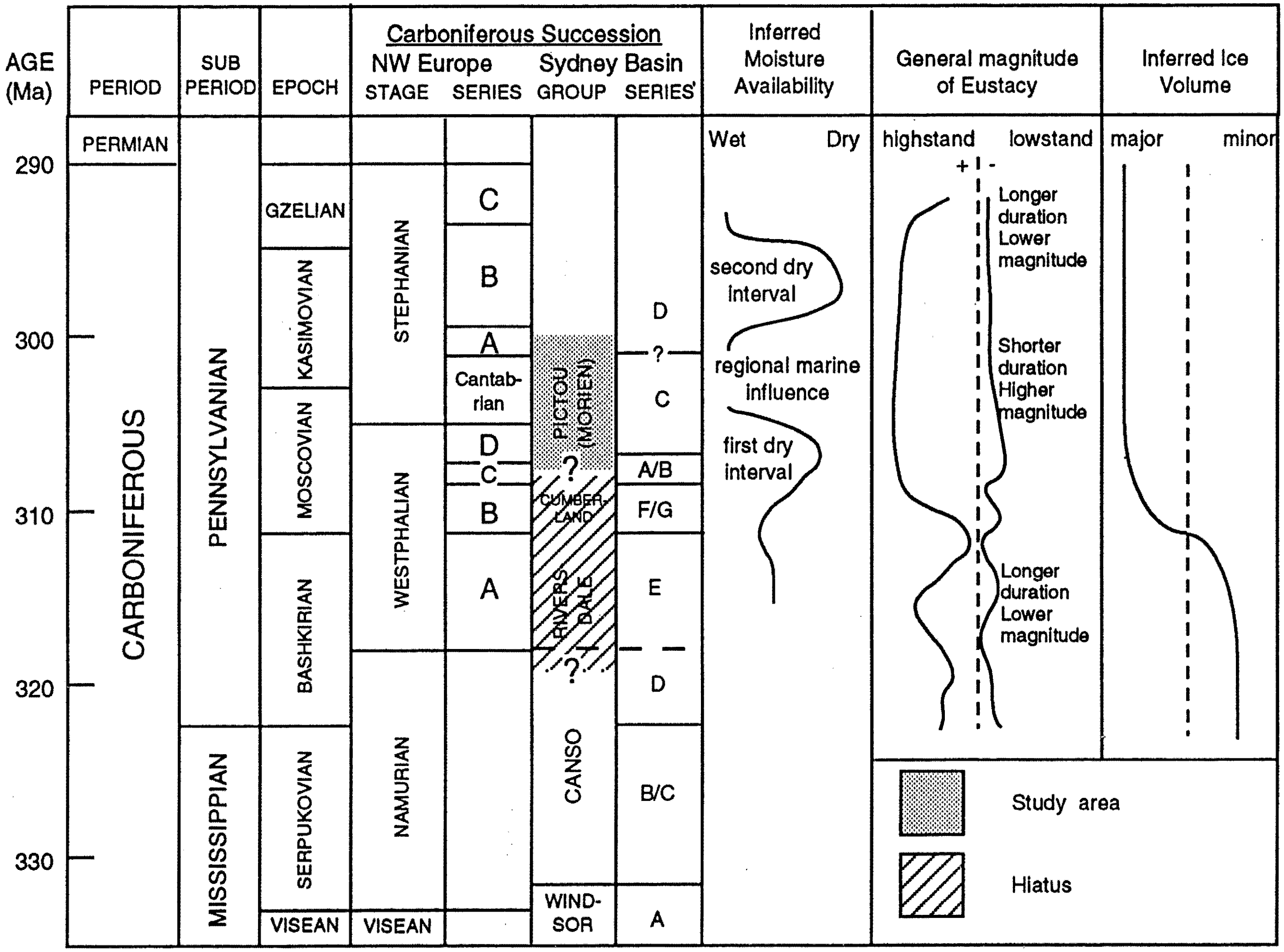

AGE (Ma)
PERIOD
SUB PERIOD
EPOCH
Carboniferous Succession
NW Europe
STAGE
SERIES
Sydney Basin
GROUP
SERIES
Inferred Moisture Availability
General magnitude of Eustacy
Inferred Ice Volume
290
300
310
320
330
PERMIAN
CARBONIFEROUS
PENNSYLVANIAN
MISSISSIPPIAN
GZELIAN
KASIMOVIAN
MOSCOVIAN
BASHKIRIAN
SERPUKOVIAN
VISEAN
STEPHANIAN
WESTPHALIAN
NAMURIAN
VISEAN
C
B
A
Cantab-rian
D
C
B
A
PICTOU (MORIEN)
?
CUMBER-LAND
RIVERS DALE
?
CANSO
WIND-SOR
D
?
C
A/B
F/G
E
D
B/C
A
Wet
Dry
second dry interval
regional marine influence
first dry interval
highstand
lowstand
+
-
Longer duration Lower magnitude
Shorter duration Higher magnitude
Longer duration Lower magnitude
major
minor
Study area
Hiatus

Figure 2

(Hacquebard, 1987, 1993) (Figure 3). Seismic studies and borehole correlations indicate that the submarine portion of the Sydney Basin strata extends nearly to Newfoundland (King and MacLean, 1976; King *et al.*, 1986). The significantly smaller onshore portion of this basin is reasonably well known from numerous detailed geologic and mining studies (Hacquebard and Donaldson, 1969; Hacquebard, 1979; Best, 1984; Bird, 1987; Gibling, Boehner, and Rust, 1987; White, 1992).

Following is a condensed summary of the lithology, and generally accepted environments of deposition, of the Carboniferous strata of the Sydney Basin. The simplified stratigraphic sequences that illustrate the relative relationships of the Groups are in Figures 2 and 4. Basin fill initiated with a thick sequence of coarse alluvial fan and fluvial channel deposits of the Horton Group [Late Devonian - Mississippian] (Bell, 1938; Barss and Hacquebard, 1967; Van der Voo, 1988). The Horton Group strata (?365-345 My) are grey and red, coarse-grained, relatively immature conglomerate (alluvial fan), sandstones (fluvial), mudstones, nonmarine limestones and evaporites (fluvio-lacustrine) (Howie and Barss, 1975; Bradley, 1982; Gibling, Boehner and Rust, 1987). Evidence of minor volcanic activity (Late Devonian to Visean age) is present in the Sydney Basin. The upper Horton Group interfingers with the lower Windsor Group (Visean, 345-335 My). The dominant lithologies of the Windsor include fossiliferous marine carbonates, evaporite minerals (gypsum, anhydrite, halite, barite, and minor potash) that are interbedded with clastic red bed sediments. The most frequently interpreted environment of deposition for the Windsor Group includes cyclic deposition, under arid climatic conditions, in a shallow, marine-influenced, coastal plain environment (Howie and Barss, 1975; Schenk, 1969; McCabe and Schenk, 1982; Gibling, Boehner, and Rust, 1987).

The lower Canso Group (Late Visean to Namurian, 335-320? My) is conformable on the upper contact of the Windsor Group. The Canso Group straddles the Mississippian - Pennsylvanian Boundary (333 My). Canso lithologies are red, green and grey mudstones and sandstones. Lesser amounts of stromatolitic limestones, sulphate evaporite minerals

Figure 3. A map of the Atlantic Region to show the submarine extent of the Sydney Basin (stipple on inset map)(after Hacquebard, 1987). The coastal geographic position of the study section is also marked (arrow head).

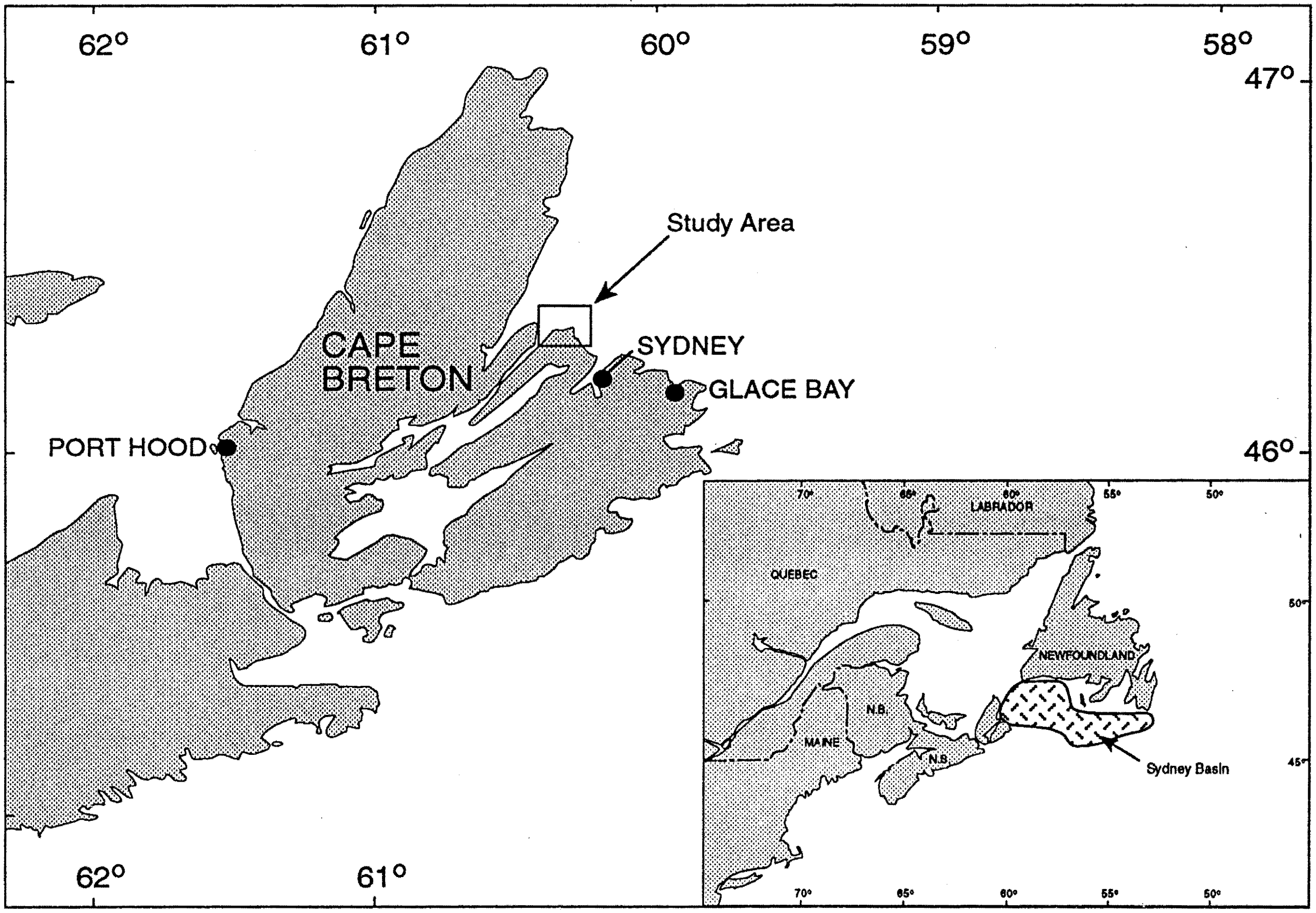

62°
61°
60°
59°
58°
47°
Study Area
CAPE BRETON
SYDNEY
GLACE BAY
PORT HOOD
46°
62°
61°
70°
65°
60°
55°
50°
LABRADOR
QUEBEC
50°
NEWFOUNDLAND
N.B.
MAINE
N.S.
Sydney Basin
45°
70°
65°
60°
55°
50°

Figure 3

Figure 4: Illustration of the simplified lithologic stratigraphic sequence (A) from the Sydney Basin (after Boehner and Giles, 1986). The second figure (B) is a generalised section of the study area. The relative position of the coal seams (in black) and the sample positions for this study are identified with a dot and the sample number (after Bird, 1985/86, 1987).

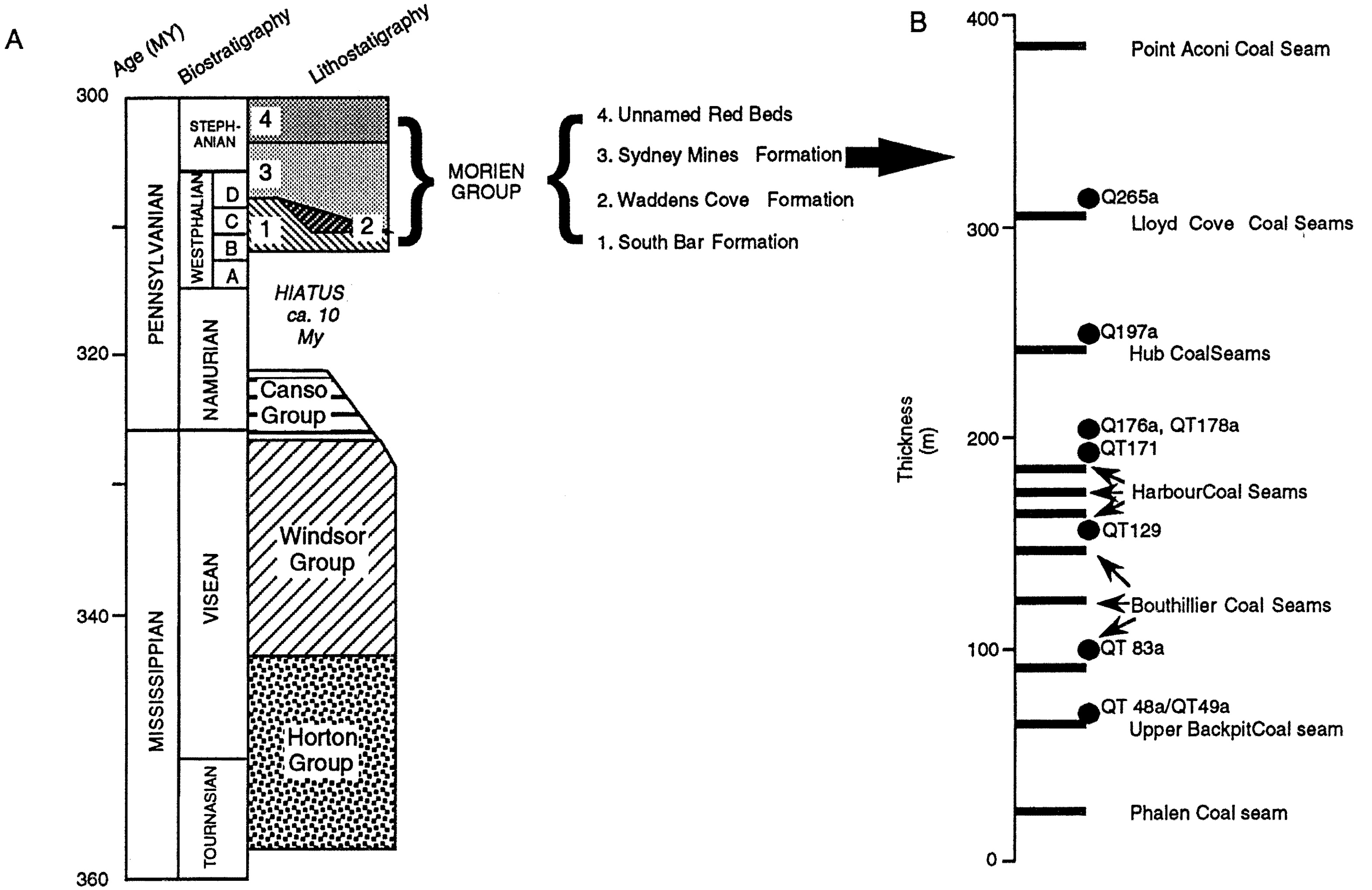

A
Age (MY)
Biostratigraphy
Lithostatigraphy
300
320
340
360
PENNSYLVANIAN
MISSISSIPPIAN
STEPH-ANIAN
WESTPHALIAN
D
C
B
A
NAMURIAN
VISEAN
TOURNASIAN
4
3
1
2
HIATUS ca. 10 My
Canso Group
Windsor Group
Horton Group
MORIEN GROUP
4. Unnamed Red Beds
3. Sydney Mines Formation
2. Waddens Cove Formation
1. South Bar Formation
B
Thickness (m)
400
300
200
100
0
Point Aconi Coal Seam
Q265a
Lloyd Cove Coal Seams
Q197a
Hub CoalSeams
Q176a, QT178a
QT171
HarbourCoal Seams
QT129
Bouthillier Coal Seams
QT 83a
QT 48a/QT49a
Upper BackpitCoal seam
Phalen Coal seam

Figure 4

and a few coalified plant fossils are documented. The interpreted environment of deposition is arid lacustrine with minor fluvial components (Hacquebard, 1972; Howie and Barss, 1975; Bradley, 1982; Gibling, Boehner and Rust, 1987).

The coal-bearing Riversdale, Cumberland and Pictou Groups are stratigraphic equivalents to the Late Namurian, Westphalian A through D and Stephanian A Stages (?320-300? My) of the European Carboniferous Succession, respectively (Hacquebard and Donaldson, 1969; Hacquebard, 1972; Howie and Barss, 1975). The strata of the Riversdale and Cumberland Groups are not known in the Sydney Basin sequence and in their place is an approximately 10 million year hiatus (White, 1992; Figure 2, this study).

The areal extent of the Pictou Group is greater than that of the other coal-bearing groups in the Atlantic Region. Deposition of this group began during the Westphalian B, continued through the Stephanian and into the Permian (309-?290 My). The Pictou Group and the Morien Group (Sydney Basin) are stratigraphic equivalents. The Morien Group is informally subdivided into the South Bar, Waddens Cove and Sydney Mines Formations. The coarse grained conglomerates and sandstones of the South Bar Formation rest unconformably on the Canso and Windsor Group strata. The measured thickness of the South Bar Formation outcrop is approximately 750 m Minor occurrences of mudstones and coals are also documented (Boehner and Giles, 1986). The environment of deposition is interpreted as braided and ephemeral fluvial with variable volumes of flow (Gibling and Rust, 1984).

An estimated 400 m thickness of the Waddens Cove Formation overlies the South Bar Formation in the southeastern region of the Sydney Basin. The dominant lithologies are mudstones, sandstones with minor limestones and coals (Boehner and Giles, 1986). The Waddens Cove Formation is absent in the study area.

The Sydney Mines Formation is dominantly sandstone and mudstone, with productive coals and minor occurrences of limestone. The dominant types of clastic sedimentation are identified as fluvial and lacustrine. In contrast, the medium to high sulphur contents (2.5-6.2%)

and some of the fauna suggest a paralic depositional setting. Until recently, the distinct possibility of marine influence was largely dismissed using negative evidence (Hacquebard and Donaldson, 1969; Hacquebard, 1987; Gibling *et al.*, 1986; 1989; Hacquebard, 1993).

Reports of brackish water, agglutinated foraminifera provided the first positive evidence for a marine influenced environment of deposition in the Upper Morien strata of the Sydney Basin. Fresh water arcellaceans are also present in restricted units (Thibaudeau and Medioli, 1986; Thibaudeau 1987; Thibaudeau, Medioli and Scott, 1987, 1988; Wightman *et al.*, 1992, 1993). Recent results from concurrent sedimentological studies that incorporate the evidence provided by the microfossils reclassify the environment of deposition as a coastal plain - deltaic environment (Bird, 1987; White, 1992).

Chapter 2. Methods

2.1 Field Methods

One hundred and twenty bulk rock samples were collected from outcrop of the Sydney Mines Formation in September of 1986 and 1987. Eighty-five (85) rock samples collected by D.J. Bird in 1985 were also accessible for this study. Freshly exposed samples were collected from along the section face. The sampling frequency was more concentrated in the lithologic units immediately below, between and above all coal seams. Samples from with in coal seams were also taken. The taxonomy of the specimens extracted from nine (9) productive samples are the focus of this study.

2.2 Laboratory Methods

A brief description of the different sample processing techniques used to recover microfossils for this study is included in this section. The quantity of sample used was variable and not constant. Table 1 (Results) lists the sample number, the genera extracted, and the processing techniques used.

2.2.1 Oven dry and Boiling Water

A small quantity of sample (20-30 g) was placed in a clean container and dried at 100° C in a low temperature drying oven over night. The dried sample was removed from the oven and boiling water was poured over it. After cooling, and settling, the excess water was decanted through a 63 µm sieve. If the sample was partially disaggregated the procedure was repeated.

2.2.2 Hot Calgon

A hot, dilute (10%) solution of Calgon® [sodium metaphosphate, $(NaPO_3)_{13} \cdot Na_2O$] was poured over an oven dried sample. The sample and solution were then heated to a boil. The excess solution was decanted through a 63 µm sieve after the sample and solution had cooled. The process was repeated to attain full disaggregation.

2.2.3 Recrystallisation

A hot, concentrated sodium sulphate solution [Na_2SO_4] was poured over an oven dried sample, and boiled hard for approximately an hour. The sodium sulphate recrystallised from solution as the sample cooled, and dried out. This mechanical process was repeated many times per sample.

2.2.4 Acid Dissolution of Carbonate-Rich Samples

Coarsely crushed, carbonate rich samples were placed in beakers in a fume hood and dilute hydrochloric acid (10% HCl) was poured slowly over them. The acid reaction was allowed to go to completion, the spent acid was decanted and fresh acid was added. Concentrated HCl was added after the effervescence from the dilute reaction subsided. After the reaction was completed the spent acid was decanted through a 63 um sieve and the sample was rinsed several times with distilled water and the residues were oven dried at 60° C over night.

2.2.5 Conodont Microfossil Collection and Processing

Two bulk (approximately 2 kg) rock samples were collected and processed for conodont microfossils. The crushing, dry sieving, acid digestion, heavy liquid separation, and post processing examinations, were performed by Dr. P. von Bitter, and associates, of the Royal Ontario Museum in Toronto. The technique utilized is described in Collinson (1963). The residues were returned to Dalhousie University for further examination.

2.2.6 Acetate Peels

Fresh, relatively flat surfaces of carbonate-rich hand samples were etched with dilute hydrochloric acid (10%) for approximately 30 seconds. The reaction was stopped with distilled water, the sample was rinsed thoroughly and placed in a low temperature oven to dry. Acetone was poured over the etched surface of the dry specimen and a thin film of acetate was placed over that surface. The acetate covered specimen was weighted and left to dry in a fume hood. The acetate film was removed from the dried sample and then examined under a binocular microscope.

2.2.7 Microfacies slabs

Fresh, flat slices were cut from rock samples with the Department of Geology rock saw. One cut surface from each sample was then ground and polished, both mechanically and by hand, with 400 and 600 grit corundum powders. The polished surfaces of the samples were then epoxy mounted onto glass microscope slides.

Each sample was then ground and polished to a thickness of approximately 70 μm. These samples were then examined under a binocular microscope with transmitted light.

2.2.8 Sample washing

All samples were washed with tap water post processing. Concentrated detergent was used on some samples to assist with disaggregation. Residues were collected in a 63 micron sieve and oven dried at low temperatures.

2.2.9 Specimen Hand-Sectioning

Several specimens were sent to Dr. J. Wall at the Institute for Sedimentary and Petroleum Geology (I.S.P.G.), Department of Energy, Mines and Resources, Calgary, for thin sectioning. Standard thin sectioning techniques were attempted. A technique modified after Finger and Armstrong (1984) was developed at Dalhousie. Individual specimens were embedded and mounted on the frosted end of glass microscope slides with a rapid drying Krazy Glue®-like adhesive. The embedded specimens were then ground by hand with very fine grained, wet grinding disks until an internal longitudinal section of the specimen was exposed. The adhesive embedded specimens were then placed in acetone $(CH_3)_2CO$ until the adhesive dissolved. The sectioned specimens were retrieved and mounted for microscopic examination.

Specimens of recent foraminifera were collected, mounted and sectioned using the above technique. External and internal structures in these specimens were used as comparative morphology guides for the Carboniferous specimens.

2.2.10 Sample Picking

Each dry sample was fractionated with a series of sieves; 63 µm, 125 µm, 250 µm, 500 µm, and 850µ. The residue fractions were examined for fossil biota with a Leitz binocular microscope under reflected light. Specimens were removed from the sample and mounted in a multi-well slide and cover slip with a gum tragacanth solution.

2.3 Photomicroscopy

2.3.1 Light Photomicroscopy

All intact specimens were photographed prior to modification by sectioning or platinum coating for scanning electron microscopy. Some of the specimens were photographed by the Dalhousie Photography Unit using a Testovar photographic microscope.

2.3.2 Scanning Electron Photomicroscopy

Repeat as in section 2.3.1. Specimens were mounted on aluminum stubs with double sided tape and placed in an Edwards high vacuum evaporator, model E12E3, prior to examination. The specimens were coated with a thin, continuous layer of gold/palladium (Au/Pd) alloy. Some of the larger specimens were coated twice to prevent charging. The stubs were transferred to the sample chamber of a Cambridge S 180 scanning electron microscope at the Bedford Institute of Oceanography. Specimens were photographed with Polaroid Type NP 55 black and white film.

Further scanning electron photomicroscopy work was performed at Dalhousie University in the Department of Biology, as well as at the Bedford Institute of Oceanography. The work at Dalhousie University included coating the specimens, under vacuum, with a Tousimis, Sam Sputter 2a, Automatic Sputter Coating Apparatus. Specimen examination was done using a Bausch and Lomb, ARL Nanolab 2000 scanning electron microscope. Specimens were photographed with Kodak, T-Max 100 ASA film, and a specially adapted Pentax K-1000 35 mm camera body. The final photomicroscopy session was done at the Atlantic Geoscience Centre, Bedford Institute of Oceanography, using the ElectroScan, Model E-3, Environmental Scanning Electron Microscope. Specimens were photographed with Polaroid Type NP 55 black and white film.

2.3.3 Photo X-radiography

Specimens were mounted in a 3"x 5" multi-well slide with a thin film of plastic for a base (Leary and Hart, 1988). The slide was taken to the Non-Destructive Testing Laboratory of the Defense Research Establishment Atlantic (DREA), Dockyard Laboratory, Department of National Defense, Halifax. The specimen slide was placed in direct contact with the Kodak Industrex Type DR (double sided emulsion) film and exposed to various exposure strengths and time periods under a Scanray Industrial X-ray Unit AS (200 KV, 8 Ma, 2.0 mm focal spot) with a 32" surface to film distance. The film was developed in an 8 minute cycle with a Dupont NDT 100 automatic chemical processor.

The x-ray films were examined under a light microscope with transmitted light. X-ray negatives of the specimens were enlarged and printed at the Bedford Institute of Oceanography Photo Unit.

Chapter 3. Modified Methodology.

3.1 Laboratory Methods

A considerable amount of effort, and consequently time, was required in this study for the application and modification of standard micropalaeontologic techniques. The results of these efforts are discussed below.

3.1.1 Specimen Extraction

Several different extraction processes were used to recover microfossils. The technique that worked the best depended on the lithological composition of the specimen. The conodont extraction method (chemical dissolution) technique provided the best results for carbonate-rich samples while the sodium sulphite and hot calgon methods (mechanical fracture) proved most productive for the clastic samples.

The specimens recovered from chemical dissolution residues appeared to be in better condition than the specimens extracted using the mechanical methods. Specimens recovered by the former technique may exhibit characteristics associated with chemical dissolution. These residues tended to be smaller and easier to pick.

The specimens recovered from mechanical fracture residues appeared to exhibit part and counterpart -type fracturing. The counterpart was often not recovered from the residue. Generally, the mechanical extraction process required more time to disaggregate the sample. Also the residues produced using this method tended to be larger and required more time to pick the specimens.

3.1.2 Microfacies slabs.

Standard whole rock thin sectioning techniques were made for selected samples known to contain Carboniferous foraminifera. The sections were too thin (<40μm) and did not reveal any microfossils. Microfacies slabbing was then used for a few selected samples. The procedure for thin sectioning and microfacies slabbing is essentially the same, with the exception that the final microfacies section (70 μm thick) is approximately twice as thick as the standard thin section (40 µm thick). The microfacies slabs were largely unproductive with the exception of sample number QT48a. Internal structures of foraminifera are present in microfacies slabs from this sample. However, these results are not illustrated in this work.

3.1.3 Comparative micromorphology

The standard sectioning exercises were largely unproductive. The inability to visually distinguish a contrast between the foraminiferal test wall and the infilling, as well as the lithologic unit from which the specimen was extracted, necessitated an alternate approach to facilitate the visual differentiation of external and internal microstructure for the Carboniferous specimens.

Recent specimens of agglutinated foraminifera were sectioned using the technique that was developed for these Carboniferous specimens. The sectioned specimens were mounted and examined carefully with SE microscopy. The arrangement of the internal features, as well as the distinct textural contrast between the organically secreted structures and the xenosomic components of the test wall were documented (Plate 9: Figures 6 through 9). Similar morphological features from the recent specimens were then identified in the Carboniferous specimens. This comparative micromorphological method was extremely useful for SE microscopical analysis and frequently provided sufficient microstructural evidence to confirm that the specimens were foraminifera.

3.1.4 Specimen Hand Sectioning

Standard thin sectioning techniques were used for the specimens sent to Dr. J.H. Wall (Institute for Sedimentary and Petroleum Geology, I.S.P.G., Department of Energy, Mines and Resources, Calgary). The results were inadequate. The failure of the technique was due to the poor state of preservation of these fossils. The specimens were very soft (Dr. J.H. Wall, pers. comm).

A sectioning technique, modified from Finger and Armstrong (1984), was developed to accommodate these specimens. The modifications of this method included; identifying a suitable mounting medium, isolating a solvent for the mounting medium that was also non-destructive to the specimens, partial sectioning of the specimens by hand, and post sectioning recovery of the specimens from both the mounting medium and the chemical solvent. The recovered specimens were then mounted and examined using scanning electron microscopy. Recent specimens of brackish water foraminifera were also sectioned and mounted using this technique. The results are illustrated on Plate 4; Figures 8, 9, and 11 (Carboniferous specimen) and Plate 9; Figures 6 through 9 (Recent specimens). Although the hand sectioning process is time consuming the results proved satisfactory for analysis using scanning electron microscopy. The textural and structural characteristics observed in the images of the recent specimens were useful guides for the examination and interpretation of structures of the Carboniferous specimens.

3.1.5 Sample Picking

The residues from the mechanically disaggregated samples were large and contained a wide range of size fractions. The sieve series was used to concentrate the grains and fragments, in all residues, by size to ease (optically) the picking process. Agglutinated foraminifera and arcellaceans are generally inconspicuous components in clastic residues due to the nature of the test wall. They are most commonly found in the smaller size fractions (<250 µm) and the size fractionation exercise aided in concentrating the specimens in a smaller portion of the sample. All size fractions of the residues were examined with reflected light microscopy.

3.1.6 Scanning Electron Photomicroscopy

The contrast in the figures in the photo plates is quite variable. This variation in contrast is partially due to the use of three (3) different SEM systems.

Many of the Carboniferous specimens were completely flattened during burial. Consequently, they have little or no vertical relief. The modification of standard photomicroscopic techniques was required to introduce relief so that the structures could be documented photographically. High angles of stage tilt were used for many of the SE photomicrographs. Some artifacts, such as specimen outline elongation or distortion, are observed in the SEM images. This modified method proved invaluable for introducing relief into the images for specimens that are completely flattened.

The SEM systems at BIO have an attached elemental analyser component (EDAX). This component proved useful for some specimens. Future work on these specimens should include, whenever possible, elemental analysis of cement compounds, as well as the analysis of any questionable test constituents.

3.1.7 Photo X-radiography

Thin sectioning is the standard method used to verify the presence of internal structures. However, it is frequently not performed because this practice is destructive. A few documented x-radiographic studies have produced reasonably good images, and definition, of internal structures from calcareous foraminifera (Hedley, 1957; Bé *et al.*, 1969). Documented use of this method for agglutinated foraminifera is rare.

A largely experimental X-radiographic technique was attempted in this study to ascertain whether internal structures in the Carboniferous specimens could be resolved. Difficulties were encountered in several steps of the process. The first attempt was made using standard dental X-radiographic equipment and film. Faint outline images were present on the x-ray film but no internal structures were visible. The second attempt (DREA X-ray equipment) provided mostly fuzzy images and outlines with a few identifiable internal structures. One of the better examples of these results is presented on Plate 2: Figure 11. Internal structure, in the form of chamber outlines, are generally visible in this photo X-radiographic image. This image is from a large specimen which is heavily pyritised. Considerable detail (resolution) has been lost during the photo-enlargement of the image.

This technique would be ideal to verify the presence of internal structures in the Carboniferous specimens because it is non-destructive. However, considerable work is required to refine the technique for these purposes. It is suggested that magnification is introduced during the X-ray exposure stage to minimise the loss of resolution during in the photo-enlargement stage. Alternately, the X-radiographic images could be photographed with transmitted light photomicroscopy equipment and then enlarged.

Chapter 4. Systematic Taxonomy and Specimen Descriptions

4.1 General Introduction

Classification and taxonomy are the main scientific disciplines of Systematic Taxonomy. Classification includes grouping designated types of organisms, as well as assigning the groups to a systemic position (Blackwelder, 1967). Taxonomy is the science where organisms are examined, and identified using comparative morphology.

For the purposes of this study, the taxonomic method used is the strict biological application where positive morphological characters must be present before a new type is erected. Therefore, the specimens which posess morphological characters common to a previously described group, and that do not exhibit visibly different morphological features, shall be designated to the existing taxonomic group which most easily accommodates the specimens. Specimen identification is, for the most part, based on external, and in some cases internal, morphology. Problematic specimens are tentatively (?) placed in the group that best accommodates them, and then discussed in the comments section.

Morphological differences and similarities are used to define types of variation in kinds of organisms. Microstructures from intact, and sectioned, specimens of recent foraminifera and serpulid worm tubes facilitated the taxonomic work in this study. Some of the more useful photomicrographic guides, of the recent specimens, are contained in this study (Plate 9; Figures 6 through 10).

Taxonomic study of fossil organisms can be difficult. This is due to the differential preservation of the soft and hard parts of organisms. The problems associated with this fossil-record bias may become manifested when millions of years exist between reported fossil finds. An approximately 250 million year gap exists between the previously reported stratigraphic ranges, and the Carboniferous age for some of the specimens documented in this study. An hiatus is regarded as negative evidence, and since these hiatuses are not morphological characteristics they are not considered pertinent to the taxonomic section in this study.

The *Treatise on Invertebrate Paleontology, Protista 2, Part C: Sarcodina, chiefly "Thecamoebians" and Foraminiferida* (Loeblich and Tappan, 1964), and *Foraminiferal genera and their classification* (Loeblich and Tappan, 1988) are utilized extensively for this chapter. The multiple excerpts from these volumes are not cited. All other sources of information are cited.

Descriptive excerpts are included for all taxonomic ranks or groups where the identification and classification is based on hard part morphology. Information based on the morphological attributes of the soft tissue (cell) are not relevant to the scope of this study and consequently are not reported. The taxonomic rank (level), taxon, and the earliest documented source are recorded for each level in the classification hierarchy.

The specimen numbers, in the plate cover pages, contain the following information: 85 represents the year the sample was collected in; -NS is an abbreviation for Nova Scotia; -SYD is an abbreviation for the geographic sample location (Sydney); -01 represents the scanning electron microscope (SEM) stub number; -Q6a is the lithostratigraphic unit number from which the specimen was extracted; -03 is the specimen number from the SEM stub; -002 is the photograph number, b identifies the roll of film, (bar = xx μm) is the scale bar for the photograph; and the superscript accompanying the scale bar value is the number of degrees tilt on the SEM stage for the respective photomicrograph.

A summary table which lists the genera of microfossils extracted from each lithologic unit, and the extraction techinique, preceeds the descriptive taxonomic section (Table 1).

4.2 Systematic Taxonomy and Specimen Descriptions

Phylum PROTISTA

Subphylum SARCODINA Schmarda, 1871

Unicellular organisms..., may have internal or external test, which may be membranous or chitinous, of secreted calcite, aragonite, silica or strontium sulphate or of agglutinated foreign matter held by ferruginous, calcareous or siliceous cement; ?Precambrian, Cambrian to

Table 1. A summary, by lithologic unit, of the assemblages of foraminifera, arcellacea and other fauna documented in this study. The method of specimen extraction is included.

Sample Number	Genera and species	Processing Method		Sample Number	Genera and Species	Processing Method
QT48a	*Difflugia sp. 3*	conodont		Q129a	*Miliammina sp. 1*	calgon & hot water
	Heleopora sp. 1	sodium sulphide			*Trochammina sp. 3*	calgon & hot water
	Miliammina sp. 1	sodium sulphide				
	Trochamminita sp. 1	conodont				
	Ammobaculites sp. 1	conodont		QT171	*Trochammina sp. 2*	sodium sulphide
	Ammobaculites sp. 1	conodont			*Spirorbis sp. 1*	picked from surface
	Ammobaculites sp. 1	conodont				
	Ammotium sp. 1	conodont				
	Buccicrenata sp. 1	conodont		Q176a	*Difflugia sp. 1*	calgon & hot water
	Buccicrenata sp. 2	conodont			*Difflugia sp. 3*	calgon & hot water
	?Buccicrenata sp. 2	conodont		QT178a	*Difflugia sp. 2*	sodium sulphide
	Trochammina sp. 1	conodont			*Ammobaculites sp. 1*	sodium sulphide
	Trochammina sp. 2	conodont			*Ammobaculites sp. 1*	sodium sulphide
	Trochammina sp. 3	conodont			*Ammobaculites sp. 1*	sodium sulphide
	Trochammina sp. 3	conodont			*Ammomarginulina sp. 1*	sodium sulphide
	Trochammina sp. 3	conodont			*Ammotium sp. 1*	sodium sulphide
	Trochammina sp. 4	conodont			*Ammotium sp. 2*	sodium sulphide
	Trochammina sp. 4	conodont			*Trochammina sp. 3*	sodium sulphide
	Trochammina sp. 4	conodont			*Trochammina sp. 3*	sodium sulphide
	?Textularia sp. 1	conodont			*Trochammina sp. 3*	sodium sulphide
	?Textularia sp. 1	conodont				
	Spirorbis sp. 1	picked from surface		Q197a	*?Paranebela sp. 1*	calgon & hot water
	Cephalopoda sp. 1	picked from surface			*Sorosphaera sp. 1*	calgon & hot water
QT49a	*Haplophragmoides sp. 1*	calgon & hot water		Q265a	*Difflugia sp. 2*	calgon & hot water
	Ammobaculites sp. 2	calgon & hot water			*Heleopora sp. 1*	calgon & hot water
	Trochammina sp. 2	calgon & hot water			*Ammobaculites sp. 1*	calgon & hot water
	Trochammina sp. 3	calgon & hot water				
QT83a	*Ammobaculites sp. 1*	sodium sulphide				
	Ammobaculites sp. 1	sodium sulphide				

Table 1

Superclass RHIZOPODA Dujardin, 1835

Class RHIZOPODEA von Siebold, 1845

Subclass LOBOSIA Carpenter, 1861

Order ARCELLINIDA Kent, 1880

With a simple or unilocular, sac-like or saucer-shaped shell or external membrane, having a definite aperture, rarely exhibiting apertural modifications, spine-like protuberances or other modifications; test composition may be gelatinous, membranous, "chitinous", or agglutinated, or may consist of loosely arranged or closely imbricated siliceous plates or scales; fresh-water [but may be washed into shallow-marine sediments]. Mississippian to Recent.

Superfamily ARCELLACEA Ehrenberg, 1832

Family DIFFLUGIIDAE Stein, 1859

Test rarely pseudochitinous, generally composed of foreign particles, not of secreted plates, form variable but with axial symmetry and terminal aperture ... Mississippian to Recent.

Genus *Difflugia* LeClerc in Lamarck, 1816

Test globular, elongate, pyriform or acuminate, typically circular in section; wall with pseudochitinous base and variable amounts of agglutinated material; aperture rounded, may be somewhat produced; .... [Fresh water lakes and ponds, non-living representatives of this genus are frequently reported from coastal marine sediments] Previously reported from the Middle Eocene to Recent; cosmopolitan distribution.

Difflugia sp. 1.

Plate 1; Figures 1 and 2.

Description: This species is yellowish-brown in colour; opaque; flattened; unilocular; sac-like; probably symmetrical; and approximately 220 µm in length (Plate 1: Fig. 1). A terminally situated aperture-like structure is present. The opening is irregular in shape and appears to be lined by a smooth, non-crystalline basal matrix. In outline the test appears to taper slightly from the oral terminus to the fundus. The agglutinated test wall is composed of a smooth, non-crystalline basal matrix embedded with coarse xenosomes. The small spherical objects may be idiosomes (Plate 1: Fig. 2; upper left). The composition of the basal matrix is unknown.

Affinities: The coarsely agglutinated test wall; and the relatively large, terminally situated aperture are characteristics that this Carboniferous specimen has in common with both Recent representatives of the arcellacean genus *Difflugia* LeClerc, in Lamarck, 1816, and the Cretaceous genus *Sibynion* Medioli, Scott, Collins and Wall, 1990.

Comments: The irregular shape of the aperture is probably due to physical flattening. The smooth, non-crystalline basal matrix is thought to be autogenous. In reconstruction this laterally flattened specimen would have a globular to urceolate outline, and a broadly rounded aperture.

Difflugia sp. 2.

Plate 1; Figure 3.

Description: This species is dark yellowish-brown in colour; opaque; globular in outline; bilaterally symmetrical; and approximately 400 µm in length. A rounded, aperture-like opening is present in a terminal position (Plate 1: Fig. 3; top centre). A rim of smooth, non-crystalline basal matrix forms a slightly produced lip around the aperture. The lip is roughly rounded in outline. The fundus is broadly rounded and without protuberances. The test wall is densely agglutinated with xenosomes of varying coarseness that are embedded in a basal matrix of an unknown composition.

Affinities: In gross external morphology and test composition this specimen is most similar to the Recent Arcellacean genera *Difflugia*, and has less in common with the genus *Cucurbitella* Penard, 1902. Morphological similarities with the Cretaceous genus *Sibynion* Medioli, Scott, Collins, and Wall, 1990, are also present.

Comments: Extant representatives of the genus *Cucurbitella* Penard, 1902, are usually smaller (140 µm in length) than the Carboniferous specimen (400 µm in length). A distinctly pronounced, visibly lobed organic lip, and an internal organic diaphragm which is situated immediately below the base of the lip, are characteristic in representatives of this genus.

Neither the distinct lip nor the internal diaphragm are present on the relatively large Carboniferous specimen. The texturally smooth, non-crystalline basal matrix appears autogenous.

Difflugia sp. 2.

Plate 1: Figure 4.

Description: The flattened specimen is dark brown in colour; opaque; symmetrical; roughly circular in outline; and approximately 250 µm in diameter. A terminally situated slit-like aperture structure is present on a slightly produced neck (Plate 1: Fig. 4; top peripheral margin). The aperture appears to be rimmed with a texturally smooth matrix which forms a lip. A centrally positioned depression, with crystalline morphocasts, is visible. The test wall is agglutinated with grains, of variable coarseness, that are embedded in a smooth, dense, non-crystalline, cement-like basal matrix. The test surface is perforated by several small pores. The composition of the test matrix is unknown.

Affinities: The terminally situated, rimmed aperture; the roughly lateral symmetry; the globular outline; and the agglutinated test wall (clastic grains embedded in a cement-like matrix) are characteristics that the Carboniferous specimen has in common with representatives of the recent Arcellacean genus *Difflugia*. Similar morphological features are also shared with the Cretaceous genus *Sibynion* Medioli, Scott, Collins and Wall, 1990.

Comments: Under reflected light microscopy the aperture appeared to be circular and centrally located. Further examination of this specimen, with scanning electron microscopy, indicated that the central depression is an artifact of diagenesis. This depression appears to be either formed and / or modified by crystal growth (Plate 1: Fig. 4; central position).

The tests of recent Difflugiid specimens have a pseudochitinous basal layer with varying amounts of agglutinated matter, and a terminal aperture with variable ornamentation. The test wall of the Carboniferous specimen is agglutinated with clastic grains that are embedded in a texturally smooth, non-crystalline basal matrix. The latter is though to be autogenous. In reconstruction this laterally flattened specimen would have a globular outline, and a broadly rounded terminal aperture with a small lip.

Difflugia sp. 3.

Plate 1: Figures 5, and 6.

Description: The compressed specimen is dark brownish-grey in colour; opaque to translucent; globular to urceolate in outline; laterally symmetrical; and approximately 300 µm in length (Plate 1: Fig. 5). The rounded aperture is terminally situated on a produced neck (Plate 1: Fig. 6). The external periphery of the aperture is ornamented with spherical, autosomal bodies that are embedded in a smooth, non-crystalline matrix. The expanded to bulbous fundus is gently rounded and unornamented. The sparsely agglutinated test wall has relatively fine xenosomes and idiosomes that are embedded in a non-crystalline, perforated, basal matrix. The non-crystalline basal matrix has an irregular surface texture and the composition is unknown.

Affinities: The gross external morphology; the agglutinated test wall; and the presence of a terminally situated aperture-like structure, are characteristics that this Carboniferous specimen has in common with Recent forms of the genus *Difflugia*.

Comments: Some recent Difflugiid specimens are very sparsely agglutinate and/or incorporate unstable biologically derived opaline silica xenosomes. Post burial dissolution of unstable, biogenically secreted compounds, such as opaline silica, is documented from recent peat forming environments (Kosters, *et al.*, 1987). The irregular surface texture of the basal matrix in this Carboniferous specimen may represent the remnants of a difflugiid test wall post xenosome and/or idiosome dissolution. The basal matrix in this specimen appears autogenous.

Difflugia sp. 3.

Plate 1: Figure 7.

Description: This specimen is white in colour; translucent to opaque; symmetrical; urceolate in outline; and approximately 120 µm in length. The aboral terminus is smoothly expanded. A constricted neck region is visible however, the apertural portion is broken off. The test wall is agglutinated with some relatively coarse xenosomes, as well as some small spherical bodies, that may be idiosomes. The grains are embedded in a smooth, non-crystalline basal matrix. The chemical composition of the glue-like basal matrix is unknown.

Affinities: This specimen is very similar, in both gross morphology and in test composition, to representatives of the recent genus *Difflugia*.

Comments: The gross morphology, and test wall composition, of this specimen are very similar to recent representatives of *Difflugia oblonga* Ehrenberg, 1838. However, the broken apertural terminus on this specimen makes identification to species difficult for this specimen. The texturally smooth, non-crystalline basal matrix appears autogenous.

Family HYALOSHPENIIDAE Schultze, 1877

Test pseudochitinous, with siliceous plates or scales, rounded or angular, with or without agglutinated material; aperture elongate or rounded. Previously reported from the Cretaceous, Middle Eocene to Recent.

Genus *Heleopora* Leidy, 1879

Test ovate, compressed, transparent, amorphous scales covering chitinoid membrane presenting a reticulated appearance, with or without agglutinated material at base; aperture, narrow, slit-like or elliptical giving notched appearance in edge view; ... Fresh-water [but may be washed into shallow marine sediments]. Previously reported from the Pleistocene to Recent. Distribution Europe, N. America, S. America, West Indies.

Heleopora sp. 1.

Plate 1: Figures 8 and 9.

Description: This species is predominantly white in colour with some evidence of internal pyritization; translucent to transparent; laterally symmetrical; roughly ovate in outline; with a bulbous fundus (aboral); a truncated (in outline) and narrowly ovate (in profile) oral terminus; and is approximately 220 µm in length (Plate 1: Fig. 8). The oral terminus has a slit-like aperture which is rimmed with a lip of smooth, non-crystalline matrix and perforated by several small pores. The autogenous test wall is agglutinated with a few small xenosomic bodies (Plate 1: Fig. 9). The density and coarseness of the agglutination increases toward the expanded fundus. Rounded to spherical ornamentations (idiosomes?), and small pyrite framboids, are also visible. An internally situated, rounded to spherical, pyritic mass is visible (with reflected-light microscopy) within the illustrated specimen.

Affinities: The terminal slit-like aperture on the truncated (outline), narrowly ovate (profile) oral terminus; an expanded to bulbous aboral terminus; the laterally symmetrical pyriform outline; the agglutinated test wall; the autogenous matrix; and the increase in both density and size of agglutinated xenosomes toward the fundus are all characteristics that this specimen has in common with extant representatives from the freshwater arcellacean genus *Heleopora.* This specimen has fewer morphological similarities with the Cretaceous genus *Sacculus* Medioli, Scott, Collins and Wall, 1990.

Comments: The Carboniferous specimen lacks the siliceous, scale-like plates that ornament extant representatives of the genus *Heleopora.* The preservation potential for these plates is reported to be low due to the relative instability of biogenic Opal A silica (Kosters, *et al.*, 1987).

Arcellaceans are sensitive to environmental changes and tend to encyst in unfavourable conditions. The internal pyritic mass (noted in the above description) may represent a pyritised internal cyst.

Heleopora sp. 1.

Plate 1: Figures 10 and 11.

Description: The specimen is dark brownish grey in colour; translucent to opaque; laterally symmetrical; laterally compressed; ovate in outline; and approximately 180 μm in length (Plate 1: Fig. 10). A non-pronounced, slit-like, aperture with a lip is present on the slightly constricted, oral terminus (Plate 1: Fig. 11; upper right). Relatively sparse, fine xenosomes are visible toward the fundus. A large xenosome is embedded in the basal matrix of the test wall on the fundus. The smooth, non-crystalline surface texture of the matrix (test wall) has reticular pattern superimposed on it that may be overlapping scales (Plate 1, Fig 11; lower left to central). The chemical composition of the test is unknown.

Affinities: The presence of a terminally situated, slit shaped aperture with a thin lip; a laterally symmetrical outline; an agglutinated test wall (idiosomes and xenosomes) as well as the increase in the coarseness of the agglutinated xenosomes toward the aboral terminus are morphological features that this specimen has in common with representatives from the recent freshwater arcellacean genus *Heleopora*.

Comments: Extant representatives of the genus *Heleopora* are frequently ornamented with thin, siliceous, scale-like plates (idiosomes). The overlapping of the basally embedded scales give the surface a reticular appearance.

The texture on the outer surface of the test wall of this specimen appears reticulated, and may delineate scale structures. The presence of these structures on the test surface supports a direct relationship with the recent genus *Heleopora.*

Superfamily EUGLYPHACEA Wallich, 1864

Test composed of variously shaped siliceous scales. Previously reported from the Middle Eocene to Recent.

Family EUGLYPHIDAE Wallich, 1864

Test hyaline, symmetrical, elongate, composed of rounded siliceous scales, aperture rounded to elongate;... Previously reported from the Middle Eocene to Recent.

Subfamily EUGLYPHINAE Wallich, 1864

Test radially symmetrical with centrally placed aperture. Previously reported from the Middle Eocene to Recent.

Genus *Paranebela* Jung, 1942

Test ovate, compressed (length 30 to 172 μm), with granular, medium to dark brown wall in which scattered irregular rounded plates are embedded; aperture rounded, with slightly thickened lip and finely scalloped or weakly dentate margin; living animal unknown. [Fresh water.] Recent, South America and Europe.

?Paranebela sp. 1.

Plate 1: Figures 12, and 13.

Description: This specimen is one of several in the sample that are infilled and sheared laterally. The test is brownish yellow in colour; opaque; symmetrical; unilocular; laterally compressed; roughly pyriform to ovate (sac-like) in shape; and approximately 220 µm in length (Plate 1: Fig. 12). A terminal, ovate to oblong apertural structure is ornamented with numerous small (roughly equal in size), triangular, tooth-like structures that appear similar in composition to the test wall (Plate 1: Fig. 13). Immediately posterior to the aperture is a thin zone of constriction with a single row of perforations. The unornamented test surface appears may be very finely agglutinated, or granular, with a dense basal matrix. Two pores are laterally situated on the fundus. One pore is clogged with foreign material, as well as being deformed by a crack in the test surface. The chemical composition of the test is unknown, and it is thought to be autogenous.

Affinities: These specimens possess structures that are characteristic to several different genera of Recent Arcellaceans. The ornamentation of the aperture with teeth is relatively common in the following genera; *Euglypha* Dujardin, 1835, *Difflugia*, and *Paranebela* Jung, 1942.

Comments: The test of Recent Euglyphiids is hyaline and ornamented with secreted siliceous plates. They rarely incorporate foreign grains in the construction of their tests. Recent Difflugiids are agglutinated, rarely compressed and the aperture is generally circular (Medioli and Scott, 1983). Very little is known about the recent Paranebellid forms. Empty tests are ovate; compressed; have a medium to dark brown granular wall; and the terminally situated aperture is rounded with a slightly thickened lip which is weakly scalloped or dentate. These forms belong in the same family as the hyaline Euglyphids. The gross morphological characteristics of these Carboniferous specimens indicate that they are Arcellaceans, and that they may be related to representatives of the Recent genus *Paranebela*. However, the combination of features present in these specimens have not been described for any single Recent Arcellacean genus. The finely agglutinated, nearly granular, appearance of the test wall is also unusual. A new genus may be required to accommodate these specimens.

Subclass GRANULORETICULOSIA de Saedeleer, 1934

Order FORAMINIFERIDA Eichwald, 1830

Test or shell with one or more interconnected chambers; wall may be homogeneous of similar or unlike layers or laminae, may be imperforate or finely to coarsely perforate, basically proteinaceous but may have agglutinated particles, or may deposit the mineral calcite, aragonite or rarely silica on the organic base, calcareous wall may be porcelaneous, microgranular, or hyaline and optically or ultrastructurally radiate or granular; canal or stolon systems or varied complexity may be present; commonly test has one or more main apertures. Free-living or rarely parasitic; benthic and attached or motile, or pelagic, in marine to brackish water, rare in fresh water. Cambrian to Recent.

Suborder TEXTULARIINA Delage and Hérouard, 1896

Test agglutinated, foreign particles held in organic or mineralised ground mass. L.Cambrian to Recent.

Family PSAMMOSPHAERIDAE Haeckel, 1894

Test free, globular to irregular or with several loosely joined chambers; wall coarsely agglutinated. Ordovician to Recent.

Superfamily ASTRORHIZACEA Brady, 1881

Test irregular, rounded, tubular, or branching, nonseptate or with interior only partially divided; wall agglutinated. Lower Cambrian to Recent.

Subfamily PSAMMOSPHAERINAE Haeckel, 1894

Test globular to irregular; wall finely to coarsely agglutinated; no recognisable aperture, but interstitial pores may occur between grains. Ordovician to Recent.

Genus *Sorosphaera* Brady, 1879

Test free, a series of subglobular chambers without definite arrangement; wall agglutinated, of loosely cemented coarse particles; no distinct aperture, but interstitial pores probably allow communication with the exterior. Silurian to Recent; Cosmopolitan.

Sorosphaera sp. 1.

Plate 2: Figures 1 to 4.

Description: This species is dark reddish-brown in colour, opaque, occur as single sphaerial forms, as well as irregular multichambered (5 or 6 chambers) forms (Plate 2: Fig. 1). The size range of the specimens is between 63µm and 1000 µm. No distinct apertural structure is present. An interstitial pore that is plugged with autogenous cement is illustrated (Plate 2: Figs. 2 and 3). The test wall has a sparse agglutinated outer layer and a dense innerlayer with autogenous cement and agglutinated grains (Plate 2: Figs 1, 2 and 3). The specimen is infilled with unorganised clastic material with an unknown composition.

Affinities: These specimens have characteristics that are common to several foraminiferal genera; *Psammosphaera* Schulze, 1875; *Blastammina* Eisenack, 1932; *Sorosphaera* Brady, 1879; and *Thuramminoides* Plummer, 1945. The single, and irregularly arranged multi-chambered forms with a bipartite test wall, and the presence of interstitial pores (rather than a primary aperture) are characteristics that these specimens have in common with the genus *Sorosphaera* Brady, 1879. More than one species may be represented by these specimens.

Comments: Numerous specimens were recovered in the residue for this sample. The results form SEM, EDAX and microprobe analyses indicate that these specimens are not sideritic concretions, as suggested previously (F. Gradstein, pers. comm).

Superfamily RZEHAKINACEA Cushman, 1933

Test planispirally enroled, with two, less commonly 3 chambers per whorl or with successive chambers added in varied planes as in the miliolines; wall finely agglutinated on an organic base, not perforate. Previously reported from the Cretaceous to Recent.

Family RZEHAKINIDAE Cushman, 1933

As in the superfamily. Previously reported from the Cretaceous to Recent.

Genus *Miliammina* Heron-Allen and Earland, 1930

Test elongate ovate, with narrow chambers a half coil in length in quinqueloculine arrangement; wall relatively thick, very finely agglutinate on an organic base and insoluble in acid; aperture at end of the chamber, rounded to semilunate, depending on the degree of compression against the previous whorl, may be produced on a short neck. Previously reported from the Lower Cretaceous to Recent; cosmopolitan.

Miliammina fusca Brady, 1870

Plate 9: Figures 6, and 7.

Recent specimens of *Miliammina fusca* were mounted and hand sectioned using the technique developed for the Carboniferous specimens. Internal morphological examinations of the sectioned specimens were made under the SEM and some feature were photographed for comparative morphological guides. The internal chamber arrangement, and wall structure for *Miliammina fusca* are visible in Figure 6 on Plate 9. Note the texture and continuity of the autogenous material lining the chambers. The distinctive textural contrast between the agglutinated component of the wall structure and the autogenous cement (matrix) is visble (Plate 9: Fig. 7; agglutinated wall, circum-peripheral, and cement; upper centre).

Miliammina sp. 1.

Plate 2: Figures 5 and 6.

<u>Description</u>: This specimen is dark greyish-brown in colour, opaque, has slight lateral compression, laterally symmetrical, fusiform to ovate in outline, ovate in profile, and approximately 250 μm long (Plate 2: Fig. 5). Narrow, latero-peripherally situated chambers, are enrolled planispirally in a quinqueloculine arrangement. The elongate initial chamber is centrally situated in a depression. An arcuate aperture, which is lined with autogenous cement, is situated on a constricted, slightly produced neck (Plate 2: Figs. 5 and 6). The test wall is

agglutinated. The fine clastic grains are embedded in a dense, autogenous cement.

Miliammina sp. 1.

Plate 2: Figures 7, 8, and 9.

Description: This specimen is yellowish-brown in colour, opaque, laterally compressed, has a symmetrical pyriform to ovate outline, and approximately 300 µm long (Plate 2: Fig. 7). The slightly domed intial chamber is centrally situated. Two shallow sutures with a longitudinal orientation, and a latero-medial situation, are visible on this specimen (Plate 2: Fig. 8). These sutures are truncated by the base of the slightly expanded, aperture-bearing terminal chamber. The key-hole shaped aperture, which is lined and rimmed with autogenous matrix, is situated on the terminal chamber (Plate 2: Figs. 8 and 9). The test wall is agglutinated.

Affinities: In gross outline, size, apertural form and location, and wall composition these specimens resemble recent representatives of the genus *Miliammina* Heron-Allen and Earland, 1930.

Comments: The Carboniferous specimens have morphological structures, such as; gross outline and form, the shape structure and position of the aperture, and the agglutinated test wall, in common with recent representatives of the genus *Miliammina* Heron-Allen, and Earland 1930. The situation and orientation of the sutures around a central initial chamber suggest a quinqueloculine chamber arrangement for the Carboniferous specimens. The suture structures may or may not be visible externally on recent forms. Hand sectioning and X-radiography have not been performed to verify the internal continuity of the suture in these specimens.

Superfamily LITUOLACEA de Blainville, 1827

Test free of attached, multi-locular, planispirally enrolled in early stage, later may uncoil; wall agglutinated, nonperforate. Upper Devonian to Recent.

Family HAPLOPHRAGMOIDIDAE Maync, 1952

Test planispirally enrolled and involute to partially evolute with septa formed by continuation of outer wall; wall agglutinated, simple, not alveolar; aperture single or multiple, equatorial in position, basal to areal. Previously reported from Upper Triassic to Recent.

Genus *Haplophragmoides* Cushman, 1910

Test planispirally enrolled, involute to slightly evolute, biumbilicate, sides somewhat flattened, chambers inflated and margin lobulate; wall thin, finely to coarsely agglutinated, exterior smoothly finished; aperture an elongate equatorial slit at the base of the apertural face. Previously reported from the Cretaceous to Recent; cosmopolitan.

Haplophragmoides sp. 1.

Plate 2: Figures 10, 11, and 12.

Description: This species is globo-discoidal in outline; has a lobulate outer margin; dark greyish-black in colour; is pyritised and opaque; dorso-ventrally compressed; ovate in profile; and approximately 600μm in breadth (Plate 2: Figs. 10, and 11). The concave umbilicus is obstructed by extraneous material. The chambers arrangement is an involute planispiral which is coiled dextrally (Plate 2: Fig. 11). A matrix-lined, slit-shaped aperture is situated in an extraumbilical-peripheral position (Plate 2: Fig. 12). The aperture is partially obscured by extraneous clastic material on the apertural face of the final chamber. One or more small, rounded supplementary apertures may be aerially situated on the terminal chamber (Plate 2: Fig. 10; right peripheral). The sparsely agglutinated test wall is densely pyritised.

Affinities: In gross outline, form and arrangement of structure this specimen is similar to representatives of the genus *Haplophragmoides*, Cushman, 1910.

Comments: Complementary photomicrographs from the dorsal perspective of this specimen are required. Some of the extraneous clastic material needs to be cleaned from surface of the specimen prior to further SE and light microscopical analysis.

Genus *Trochamminita* Cushman and Bronnimann, 1948b

Test free, planispirally enrolled at least in the early stage, later chambers irregular in form and arrangement, sutures radial in early part, slightly depressed, periphery rounded, peripheral outline lobulate; wall thin, brownish, with fine to coarse quartz grains on a proteinaceous base; aperture areal, one or more rounded to irregular openings in the lower part of the apertural face, each surrounded by a distinct lip. Previously reported from the Recent, brackish water; Trinidad, West Indies; USA: Louisiana, and New Zealand.

Trochamminita sp. 1.

Plate 2: Figures 12 and 13.

Description: This species is lobulate in outline; greyish-brown in colour; opaque; bent in an aboral over oral direction; asymmetrically ovate in profile; and approximately 700µm in length (Plate 5: Figs. 13 and 14). The specimen is cracked along the left peripheral margin. The prolocular chamber arrangement is an irregular planispiral which changes to an evolute planispiral in the outer roll. The direction of coiling is sinistral. The septa originate in the proloculus and extend radially toward the peripheral margin (Plate 2: Figs. 13, and 14). More than one, rounded, aperture, with an autogenous lip, is situated on the apertural face of the terminal chamber. The test wall is finely agglutinated.

Affinities: This specimen shares many morphological characteristics with representatives of the genus *Trochamminita* reported by Cushman and Brönnimann (1948b) from the mangrove swamps in Trinidad. Saunders (1957) enended this genus to include trochospiral forms.

Comments: Hand sectioning and X-radiography have not been performed to verify the internal continuity of the external septal structures. A more detailed examination of this specimen is required.

Family LITUOLIDAE de Blainville, 1827

Early stage enroled, later may be uncoiled and rectilinear; wall agglutinated, interior simple; aperture terminal. Lower Carboniferous, Lower Mississippian (Kinderhookian) to Recent.

Subfamily AMMOMARGINULININAE Podobina, 1978

Early stage coiled, later uncoiling; wall simple. Lower Carboniferous, Lower Mississippian (Kinderhookian) to Recent.

Genus *Ammobaculites* Cushman, 1910

Test free, elongate, early portion close coiled, later uncoiling and rectilinear, rounded in section; wall coarsely agglutinated, interior simple; aperture terminal, rounded. Lower Mississippian (Kinderhookian) to Recent, cosmopolitan.

Ammobaculites sp. 1.

Plate 3: Figures 1 to 17.

Description: The first specimen is elongate; yellowish-brown in colour; opaque; laterally sheared, and compressed; narrowly ovate in profile; spatulate in outline; roughly laterally symmetrical; and approximately 1200µm in length (Plate 3: Fig. 1). The expanded base has several sutures that radiate outward from the proloculus, and delimit a coil of planiserially enroled chambers. The direction of coiling is dextral. The chambers uncoil in the elongate neck, and are probably uniserial. Faint sutures extend across the width of the neck, are connect with pores that are lined with autogenous cement. A small, rounded aperture is visible on the terminal chamber of the neck (Plate 3: Figs. 1, and 2). The subterminal position of the aperture is probably an artifact of burial. The test wall is agglutinated.

Ammobaculites sp. 1.

Plate 3: Figures 3, and 4.

Description: This elongate specimen is dark greyish-brown in colour; opaque; laterally compressed; ovate in profile; spatulate in outline; and approximately 350µm in length (Plate 3: Fig. 3). The coiling end has sutures (bottom right) that delimit chambers. The chamber series is planiserially enroled in a sinistral direction around the proloculus, and becomes uncoiled in the neck. A small, rounded aperture is present on the terminal chamber of the neck (Plate 3: Fig. 4). The aperture has a lip of autogenous cement. The test wall is finely agglutinated. The specimen is broken along the left lateral margin.

Ammobaculites sp. 1.

Plate 3: Figures 5 and 6.

Description: This specimen is dark greyish-brown in colour, partially pyritised, opaque, laterally compressed, thinly ovate in profile, laterally symmetrical, broadly spatulate in outline, and approximately 600µm in length. The bulbous coiling portion has several sutures that radiate outward from the umbilicus, and delimit chambers (Plate 3: Fig. 5). The series of chambers is coiled in a dextral direction around the centrally positioned proloculus. The prolocular chambers form an irregular 'daisy-like' structure in the umbilical area. A rounded aperture is terminally situated on the short neck (Plate 3: Fig. 6). The test wall is finely agglutinated. A few small pyrite framboids are visible on the surface of this specimen.

Ammobaculites sp. 1.

Plate 3: Figure 7.

Description: This elongate specimen is dark reddish-brown in colour; opaque; with slight lateral compression; ovate in profile, spatulate in outline; and approximately 300µm in length (Plate 3: Fig. 7). The chamber arrangement in expanded base is not clear from external structures. The chamber arrangement in the neck is uniserial. A small, rounded aperture is terminally situated on the final chamber of the neck. The test wall is agglutinated. This specimen is broken along the left lateral margin.

Comments: This specimen is one of early specimens that we examined. A more detailed SEM examination is required.

Ammobaculites sp. 1.

Plate 3: Figures 8, 9 and 10.

Description: This spatulate specimen is dark yellowish-brown in colour; opaque; laterally compressed; narrowly ovate profile; and approximately 700µm in length (Plate 3: Fig. 8). The planiserially coiled chambers are enrolled (3 rows) in a sinistral direction around a centrally situated proloculus. The prolocular chambers are exposed, and resemble a propeller in form (Plate 3: Fig. 9; darker propeller shaped structure). The chamber arrangement in the short neck is uniserial. A small, oval, slightly produced, aperture is terminally situated on the final chamber of the neck (Plate 3: Fig. 10; upper right). The aperture smoothly lined, and rimmed with lip of autogenous cement. The test wall is agglutinated.

Ammobaculites sp. 1.

Plate 3: Figures 11 and 12.

Description: This elongate specimen is dark reddish-brown in colour; opaque; laterally compressed; ovate profile and spatulate in outline; and approximately 250µm in length (Plate 3: Fig. 11). The chamber arrangement in the coiling end is planiserially enrolled, in a dextral direction, around the centrally situated proloculus. The outermost roll, of the three rolls of chambers, is clearly defined in this specimen. The chamber arrangement in the neck is uniserial, and an obliquely oriented septa is visible (Plate 3: Fig. 12). An ovate aperture is terminally situated on the final chamber of the neck (Plate 3: Fig. 12; lower, right, central). The aperture is rimmed with a smooth lip of autogenous material. The test wall is agglutinated with clastic grains of varying coarseness.

Comments: This specimen was one of the first specimens we examined using SEM. More detailed examination is required.

Ammobaculites sp. 1.

Plate 3: Figures 13, 14 and 15.

Description: This specimen has a spatulate outline; is dark greyish-brown in colour; opaque; laterally compressed; narrowly ovate in profile; and approximately 280µm in length (Plate 3: Fig. 13). The specimen is fractured along the bottom. The chamber arrangement is planiserial, enroled dextrally around the centrally situated proloculus, and becomes uniserial in the neck. A rounded, aperture is terminally positioned on the final chamber of the neck (Plate 3: Fig. 14). The aperture is rimmed with autogenous matrix and plugged with clastic material. The pores in the neck are also lined with autogenous cement. The uppermost pore is contiguous with a transversely oriented septum (Plate 3: Fig. 15; left). The test wall is sparsely agglutinated.

Ammobaculites sp. 1.

Plate 3: Figures 16, and 17.

Description: This specimen is spatulate in outline; dark greyish-brown in colour; opaque; dorso-ventrally compressed; ovate in cross section; and approximately 500µm in length (Plate 3: Fig. 16). The specimen is fractured along the left lateral margin, and the test surface appears peeled off, with the exception of the bottom right peripheral margin (Plate 3: Fig. 17). In this area the remnants of a septum, and the inner wall structure of the specimen are visible. The chamber arrangement is planiserially coiled in a dextral direction around the centrally situated inital chamber. The chamber series becomes uncoiled and forms a neck. No aperture was located on this specimen. The test wall appears to be finely agglutinated (Plate 3: Figs. 16 and 17).

Comments: This specimen may be the part of the fossil, and the counter-part is missing. The structure of the test wall, and the nature of the inner lining of the test needs further examination.

Ammobaculites sp. 1.

Plate 4: Figures 1, 2 and 3.

Description: This elongate specimen is dark greyish-brown in colour; opaque; laterally compressed and sheared; narrowly ovate in profile and spatulate in outline; and approximately 400µm in length (Plate 4 Fig. 1). The specimen is fractured along the right lateral periphery. The enrolled planiserial chamber arrangement (3 rolls) becomes unrolled and uniserial in the neck. The direction of coiling is sinistral. The initial chambers are centrally situated (Plate 4: Fig. 3; proloculus bottom centre). The smooth wall of a prolocular chamber is bordered (on the right) by a suture (Plate 4: Fig. 3; centrally situated). A rounded, aperture is terminally situated on the final chamber of the neck (Plate 4: Fig. 2). The aperture is rimmed, and plugged, with autogenous matrix. The test wall is finely agglutinated.

Ammobaculites sp. 1.

Plate 4: Figures 4, 5, and 6.

Description: This large, elongate species is bulbo-arcuate in outline; dark yellowish-brown in colour; opaque; has slight lateral compression; ovate in profile; and is approximately 1200μm in length (Plate 4: Fig. 4). The specimen is fractured along the bottom left periphery. The enrolled planiserial chamber arrangement coils dextrally around the initial chamber (Plate 4: Fig. 5). The chamber series is unrolled in the neck. A small, rounded, aperture is terminally situated on the final chamber of the neck (Plate 4: Fig. 6; top right). The aperture lip is slightly produced, and is composed of autogenous material. The test wall is agglutinated with clastic grains, of various sizes.

Affinities: These specimens are very similar in gross morphology, microstructure arrangement and form to representatives of the genus *Ammobaculites* Cushman, 1910.

Comments: The internal continuity, and arrangement of the externally visible sutures and septa for the illustrated forms has not been verified by hand sectioning and X-radiography. The quality of preservation for these specimens is variable. The intraspecific growth form, and external morphology, of recent representatives of the genus *Ammobaculites* is quite variable (Poag, 1978; Ellison and Murray, 1987). Consequently, it is proposed that all of the illustrated specimens belong to a single species.

Genus *Ammomarginulina* Wiesner, 1931

Test elongate, strongly compressed; enrolled and planispiral in early stage, later uncoiled and rectilinear with oblique sutures; wall agglutinated, roughly finished; aperture terminal, rounded, at dorsal angle of the test. Previously reported from Jurassic to Recent; cosmopolitan.

Ammomarginulina sp. 1.

Plate 4: Figures 7, 8, 9, 10, and 11.

Description: This elongate species is yellowish-brown in colour; opaque; roughly fusiform in outline; narrowly ovate profile; and approximately 950 um in length (Plate 4: Fig. 7). The chamber arrangement in the prolocular area is evolute planispiral, and the direction of coiling is sinistral (Plate 4: Fig. 8). The sparsely agglutinated wall of the prolocular chambers is lined with autogenous matrix. A septum, that was exposed during sectioning, is made of the same autogenous substance (Plate 4: Fig. 9; lower right to upper left). The chamber arrangement in the neck section is unrolled, and rectilinear. The orientation of the septa,inthe neck, is oblique to the long axis of the specimen. A rounded aperture is visible on the terminal chamber of the neck (Plate 4: Fig. 7; upper right; and Fig. 10; centre). The aperture is rimmed, and infilled, with an autogenous cement. In section, continuity of the autogenous lining is is visible (Plate 4: Fig. 11). In this area the autogenous component of the test wall is approximately 5 µm thick. The test wall is agglutinated.

Affinities: In gross form, morphology and arrrangement of microstructure this specimen is very similar to representatives of the genus *Ammomarginulina* Wiesner, 1931.

Comments: The internal continuity and arrangement of some of the structures (chambers and septa) have been verified by hand sectioning.

Genus *Ammotium* Loeblich and Tappan, 1953

Test free, compressed, ovate in outline, planispirally enrolled and evolute, with a tendency to uncoil, later chambers extending back toward the proloculus at the inner margin, microsphaeric proloculus, completely surrounded by enroled chambers, whereas the megalosphaeric proloculus is not overlapped by the last chambers of the early portion; wall coarsely agglutinated on an organic lining that also covers the septa, imperforate and lacking calcareous cement; aperture simple, rounded, terminal, at dorsal angle of final chamber, may be temporarily sealed with a plug of debris. Previously reported from Lower Cretaceous (Neocomian) to Recent; cosmopolitan.

Ammotium sp. 1.

Plate 4: Figures 12 and 13.

Description: This elongate species is bulbo-lenticular in outline; dark greyish-brown in colour; opaque; orally-aborally compressed; narrowly ovate in prolocular profile; and approximately 350µm in length (Plate 4: Fig. 12). The specimen is fractured along the top left peripheral margin. The fractured aperture-bearing chamber was sheared down and into the centre of the specimen causing the specimen to split open laterally. This chamber currently rests on the upper left periphery of the specimen, and a depression remains in the former position (Plate 4: Fig. 13). The initial chambers are enrolled in an evolute planispiral, and coil in a sinistral direction around the proloculus (Plate 4: Fig. 13). The chamber arrangement in the neck is uniserial. No aperture is discernable in these photos. The test wall is agglutinated.

Ammotium sp. 2.

Plate 4: Figures 14 and 15.

Description: This specimen is lenticular to flabellate in outline; yellowish-brown in colour; opaque; laterally compressed; narrowly ovate in profile; and approximately 300µm in length (Plate 4: Fig. 14). The specimen is fractured along the right peripheral margin. The prolocular chambers are enrolled in an involute planispiral, and coil in a dextral direction (Plate 4: Fig. 15). The outer roll of chambers is broken off. The chamber arrangement in the neck is unrolled. The septa in the neck are obliquely oriented and trend upward from the proloculus toward the left peripheral margin (Plate 4: Fig. 14). No aperture is visible in these photomicrographs. The test wall is finely agglutinated. The involute planispiral coiling arrangement in the proloculus, and the relatively small test size, suggest that this specimen may be a microspheric form (Culver, 1987).

Ammotium sp. 2.

Plate 5: Figures 1, 2, 3, and 4.

Description: This large, elongate specimen is lenticular in outline; yellowish-brown in colour; opaque; laterally compressed; narrowly ovate profile; and approximately 700µm in length (Plate 5: Figs. 1, and 2). The specimen is fractured along the right lateral periphery. The prolocular chambers are enrolled in an evolute planispiral, and coil in a sinistral direction (Plate 5: Fig. 1). The chambers in the neck are uniserial. The septa, in the neck, originate in the prolocular area, and extend obliquely across the neck toward the apertural terminus (Plate 5: Fig. 1). A small, slit-like, aperture is terminally situated on the final chamber of the neck (Plate 5: Figs. 3; top left, and 4; top). The aperture has a thin, slightly raised, lip that is lined with autogenous material. The slit-like shape of the aperture is probably an artifact of burial. The test wall is agglutinated. The large test size, and the evolute chamber arrangement in the proloculus suggest that this may be a megalospheric morphotype (Culver, 1987).

Affinities: In gross morphology and external microstructure these specimens are similar to representatives of the genus *Ammotium* Loeblich and Tappan, 1953.

Comments: The internal continuity of the septa has not been verified by hand sectioning or X-radiography. These specimens are relatively large, and may be good specimens for X-radiographic examination.

Superfamily LOFTUSIACEA Brady, 1884

Test multilocular, coiling planispiral, streptospiral, or rarely trochospiral with axis of coiling of varied length, may uncoil in later stage and flare or become peneropliforme; wall agglutinated, with differentiated outer imperforate layer and inner alveolar layer. Previously reported from the Middle Triassic to Recent.

Family CYCLAMMINIDAE Marie, 1941

Test enrolled, involute, or rarely uncoiling; agglutinated wall with outer imperforate layer and inner alveolar layer septal structure always differentiated from that of outer wall; aperture interiomarginal or near septal base. Previously reported from L. Jurassic to Recent.

Subfamily BUCCICRENATINAE Loeblich and Tappan, 1985

Test planispiral with few chambers per whorl, later may uncoil; wall agglutinated, earliest whorls may have solid wall and septa, later with thin but distinctly alveolar wall with coarse alveoles of nearly circular section, chamber cavity open, apertural face solid and non-alveolar below the slitlike opening, base of the septa thickened against the previous whorl and may form a continuous imperforate basal layer, with solid triangular chomata-like mounds against the previous whorl at the position of the septa; aperture areal, ranging form just above the base of the apertural face to terminal, an elongate straight to zig-zag slit in the plane of coiling. Previously reported from Lower Jurassic to Recent.

Genus *Buccicrenata* Loeblich and Tappan, 1949

Test planispirally enrolled, compressed, involute in the early stage, later with a tendency to uncoil and become rectilinear; wall agglutinated of calcareous particles mixed with quartz, imperforate epidermal layer covering a shallow alveolar layer in which the alveoles may bifurcate, septa solid, thickened septal base against the previous whorl forming a triangular mound at the position of the septum as seen in median section; aperture elongate, terminal, a straight to zig-zag slit. Previously reported from L. Cretaceous (Aptian) to U. Cretaceous (Cenomanian); Oklahoma; Texas; Florida; Venezuela; Libya; Middle East; Persian Gulf.

Remarks: *Buccicrenata* is characterised by the planispiral early stage and later tendency to uncoil, lobulate margin, thick agglutinated and alveolar wall, chomata-like deposits at the base of the septa against the previous whorl, and elongate zig-zag aperture. Sections of *Buccicrenata* may intersect areas of the alveolar wall at the deeply indented and incised sutures, falsely resembling alveolar septa, but the alveolar character does not extend across the whorl to separate adjacent chambers, and the septa are solid beneath the surface.

?*Buccicrenata sp.* 1.

Plate 5: Figures 5, 6, 7, 8, and 9.

Description: This species is flabellate to broadly spatulate in outline; dark greyish-brown in colour; opaque; dorso-ventrally flattened; narrowly ovate in cross section; and approximately 550µm in length (Plate 5: Fig. 5). The specimen is fractured along the right peripheral margin. An irregular shaped aperture is sub-terminally situated on the final chamber of the neck of this specimen (Plate 5: Figs. 5; top and 6; central) and is rimmed with a lip of autogenous material (Plate 5: Fig. 7). The sphaerical objects may be idiosomes. The chamber arrangement in the neck is unrolled, and rectilinear (Plate 5: Fig. 5). The alveolar wall structure is visible in the neck region of the specimen, and underlies an imperforate epidermal covering (Plate 5: Fig. 8). The chamber arrangement in the prolocular area is involute, and coils in a dextral direction (Plate 5: Fig. 5). The outer wall covering of the coiling section is a smooth non-perforate layer. The alveolor layer is not visble in either the apertural or the prolocular areas. A protruding wedge shaped structure is centrally situated in the coiled end (Plate 5: Fig. 9). The the outer test wall is sparsely agglutinated (Plate 5: Figs. 6, 7, 8, and 9). The agglutinated layer overlies an imperforate epidermal layer, and an alveolar layer.

Affinities: The flabellate outline; narrowly ovate cross section; the involute planispiral to uniserial chamber arrangement; the centrally situated raised wedge-shaped structure in the prolocular area; the terminally positioned, irregular shaped terminal aperture; and the tripartite wall structure (agglutinated grains over an epidermal layer, and an underlying alveolar layer) are all characteristics that this specimen has in common with representatives of the genus *Buccicrenata* Loeblich and Tappan, 1949.

Comments: The internal continuity of the esternally visible structures has not been determined by sectioning or X-radiography. The subterminal position of the apertural structure is an artifact of longitudinal shear during burial. The type species for this genus is *Ammobaculites subgoodlandiensis*, Vanderpool, 1933. The type species, and other previously described forms, were split out of the genus *Ammobaculites* primarily because they produce an alveolar wall structure (Loeblich and Tappan, 1985).

?*Buccicrenata sp.* 2.

Plate 5: Figures 10, 11, and 12.

Description: This species is lenticular in outline; has a lobulate outer margin; dark greyish-brown in colour; opaque; dorso-ventrally flattened; narrowly ovate in cross section; and approximately 300µm in breadth (Plate 5: Fig. 10). The specimen is fractured along the right peripheral margin. The coiling arrangement of this specimen is an involute planispiral, with the final chambers tending to uncoil. The coiling direction is dextral. The irregular opening in an extraumbilical-umbilical position, on the terminal chamber is a detachment along a suture (Plate 5: Figs. 10 and 11). Immediately beneath this crack is an impression which is identical in shape to the margin of the crack. Alternately, this structure may be a supplementary aperture. The underlying alveolar mesh-work is visible in the area where the chambers uncoil (Plate 5: Figs. 10, 11 and 12). The alveolar layer is covered by an imperforate basal layer on both the apertural face, and in the umbilical area (Plate 5: Figs: 10; right, and 11; right). The septum which bounds the terminal chamber is exposed, and is solid (Plate 5: Figures 10, 11, and 12). A protruding pyramidal structure is centrally situated in the umbilical area (Plate 5: Fig. 12). The outer test wall is sparsely agglutinated (Plate 5: Figs. 10, 11, and 12). The agglutinated layer overlies an imperforate epidermal layer, and an alveolar layer.

?*Buccicrenata sp.* 2.

Plate 5: Figures 13, and 14.

<u>Description</u>: This specimen is lenticular to discoidal in outline; has a rounded to lobulate outer margin; dark greyish-brown in colour; opaque; dorso-ventrally compressed; narrowly ovate in cross section; and approximately 200μm in breadth (Plate 5: Fig. 13). A section of the test wall is fractured and displaced upward (Plate 5: Fig. 14; bottom peripheral margin). The coiling is a sinistral, involute planispiral, with an uncoiled final chamber. An irregular apertural opening on the peripheral margin of the terminal chamber is rimmed with a lip of autogenous material (Plate 5: Fig. 13). The wall structure is tripartite with an inner alveolar layer, an imperforate layer and an outer agglutinated layer (Plate 5: Figs. 13, and 14). The alveolar layer is continuous through to the inner wall of the specimen, and is visible through the broken test wall (Plate 5: Fig. 14; bottom). A slightly raised, wedge shaped protuberance is centrally situated in umbilical area (Plate 5: Fig. 13).

<u>Affinities</u>: The lenticular outline; narrowly ovate cross section; the involute planispiral to uncoiled chamber arrangement; the presence of a raised wedge or pyramidal chomata-like structure in the umbilical area; the lack of visible alveolar structures near the apertural face; and

the tripartite wall structure (sparse agglutinated grains, epidermal layer, and alveolar layer) are all characteristics that these specimens have in common with the coiled members of the genus *Buccicrenata* Loeblich and Tappan, 1949.

Comments: The internal continutity of the external structures has not been verified by hand sectioning or X-radiography. However, the externally visible alveolar layer is continuous on the inside surface of the test wall. Closer examination of these specimens is required. This genus has been identified as the best fit for these specimens.

Superfamily TROCHAMMINACEA Schwager, 1877

Test multilocular, chambers in a low trochospiral coil, rarely tending to uncoil in the later stage; wall agglutinated, noncanaliculate, usually with an inner organic lining. Upper Carboniferous to Recent.

Family TROCHAMMINIDAE Schwager, 1877

Test trochospirally coiled; wall agglutinated; aperture interiomarginal to areal, single or multiple and may have supplementary umbilical openings. Upper Carboniferous to Recent.

Subfamily TROCHAMMININAE Schwager, 1877

Test trochospiral or may tend to uncoil in later stage; wall agglutinated; aperture interiomarginal. Upper Carboniferous to Recent.

Genus *Trochammina* Parker and Jones, 1859

Test free, trochospiral, chambers increasing gradually in size as added, sutures radial, periphery rounded; wall agglutinated, imperforate, with inner and outer organic layers and smoothly finished surface; aperture an interiomarginal, umbilical-extraumbilical arch with narrow bordering lip, those of earlier chambers completely covered by later chambers. Previously reported from the Carboniferous to Recent; cosmopolitan.

Trochammina inflata Montague, 1808

Plate 9: Figures 8, and 9.

These two recent specimens were hand sectioned using the technique developed for the Carboniferous specimens. The arrangement, and structure of the exposed proloculár chambers (Plate 9: Fig. 8; centre) and the texture of the autogenous wall (Plate 9: Fig. 9; centre and right respectively) were used to interpret structures on the Carboniferous specimens.

Trochammina sp. 1.

Plate 6: Figures 1, and 2.

Description: This species is globo-lenticular in outline; has a rounded to lobate outer margin; is dark greyish-black in colour; partially pyritised; opaque; ventrally concave; ovate in profile; and approximately 300µm in breadth (Plate 6: Fig. 1). The terminal chamber is crushed. Otherwise, individual chambers are outlined by deeply incised sutures (Plate 6: Figs. 1 and 2). The chamber arrangement is an evolute trochospiral that is enrolled in a sinistral direction. Supplementary apertures may be present in the umbilical area (Plate 6: Fig. 1). The damaged terminal chamber is displaced from its original position, and currently rests on the left peripheral margin of the specimen (Plate 6: Fig. 1). A rounded aperture-like opening is visible on the left peripheral margin of the displaced terminal chamber. A closer examination of the dorsal perspective and the apertural face are required. The test wall is sparsely agglutinated and partially pyritised.

Trochammina sp. 1.

Plate 6: Figures 3, 4, 5, and 6.

Description: This specimen is discoidal in outline; has a lobate outer margin; dark greyish-black in colour; pyritised; opaque; dorso-ventrally compressed; plano-convex in profile; and approximately 950µm in breadth (Plate 6: Figs. 3, 4, and 5). The coiling arrangement is an evolute trochospiral (Plate 6: Fig. 3). The concave umbilcus is partially obscurred by allochthonous material. A slit-like aperture that is rimmed with a lip of autogenous material is situated on the terminal chamber in an areal-peripheral position (Plate 6: Figs. 4, 5 and 6). The umbilical, and terminal chamber areas need to be examined more carefully to fully define the aperture. The sparsely agglutinated test wall is partially pyritised. The large size of this specimen, and the dense pyrite substitution may make this a good specimen for X-radiographic analysis.

Trochammina sp. 2.

Plate 6: Figures 7, and 8.

Description: This species is discoidal in outline; has a lobate outer margin; greyish-brown in colour; translucent to opaque; dorso-ventrally flattened; sheared laterally; narrowly ovate in profile; and is approximately 250 µm in breadth (Plate 6: Fig 7). Three whorls of chambers are visible around the slightly concave proloculus. The chamber arrangement is trochospiral, and coils in a dextral direction. The texturally smooth septal remnants delimit the chambers (Plate 6: Figure 8). The ventral perspective has not been examined with SEM. No aperture is visible on this perspective of the specimen. The test wall is sparsely agglutinated. This totally flattened specimen is fragile. A moderately high angle of tilt on the SEM stage was required to introduce depth into the image and the outline is artificially elongate.

Trochammina sp. 2.

Plate 6: Figures 9, and 10.

Description: This specimen is rounded in outline; has a lobed outer margin; is dark greyish-brown in colour; opaque; dorso-ventrally compressed; ventrally concave; narrowly ovate in profile; and approximately 250µm in breadth (Plate 6: Fig. 9). The shallowly concave umbilicus is cemented densely with autogenous cement (Plate 6: Fig. 10). Ventrally the chamber arrangement is involute, and the chambers are enrolled in a sinistral direction. The wedge-shaped chambers are narrow at the umbilical point of origin, and increase in breadth toward the peripheral margin. Similarly, the suture of the terminal chamber originates in the umbilical area, and continues to the outer left peripheral margin (Plate 6: Figs. 9 and 10). An hemisphaeric hemisphaeric aperture that is rimmed by a lip of autogenous material, and infilled with allochthonous matrix, is situated on the peripheral margin of the terminal chamber (Plate 6: Fig. 9; upper left). The wedge-shaped split, immediately below the aperture, is along a septa or suture of a chamber in the previous whorl. The relatively smooth test wall is sparsely agglutinated.

Trochammina sp. 3.

Plate 6: Figures 11, 12, and 13.

Description: This species is rounded in outline; with a lobed outer margin; is dark greyish-brown in colour; partially pyritised; opaque; dorso-ventrally compressed; ovate in profile; and approximately 350μm in breadth (Plate 6: Fig. 11). The centrally situated proloculus is slightly concave (Plate 6: Figs. 11, and 12; lower, central position). Three whorls of chambers coil in a trochspiral in a sinistral direction around the proloculus. The displacement of the terimal chamber is probably of shear during burial (Plate 6: Figs. 11; left, and 12; left). An equatorially oriented, slit-shaped, aperture is situated subaerially on the terminal chamber (Plate 6: Figs.11, 12, and 13). The aperture has a distinct upper lip of autogenous matrix, and the orifice is plugged with the same material. The test wall is agglutinated.

Trochammina sp. 3.

Plate 7: Figures 1, 2, 3, and 4.

Description: This specimen is yellowish-brown in colour; opaque; dorso-ventrally compressed; plano-convex to concavo-convex in profile: rounded in outline with a lobate outer margin; and approximately 200 μm in diameter (Plate 7: Figs. 1, 2, and 3). The slightly depressed umbilicus is centrally situated on the ventral surface (Plate 7: Fig. 1). The umbilical cavity is large, and at least one intra-umbilical chamber margin is ornamented with a tooth. The wedge-shaped chambers originate in the umbilical area, and expand toward the periphery (Plate 7: Fig. 1). The prolocular chambers are centrally situated on the dorsal surface (Plate 7: Figs. 2, and 3). The chamber arrangement is trochospiral, and coiling is in a sinistral direction (Plate 7: Figs. 3, and 4). Three whorls of chambers can be discerned. The septa are clearly visible on the dorsal surface of this specimen (Plate 7: Figs. 2, 3, and 4). The expanded terminal chamber is crushed, and broken. No aperture was identified on this specimen. The test wall is agglutinated.

Trochammina sp. 3.

Plate 7: Figures 5, 6, and 7.

Description: This specimen is greyish-brown in colour; opaque; dorso-ventrally compressed; narrowly ovoid in profile; rounded to lobed in outline; and approximately 300 µm in diameter (Plate 7: Fig. 5). This specimen is broken along the left peripheral margin. The dorsal chamber arrangement is trochospiral, and coiling is in a sinistral direction around the centrally situated proloculus (Plate 7: Figs. 5, 6, and 7; lower right, immediately below the silt sized clast). A silt-sized grain is positioned between 2 chambers in the initial whorl. The chamber wall surfaces, in both the initial and second whorls, are smoothly lined with autogenous matrix. The outer whorl of chambers is also visible (Plate 7: Figs. 6, and 7). The chambers can be delimited using sutural indentations and grooves, as well as with septa (Plate 7: Fig. 6; top). The later chambers in the oter whorl increase in size toward the terminal chamber. An aperture was not detected on this specimen. The test wall is agglutinated.

Trochammina sp. 3.

Plate 7: Figures 8, and 9.

Description: This specimen is dark yellowish-brown in colour; opaque; dorso-ventrally compressed; narrowly ovoid in profile: rounded to lobed in outline; and approximately 600 µm in diameter (Plate 7: Fig. 8). This specimen is broken along the right peripheral margin. The chamber arrangement is trochospiral, and the dorsal coiling direction is dextral. The proloculus is centrally situated on the dorsal surface (Plate 7: Figs. 8, and 9; centre). Several slightly curved septa, that are lined with autogenous material, are visible on the dorsal perspective. The outer margin of the second whorl of chambers is visible as a dark, curved ridge (Plate 7: Figs. 8; right medial position, and 9; upper right corner around to lower centre). The outward radiating septa abut perpendicularly, and terminate abruptly with the sutural ridge. The chambers in the outer whorl are delimited by sutural depressions and indentations in the lobed peripheral margin (Plate 7: Fig. 8). The final chambers are larger than the earlier chambers in this whorl (Plate 7: Fig. 8; top, centre). No aperture was not identified on this specimen. The test wall is agglutinated.

Trochammina sp. 3.

Plate 7: Figures 10, 11, and 12.

Description: This specimen is dark yellowish-brown in colour; opaque; dorso-ventrally compressed; ovoid in profile; rounded in outline; and approximately 250 µm in diameter (Plate 7: Fig. 10). This specimen is broken along the right and lower peripheral margin on the ventral perspective, and on the left lateral margin on the dorsal perspective (Plate 7: Figs. 10, and 11, respectively). The photomicrograph of the ventral surface was taken with the stage tilted at an high angle, and some length-wise distortion has been introduced. Five, gently curved septa radiate outward from the centrally situated, slightly depressed umbilicus (Plate 7: Fig. 10). The dorsal chamber arrangement is trochospiral, and the coiling direction is sinistral (Plate 7: Figs. 10, and 11). A propeller shaped proloculus is eccentrically situated on the dorsal surface (Plate 7: Figs. 11, and 12; lower, centre). The wall of these chambers is smoothly lined with autogenous matrix. Four chambers are visible in the initial coil (Plate 7: Fig. 12). The final chambers in the outer whorl increase in size the expanded and distorted terminal chamber (Plate 7: Fig. 10; top, centre). The terminal chamber is detached, and rotated outward from the original position (Plate 7: Fig. 10). No aperture was found on this specimen. The test wall is finely agglutinated with clastic grains.

Trochammina sp. 3:

Plate 8: Figures 1, 2, and 3.

Description: This specimen is dark yellowish-brown in colour; opaque; dorso-ventrally compressed; ovoid in profile; rounded to lobulate in outline; and approximately 600 µm in diameter (Plate 8: Fig. 1). This specimen is broken along the lower left peripheral margin. The dorsal chamber arrangement is trochospiral, and the direction of coiling is sinistral (Plate 8:

Figs. 1, and 2). A propeller shaped proloculus is centrally situated on the dorsal surface (Plate 8: Figs. 1; centre, and 2; upper left). The sutures and the and initial whorl of chambers are lined with autogenaous matrix. The chambers in the outer whorl increase in size toward the terminal chamber (Plate 8: Fig. 1; top, left). An equatorially-oriented, slit-shaped aperture is peripherally situated on the terminal chamber (Plate 8: Figs. 1, and 3). The aperture has a distinct upper and lower lip that are composed of autogenous matrix. The test wall is finely agglutinated.

Trochammina sp. 4.

Plate 8: Figures 4, and 5.

Description: This species is dark greyish-brown in colour; translucent to opaque; dorso-ventrally flattened; narrowly ovoid in profile: rounded in outline; and approximately 250 µm in diameter (Plate 8: Fig. 4). This specimen is sheared along the lower right peripheral margin. The dorsal chamber arrangement is trochospiral, and the coiling direction is sinistral (Plate 8: Fig. 4). The proloculus is eccentrically situated. The surfaces of the chambers in the proloculus and initial whorl are densely lined with autogenous material. Four chambers are clearly visible in the initial whorl. The chambers in the outer whorl are delimited by remnants of septa. The chambers increase in size toward the terminal chamber (Plate 8: Fig. 4; upper, left). A double aperture structure is present on the apertural face of the terminal chamber (Plate 8: Figs. 4; left peripheral margin, and 5; left, centre). An equatorially oriented, interiomarginally positioned, slit-shaped aperture is accompanied by one or more aerially situated supplementary apertures (Plate 8: Figs. 4, and 5). All the apertures are lined and rimmed with a lip of autogenous matrix. The test wall is agglutinated.

The characteristics of this specimen, most specifically the apertural arrangement, are very similar to those observed in recent representatives of the species *Jadammina polystoma* Bartenstein and Brand, 1938. Scott and Medioli (1980) presented several specimens from both species *Trochammina macrescens* Brady, 1870, and *Jadammina polystoma*, and clearly illustrated an intergradational series between these two species. Loeblich and Tappan, (1988) re-examined the type specimen for *Jadammina polystoma* and placed the type specimen in synonymy with *Trochammina macrescens*.

Trochammina sp. 3.

Plate 8: Figures 6, and 7.

Description: This specimen is dark greyish-brown in colour; translucent to opaque; dorso-ventrally flattened; narrowly ovoid in profile: rounded in outline; and approximately 250 µm in diameter (Plate 8: Fig. 6). This specimen is broken along the lower left peripheral margin. The dorsal chamber arrangement is trochospiral, and the coiling direction is dextral (Plate 8: Fig. 6). The centrally situated proloculus is surrounded by the initial whorl of chambers. Six chambers can be discerned in the initial whorl with the final, and largest, chamber being clearly visible (Plate 8: Fig. 6; centre). The chamber surfaces are smoothly lined with autogenous material and are separated by septal remnants. The chambers in the outer whorl can be delimited by the curved remnants of sutures and the slight indentations on the outer margin. The chambers of the outer whorl increase in size toward the terminal chamber (Plate 8: Fig. 6; right, centre). The terminal chamber is crushed. An equatorially oriented, slit-shaped aperture is present in an interiomarginal position on the apertural face of the terminal chamber (Plate 8: Fig. 7; top right). The aperture is densely lined with autogenous cement and the crescent-shaped upper lip may be displaced upward from the original position. The test wall is finely agglutinated (Plate 8: Figs. 6, and 7).

Trochammina sp. 4.

Plate 8: Figures 8, and 9.

Description: This specimen is dark greyish-brown in colour; translucent to opaque; longitudinally compressed; concavo-convex in profile: rounded to fusiform in outline; and approximately 150 µm in diameter (Plate 8: Fig. 8). This specimen is broken along the left peripheral margin. The dorsal chamber arrangement is trochospiral and the direction of coiling is dextral (Plate 8: Fig. 8). The propellar-shaped proloculus is centrally situated. Three chambers of the initial whorl can be distinguished by the smooth wall texture (Plate 8: Fig. 8; lower centre). Some chambers are delimited by septa, and sutural invaginations in the peripheral margins. The chamber size, in the outer whorl, increases toward the terminal chamber (Plate 8: Fig. 8; bottom, centre). The once inflated terminal chamber is crumpled inward. An equatorially oriented, slit-shaped aperture is situated below the terminal chamber in an interiomarginal position (Plate 8: Figs. 8; bottom left periphery, and 9; left centre). The aperture is smoothly lined with autogenous cement. The apertural face is ornamented with as many as four rounded openings that have a slightly produced lip of autogenous material (Plate 8: Fig. 8). These openings may be supplementary apertures, similar to those that characterise recent species *Jadammina polystoma.* The smooth autogenous chamber lining is visible in the fractured early chambers that are situated abovethe slit-shaped aperture (Plate 8: Figs. 8; left periphery, and 9; upper left periphery). The test wall is agglutinated. The outline of the specimen is distorted in the SEM image due to the relativley high angle of stage tilt used to introduce relief in the images.

Trochammina sp. 3.

Plate 8: Figures 10, 11, and 12.

Description: This specimen is dark greyish-brown in colour; translucent to opaque; concavo-convex in profile; rounded to lobulate in outline; and approximately 180 μm in diameter (Plate 8: Fig. 10). The specimen is broken along the lower left peripheral margin. The chamber arrangement is trochospiral and the coiling direction is dextral (Plate 8: Fig. 10). Five prolocular chambers are visible and the fifth, and final chamber, is the largest and most pronounced [arrow heads] (Plate 8: Figs. 10; centre, and 11; centre). Two whorls of chambers are visible on the dorsal perspective of this specimen. The chamber walls are lined with autochthonous matrix. Septal remnants, and the sutural invaginations into the outer peripheral margin also aid in delimiting the chamber arrangement. The chamber size increases toward the damaged terminal chamber. The apertural face of the terminal chamber currently rests on the outer periphery of the terminal chamber (Plate 8: Fig. 10; lower periphery). An equatorially oriented, slit-shaped aperture rests immediately below the intracameral interstice of an earlier chamber (Plate 8: Fig. 12; intracameral interstice upper left; aperture lower left). The aperture is lined with autogenous material. The test wall is sparsely agglutinated. The SEM image for this specimen is distorted (elongated) due to the angle of stage tilt used to photograph this specimen.

Trochammina sp. 3.

Plate 9: Figures 1, and 2.

Description: This specimen is dark yellowish-brown in colour; opaque; dorso-ventrally flattened; narrowly ovoid in profile; rounded to lobulate in outline; and approximately 330 μm in diameter (Plate 9: Figs. 1, and 2). The chamber arrangement is trochospiral and the coiling direction is sinistral. Two whorls of chambers are visible around a centrally situated proloculus. The truncated wedge-shaped chambers in the outer whorl increase in size toward the terminal chamber (Plate 9: Figs. 1, and 2; top left). The terminal chamber is broken on this specimen. The test wall is finely agglutinated.

Trochammina sp. 3.

Plate 9: Figure 3.

Description: This specimen is greyish-brown in colour; translucent to opaque; dorso-ventrally flattened; narrowly ovoid in profile; rounded to lobulate in outline; and approximately 250 μm in diameter (Plate 9: Fig. 3). The chamber arrangement is trochospiral and the direction of coiling is dextral. Five chambers in the initial whorl surround a centrally situated proloculus. The chambers in the outer whorl increase in size toward the terminal chamber (Plate 9: Fig. 3). The apertural face of the terminal chamber is broken off this specimen. The test wall of this specimen is agglutinated.

Affinities: The specimens illustrated on Plates 6, 7, 8, and 9; Figures 1 through 4, have morphological characteristics that are common to recent representatives of the genera *Trochammina,* and *Jadammina*. Four species are tentativley identified in this work. Some specimens are not adequately illustrated and require more examination to complement this work.

Superfamily TEXTULARIACEA Ehrenberg, 1838

Test trochospiral, triserial or biserial in early stages; later may be biserial or uniserial; wall agglutinated, caniculate. Previously reported form the Middle Jurassic (Bajocian) to Recent.

Family TEXTULARIIDAE Ehrenberg, 1838

Test biserial, at least in the early stage, later may be reduced to uniserial; wall agglutinated, caniculate; aperture interiomarginal to areal, single or multiple. Previously reported from the Palaeocene to Recent.

Subfamily TEXTULARIINAE Ehrenberg, 1838

Test free, aperture interiomarginal, at least in the early stage, may become areal when the test is terminally uniserial. Previously reported from the Palaeocene to Recent.

Genus *Textularia* Defrance, 1824

Test biserial throughout or may have an adventitious third chamber against the first pair of chambers in the microsphaeric generation; wall agglutinated, traversed by canaliculi that may open as perforations or be closed externally by a thin agglutinated layer and typically are closed internally by the organic lining of the test; aperture a low arch or slit at the base of the apertural face. Previously reported form the Palaeocene to Recent; cosmopolitan.

?*Textularia sp.* 1.

Plate 9: Figure 4.

Description: This species is greyish-brown in colour; translucent to opaque; laterally compressed; broadly ovoid in profile: lobulate in outline; and is 35µm at the base flaring to 180 µm in diameter at the expanded apertural terminus (Plate 9: Fig. 4). The early coiling stage is broken off, and the chamber arrangement is biserial throughout. The chambers increase in size toward the apertural terminus. An arch shaped aperture is situated at the base of the terminal chamber (Plate 9: Fig. 4; top right). The test wall of this specimen is agglutinated.

?*Textularia sp.* 1.

Plate 9: Figure 5.

Description: This specimen is greyish-brown in colour; translucent to opaque; laterally flattened; narrowly ovoid in profile: lobulate in outline; and is 60µm at the base flaring to 150 µm in diameter at the expanded apertural terminus (Plate 9: Fig. 5). The early coiling stage of this specimen is broken away. The chamber arrangement is biserial throughout. The chambers increase in size toward the terminal chamber (Plate 9: Fig. 5; top). The terminal chambers of this specimen are damaged, and apertural remnants may be present.

Affinities: Morphologically these specimens resemble recent representatives of the genus *Textularia* Defrance, 1824. Species of this genus are split into two separate groups based upon cement composition and wall structure. Since these specimens are more than 300 million years in age the original composition of the cement cannot be determined. These specimens survived conodont processing techniques, and it is unlikely that the cement is presently calcareous. Textulariids characteristically produce an autogenous caniculate inner wall which underlies, and is inter-fingered with the agglutinated outer layer. Perforations from this layer may not be visible externally. The wall structure of the Carboniferous specimens requires a detailed examination, perhaps sectioning, to determine if the caniculate inner wall is present. In the absence on the caniculate wall structure these specimens should be reassigned to the following group:

Superfamily SPIROPLECTAMMINACEA Cushman, 1927

Test planispirally coiled in early stage, later biserial; wall agglutinated, noncanaliculate. Previously reported from the Carboniferous to Recent.

Family TEXTULARIOPSIDAE Loeblich and Tappan, 1982

Test free, early stage biserial, or may have a single adventitious chamber resulting in a pseudotriserial base, later may be biserial, loosely biserial of uniserial. Previously reported from the Lower Jurassic (Pliensbachian) to Upper Cretaceous (Maastrichtian).

Genus *Textulariopsis* Banner and Pereira, 1981

Test biserial throughout, but may have a single adventitious third chamber at the base, later may be flaring or elongate and parallel sided; wall agglutinated, commonly of calcareous particles, solid, noncaniculate; aperture a low arch of slit at the base of the apertural face. Previously reported from the Lower Jurassic (Pliensbachian) to Upper Cretaceous (Maastrichtian); cosmopolitan. The wall ventral perspective of this specimen requires examination.

Phylum ANNELIDA

Worms with distinct head, segmented trunk, and unsegmented pygidium. Proterozoic to Recent. (after Howell, 1962).

Class POLYCHAETA Grube, 1851

Segments of trunk bearing lateral bundles of bristles called chaetae. [Mostly marine but some live in brackish and fresh waters.] Cambrian to Recent.

Order SEDENTARIDA Lamarck, 1818

Worms that build tubes or burrows in which they live; no teeth or jaws present. [Marine.] Cambrian to Recent.

Family SERPULIDAE Johnston, 1865

.....calcareous or horny operculum, builds calcareous tube that is circular, polygonal or triangular in cross section, and may be ornamented on outside with concentric raised rings or longitudinal ridges or keels; usually attached for part or all of its length to substratum but some free throughout entire length [Mostly marine but may occur in fresh waters.] Cambrian to Recent.

Genus *Spirorbis* Daudin, 1800

Tube small, coiled in flat spiral, some shells bearing concentric ridges, attached to substratum. [Marine and fresh water.]. Ordovician to Recent, cosmopolitan.

Habitat: Commonly attached to kelps, Irish moss, and other algae, and seldom attached to rocks and shells; from above the tide line to shallow depths. [Marine.] (after, Gosner, 1978; and Meinkoth, 1981).

Spirorbis borealis Daudin, 1800

Plate 9: Figure 10.

This recent specimen was collected and photographed for comparative morphological purposes. The slightly raised coil of this specimen is rounded in outline, and approximately 2 mm in diameter. The smooth, outer surface of the tube is without unornamentation (longitudinal ridges). The direction of coiling is sinistral (counterclockwise from the opercular opening inward).

Spirorbis sp. 1.

Plate 9: Figure 11.

Description: The Carboniferous specimen is rounded in outline; the sinsitrally coiled tube is slightly raised; and is 1.1 mm in diametre. The umbilicus and the operculum of this specimen obstructed by allochthonous material. The latter may be damaged. The relatively smooth outer surface of the tube has concentric rings that may record annular or seasonal variation in growth, and is unornamented by longitudinal ridges. The tube composition is calcareous. The base of attachment is open, and the object of attachment was not identifiable (substrate).

The tube of this specimen is essentially indistinguishable from recent representatives of the genus *Spirorbis.*

Phylum ARTHROPODA

Superclass CRUSTACEA

Class BRANCHIOPODA Latreille, 1802

Crustacea in which carapace may form dorsal shield or bivalve shell or be absent...

Lower Devonian to Recent.

Subclass DIPLOSTRACA Gertstaecker, 1866

Bivalve carapace (single piece in cladocerans), laterally compressed, enclosing body and appendages... Lower Devonian to Recent.

Order SPINICAUDATA Linder, 1945

Laterally compressed, with or without umbones and with many lines of growth, connection between halves elevated;.... Lower Devonian to Recent.

Superfamily LIMNADIOIDEA Baird, 1849

Valves characterised by prominent umbo. Carboniferous to recent.

The carapaces of several genera of the Limnadioidea exhibit well-marked curvature of the posterior margin near the dorsal line, thus producing a distinctive outline. Branchiopod bivalves of this type are designated as **limnadiiformes**. Such recurvature is observed in some other superfamilies (e.g., Leaioidea, Vertexioidea) of the Spinicaudata and may result in a spinous projection above the dorsal margin of the carapace (e.g., *Keratestheria*, Ipsilonidae)

Family LIMNADIIDAE Baird, 1849

Carapace broadly oval, compressed, with variable number of concentric growth lined around prominent umbo... Carboniferous to Recent.

Subfamily ESTHERIININAE Kobayashi, 1954

Valves with large, prominent umbo resembling living *Limnadia*. Carboniferous to Lower Cretaceous.

Genus ?*Limnestheria* Wright, 1920

Carapace oval, punctate, about 10 growth lines surrounding large, smooth umbonal area... Carboniferous.

?*Limnestheria sp.* 1.

Plate 9, Figures 12 and 13.

Description: The shell of this specimen is dark brown in colour; ovoid in outline; compressed biconvex in profile; bilaterally symmetrical; the carapace surface is punctate; the dorsal line is curved; and is approximately 500 μm in diameter (Plate 9: Figs. 12 and 13). The umbones are expanded beyond the dorsal line, and their surfaces are smooth and unornamented. Five or 6 circum-peripheral growth lines can be distinguished on this specimen.

Comments: This specimen is small and may be a larval form rather than a mature adult (adult range is 2-16 mm).

Phylum MOLLUSCA

Class CEPHALOPODA

?Cephalopoda specimen 1. Plate 9: Figure 14.

Description: The specimen is dark brown in colour; laterally flattened; dextrally coiled, distinctly chambered, shell that appears to have a crystalline texture; sutures are simple, and without distinct lobes and saddles (orthoceratitic); and a tubular structure (siphuncle) in an anterio-ventral position. The specimen is approximately 1.2 mm in diameter and is thought to be a juvenile form (nepionic whorl) of a nautiloidean cephalopod.

Chapter 5. Transport

The probability that fossils, especially microfossils, are reworked from older strata must always be considered and can never be totally discounted. The following section provides several reasons why the specimens documented in this study are thought to be *in situ* rather than reworked.

Transport during the Carboniferous was controlled by physical processes, namely aero- and hydrodynamics. The Carboniferous foraminiferal specimens are larger in size than the component grains in the associated lithologic unit. Consequently, the higher flow velocity required to transport the specimens would preclude the deposition of the finer clastic grains observed in the associated lithologic unit.

The assemblage member composition, of agglutinated foraminifera, varies at the genus level when compared across the 8 lithologically isolated units. This variation suggests that these microfossils have not been reworked from a common source. This is the first Palaeozoic aged strata from which agglutinated brackish water foraminifera have been extracted. These types of foraminifera are not reported from the marine members of the Windsor group.

Some of the Carboniferous specimens are completely flattened and are not infilled. Many of the compressed specimens are extracted from fossiliferous horizons for which the biota are considered *in situ*. The xenosomes that are incorporated into the agglutinated test wall by the protistan amoebae are collected from the milieu in which they exist. The constituent grains of the test walls, in these specimens, are indistinguishable from those in the lithologic unit from which they were extracted. In addition, none of the infilled specimens contain material that is visibly or chemically different from that of the surrounding lithotype. These relationships suggest specimen infilling and compression, during or shortly after burial, and reflect *in situ* assemblages of microfossils.

Chapter 6. Protistan assemblages and environments of deposition

Genus-level assemblages of agglutinated foraminifera and arcellaceans from modern marine-influenced and fresh water environments, were compiled for comparative analyses. For the purposes of this study, the more recently evolved calcareous-walled foraminifera are distilled out of the modern model assemblages. Protistan assemblages from modern mangrove swamp and saline-lacustrine environments were also compiled for this study and are discussed briefly in the following text.

The genera of agglutinated foraminifera that characterise modern mangrove swamp environments are as follows: *Haplophragmoides*, *Ammobaculites*, *Trochammina* (several forms), *Ammoastuta*, *Ammotium*, *Miliammina*, with minor presences of *Textularia* and *Polysaccammina*. A representative mix of arcellacean taxa are also reported (Cushman and Brönnimann, 1948a, 1948b; Brönnimann and Keij, 1986; Scott *et al.*, 1990, 1991). The geographic and climatic distribution of the mangrove swamp assemblage is limited to a narrow, circum-equatorial tropical to subtropical zone.

Saline lacustrine environments are generally populated by exotic (imported) calcareous benthic foraminifera (Mesozoic to Recent). These foraminifera are most commonly reported from a nearshore, marine habitat. The transport of the foraminifera into the saline lakes is facilitated by migratory birds. Consequently, the assemblage diversity can be variable (Patterson, 1987).

The foraminiferal assemblages from brackish water, lacustrine environments are, for the most part, dominated by a single morphologically stable species of foraminifera, such as; *Jadammina*. A moderately diverse population of arcellinids is also reported from the environment. Again, the transport of the protistans, especially the foraminifera, is by migratory birds (Patterson, Scott, and McKillop, 1990; Patterson, and McKillop, 1991). Few studies document the distribution of protists in non-classical habitats and due to this there is little data for qualitative comparison. These environments were not interpreted from the suite of lithic units studied. The modern environments and assemblages that are identified as analogous to the Carboniferous environments are listed in Table 2.

The assemblage of agglutinated protists extracted from Unit QT48a includes the following taxa: *Ammobaculites*, *Trochammina* (4 forms), ?*Buccicrenata* (2 forms), ?*Textularia*, *Trochamminita*, and *Ammotium*. Two arcellacean genera, *Difflugia* and *Heleopora* are also present. The dominance of this assemblage by *Ammobaculites* and *Trochammina* indicate that this was a shallow, subtidal environment with salinities >10 and <25‰.

This black, carbonate rich, shale unit has wavy bedding and parallel laminations that are not interrupted by either bioturbation or root mottling. The lamination planes are populated by low diversity and high density community of epifaunal bivalves, serpulid worm tubes and ostracods. Pyrite is present as framboids, amorphous agglomerations, and as totally infilled serpulid worm tubes, bivalves and ostracods. This is suggestive of activity by predominantly marine, sulphate reducing, bacteria and of intermittent hypoxic conditions at or below the sediment water interface.

Outcrop, drill core, and borehole correlations indicate that Unit QT48a is laterally continuous for several ten's of kilometres (Best, 1984; Bird, 1987; White, 1992). Areal isolation from a clastic source is indicated by the paucity of siliclastic grains recovered from this unit (White, 1992). Indicators of sustained turbulence are the club- and column-like algal growth morphs (Masson and Rust, 1983; Vasey and Zodrow, 1983), and rill-like lags of fragmented and disarticulated bivalve shells (White, 1992). A nearshore to abandoned delta lobe environment is interpreted for this unit, and a bioconstructive, calcite secreting algae is proposed as the base for this community.

Unit QT49a directly overlies the bioconstructive algal-based community. The lower contact of this silty, carbonaceous claystone is abrupt. Internal structures include planar bedding and low angle ripple cross stratification. The foraminiferal assemblage extracted from this unit includes *Ammobaculites*, *Haplophragmoides*, and two forms of *Trochammina*. The

Table 2: The environment of deposition for each lithologic unit in this study. The qualitative lithological descriptions for each unit are after Bird (1985/1986).

Modern Assemblages Genera and Species	References	Sample Number	Carboniferous Assemblages	Lithology and Structures (after Bird, 1985, 1986)	Environment
Ammobaculites sp. *Trochammina sp.* *Ammotium sp.* *Miliammina sp.* *Haplophragmoides sp.* *Textularia sp.* *Difflugia sp.*	Poag, 1978; Haman, 1982; Haman, 1983 Scott, and others, 1990; Scott, and others, 1991.	QT48a	*Difflugia sp. 3* *Heleopora sp. 1* *Miliammina sp. 1* *Trochamminita sp. 1* *Ammobaculites sp. 1* *Ammobaculites sp. 1* *Ammobaculites sp.1* *Ammotium sp. 1* *Buccicrenata sp. 1*	Lithology: black limestone; Thickness: 30 cms; Basal contact: abrupt; Style of bedding: wavy (stromatolites?); Colour: dark grey (fresh), brownish grey (weathered); Calcareous: highly; Concretions: no; Organic Material: bivalve bed.	shallow, subtidal , photic zone, nearshore to abandoned delta lobe, distal to clastic source, bioconstructive algal-bivalve-serpulid community; estuarine to marine salinity
			Buccicrenata sp. 2 *?Buccicrenata sp. 2*	Sedimentary Structures: very fine, horizontal, wavy laminations (<1 mm)	
			Trochammina sp. 1		
			Trochammina sp. 2		
			Trochammina sp. 3		
			Trochammina sp. 3		
			Trochammina sp. 3		
			Trochammina sp. 4		
			Trochammina sp. 4		
			Trochammina sp. 4		
			?Textularia sp. 1		
			?Textularia sp. 1		
			Spirorbis sp. 1		
			Cephalopoda sp. 1		
Ammobaculites dominated; *minor representatives:* *Haplophragmoides* *Miliammina* *Ammotium* *Trochminita* *Trochammina*	Poag, 1978; Haman, 1983; Hiltermann and Haman, 1985; Ellison and Murray, 1987 Scott and others, 1991	QT49a	*Haplophragmoides sp. 1* *Ammobaculites sp. 2* *Trochammina sp. 2* *Trochammina sp. 3*	Lithology: silty, carbonaceous claystone; Thickness: 50 cms; Basal contact: abrupt; Style of bedding: planar; Colour: dark grey (fresh), dark brownish grey (weathered); Calcareous: no; Concretions: no; Organic Material: abundant? fine fragments.	levee/crevasse splay; distal to clastic source perhaps lower delta plain; low salinity
				Sedimentary Structures: very fine, horizontal laminations (<1 mm)	

Table 2; p. 1 of 3.

Modern Assemblages Genera and Species	References	Sample Number	Carboniferous Assemblages	Lithology and Structures (after Bird, 1985, 1986)	Environment
Ammobaculites dominated; *minor representatives:* *Haplophragmoides* *Miliammina* *Ammotium* *Trochminita* *Trochammina*	Poag, 1978; Haman, 1983; Hiltermann and Haman, 1985 Ellison and Murray, 1987 Scott and others, 1991	QT83a	*Ammobaculites sp. 1* *Ammobaculites sp. 1*	Lithology: silty sandstone; Thickness: 220 cms; Basal contact: abrupt; Style of bedding: planar; Colour: grey (fresh), greenish brown grey (weathered); Calcareous: no; Concretions: occur in restricted zones, 4-6 cms thick (10% concretions).	Levee/crevasse splay; brackish, low salinity
				Organic Material: small roots and traces evident throughout, concentrations on bedding planes(comminuted?); Sedimentary structures: some planar laminations, some low angle ripples, both concentrated in more sand rich areas.	
Miliammina sp. *Trochammina sp.*	Scott, 1976; Scott and Medioli, 1978; Scott, and Medioli, 1980; Petrucci, and others, 1983;	Q129a	*Miliammina sp. 1* *Trochammina sp. 3*	Lithology: claystone, partial redbed; Thickness: 50 cms; Basal contact: gradational; Style of bedding: unbedded; Colour: n/a (fresh), red, green, grey (weathered); Calcareous: no; Concretions: no;	Low marsh to middle marsh; brackish, variable salinity.
	Scott, and Medioli, 1986; Scott and others, 1990; Scott and others, 1991.			Organic Material: concentrated around mottles. Sedimentary Structures: bedding mottled away (bioturbated), 15 to 20 cms from the top is a grey band (bed?).	
Ammobaculites *Trochammina* *Ammotium* *Miliammina* *Haplophragmoides* *Textularia* *Difflugia*	Poag, 1978; Haman, 1982; Haman, 1983; Hiltermann and Haman, 1985; Scott, and others, 1990; Scott, and others, 1991.	QT171	*Trochammina sp. 2* *Spirorbis sp. 1*	Lithology: carbonaceous silty claystone; Thickness: 35 cms; Basal contact: abrupt; Style of bedding: wavy planar; Colour: dark grey (fresh), rusty brown (weathered); Calcareous: no; Concretions: no.	marine influenced, shallow, subtidal , photic zone, nearshore to abandoned delta lobe, distal to clastic source, bioconstructive algal-bivalve-serpulid community; esutarine to marine salinity
				Organic Material: abundant (60%), bivalve beds, coalified plant fragments; Sedimentary Structures: none.	
Difflugia sp. (several species) *Centropyxis sp.* *Pontigulasia sp.*	Haman, 1982; Scott, and Medioli, 1983; Hiltermann and Haman, 1985; Medioli, and others, 1986;	Q176a	*Difflugia sp. 1* *Difflugia sp. 3*	Lithology: siltstone; Thickness: 60 cms; Basal contact: abrupt; Style of bedding: unbedded; Colour: light greenish brown (fresh), purply rusty brown (weathered); Calcareous: no; Concretions: trace;	fresh water, lacustrine; upper estuarine to riverine

Table 2; p. 2 of 3.

Modern Assemblages Genera and Species	References	Sample Number	Carboniferous Assemblages	Lithology and Structures (after Bird, 1985, 1986)	Environment
	Medioli and Scott, 1988; Medioli, and others, 1990; Haman, 1990; Scott, and others, 1991			Organic Material: trace, fragmentary; Sedimentary Structures: none, bioturbated away.	
Trochammina sp. *Ammotium sp.* *Ammobaculites sp.* *Miliammina sp.* *Haplophragmoides sp.* *Difflugia sp.*	Scott, Medioli and Schafer, 1977; Poag, 1978; Scott and Medioli, 1980; Scott, Schafer, and Medioli, 1980; Scott and Martini, 1982;	QT178a	*Difflugia sp. 2* *Ammobaculites sp. 1* *Ammobaculites sp. 1* *Ammobaculites sp. 1* *Ammomarginulina sp. 1* *Ammotium sp. 1* *Ammotium sp. 2*	Lithology: clayey siltstone; Thickness: 150 cms; Basal contact: abrupt; Style of bedding: homogeneous; Colour: greenish brown grey (fresh), purply brown, locally rusty (weathered); Calcareous: no; Concretions: trace, sideritic? cement common;	Estuarine to transitional marine
	Alve and Nagy, 1987; Nagy and Alve, 1986; Ellison and Murray, 1987;		*Trochammina sp. 3* *Trochammina sp. 3* *Trochammina sp. 3*	Organic Material: none observed but morphocasts observed; Sedimentary Structures: none.	
Ammobaculites dominated; *minor presence of:* *Psammosphera sp.*	Haman, 1982; Haman, 1983; Hiltermann and Haman, 1985; Haman, 1990; Scott, and others, 1991	Q197a	*?Paranebela sp. 1* *Sorosphaera sp. 1*	Lithology: carbonaceous siltstone; Thickness: 150 cms; Basal contact: nd; Style of bedding: homogeneous; Colour: dark grey (fresh), dark purply, rusty grey (weathered); Calcareous: no; Concretions: common; small, lenses present.	marine influenced brackish (low salinity) shallow water to intermittently emergent; vegetated; interdistributary bay to distal levee; brackish, low salinity
				Organic Material: abundant, roots in subvertical positions, also accumulations of fragmentary material; Sedimentary Structures: none, bioturbated away.	
Ammobaculites dominated; *minor representatives:* *Difflugia sp.*	Poag, 1978; Haman, 1982; Haman, 1983; Hiltermann, and Haman, 1985; Ellison and Murray, 1987;	Q265a	*Difflugia sp. 2* *Heleopora sp. 1* *Ammobaculites sp. 1*	Lithology: siltstone, minor clay; Thickness: 60 cms; Basal contact: gradational; Style of bedding: wavy; Colour: dark grey (fresh), rusty brown (weathered); Calcareous: no; Concretions: trace.	marine influenced, brackish (low salinity), levee-crevasse splay; brackish, low salinity
	Haman, 1990; Scott and others, 1991			Organic Material: abundant, fragment accumulations on lamination planes; Sedimentary Structures: subplanar horizontal laminations present.	

Table 2; p. 3 of 3.

composition of this assemblage is similar in genetic diversity to the upper estuarine assemblage reported by Scott and others (1980). This assemblage is also similar to the *Ammobaculites*-dominated assemblage identified from a levee-crevasse splay environment on the lower delta plain of the Mississippi Delta (Haman, 1983). The lithology and sedimentary structure of this unit are consistent with a distal levee-crevasse splay depositional environment (Coleman and Prior, 1980; Elliot, 1986).

Unit QT83a contains representatives of the foraminiferal genus *Ammobaculites*. Modern species of this genus are common in marine influenced, estuarine and lower delta plain environments. This silty sandstone is situated in the upper portion of a 3 m thick coarsening up sequence of interbedded silt and fine sand. Internal structures include planar bedding and small-scale ripple cross-stratification (stacked, graded beds?). The lower contact is abrupt. The foraminifera indicate that Unit QT83a was marine influenced, and the sedimentary structures are consistent with a levee-crevasse splay sedimentary environment.

Unit Q129 has an assemblage of foraminifera which is characteristic of modern, marine influenced, low to middle marsh environments. The co-occurrence of *Trochammina* and *Miliammina* is a diagnostic combination of taxa for this habitat. The bioturbated and mottled clays, as well as rare concentrations of organic material are also consistent with this interpretation (Bird, 1985/1986). The characteristic assemblage of foraminifera and the sedimentary structures support an interpretation of a marine influenced, low to middle marsh environment.

Unit QT171 immediately overlies the Harbour Coal seam and is, in turn, overlain by an erosive based, multi-storey channel sandstone unit. Unit Q171a is similar to Unit QT48a in both sedimentary structure and biotic diversity. However, a decrease in carbonate content, an increase in comminuted plant fragments and a less diverse foraminiferal assemblage are reported. The foraminifera extracted from this unit are representatives of the genus *Trochammina*. The environment of deposition for this unit is a shallow, submarine nearshore to abandoned delta lobe with a salinity range between 10 and 25‰. Again, this unit is laterally continuous and the unit occupies a similar sequential position in the section to unit QT48a. This bioconstructive lithic unit probably formed under a marine nearshore to abandoned delta lobe environment.

Unit QT176 is a thin, silty clay horizon with homogenous bedding and few traces of organic material. Two (2) forms of arcellaceans, genus *Difflugia,* were extracted from this unit. Recent arcellaceans characteristically inhabit fresh water lacustrine and riverine environments. The information derived from the microfossil presence and the sedimentary structures indicate that the environment of deposition was fresh water and may have been lacustrine to upper estuarine-riverine.

The Carboniferous foraminiferal assemblage in Unit QT178a is comprised of the following genera; *Ammobaculites*, *Ammotium* (2 forms), *Trochammina*, and *Ammomarginulina*. Assemblages with similar composition are characteristic in lower estuarine to transitional marine environments. *Ammomarginulina* is commonly reported from fully marine, inner to outer shelf environments (Culver and Buzas, 1983). The unit is a bioturbated to homogenous clayey mudstone with traces of organic material and small concretions. The generic diversity of the foraminiferal assemblage, and the sedimentological structures are consistent with an upper estuarine to transitional marine environment of deposition and salinities >10 and <25‰ (Scott, Schafer and Medioli, 1980).

Unit QT197a overlies the multiple splits of the Lower Hub coal seam. This structureless siltstone has abundant coalified material and root mottles. In this sample specimens of the foraminiferan *Sorosphaera* are common. The genus-characteristic bipartite wall structure was identified using SEM analysis. Modern sorosphaerans are common in slope and abyssal plain environments. In contrast, Palaeozoic representatives were frequent members of shallow marine, carbonate producing environments (Conkin and Conkin, 1968; Conkin, Conkin and Thurman, 1979). Related foraminifera, with similar form and appearance, are often reported from modern coastal environments (Haman, 1983; Scott and others, 1991). Specimens of an arcellacean genus, tentatively identified as *Paranebela*, are also present in this sample. The Carboniferous specimens have morphological characteristics that are common to several extant arcellacean genera, however, no single genus displays all these features. A marine influenced, shallow water to intermittently emergent, vegetated interdistributary bay to distal levee environment of deposition is interpreted for this unit.

Two genera of arcellaceans; *Difflugia*, and *Heleopora*, and a single foraminiferal genus (*Ammobaculites*) were extracted from Unit Q265a. A mixed assemblage of arcellaceans and foraminifera is indicative of low, and perhaps fluctuating, salinities in the environment of deposition. This Carboniferous assemblage is similar, in both diversity and composition, to the overbank distributary, levee-crevasse splay assemblage reported from the lower delta plain environment of the Mississippi Delta (Haman, 1982, 1983).

Unit Q265a is the middle member in a small coarsening up succession. At the base of this sequence is the Upper Lloyd Cove coal seam. This thin seam (1 m) has an increased proportion of claystone interbeds toward the top. The upper contact is gradational. Unit Q265a is a wavy bedded siltstone, with minor claystones. Comminuted plant fragment concentrations are visible between the subplanar to horizontal laminations. The upper contact of this unit is terminated abruptly by a single storey, medium grained sandstone which has an erosive base. The base of the sandstone unit has planar laminations that grade upward into ripple and low angle cross laminations and finally into a rooted horizon. The interpretation for the environment of deposition, derived from the micropalaeontological and the sedimentological data, is a marine-influenced, levee-crevasse splay that may be distal to the main channel. The agglutinated foraminifera positively indicate marine influence. The arcellaceans indicate either fresh water discharge or reduced salinities (Scott, Schafer and Medioli, 1980).

Chapter 7. Other biota

7.1 General discussion

Representatives from other groups of organisms were encountered in some of the lithologic units examined for this study. The positive association of foraminifera with the other biota indicates that the environment of deposition was marine influenced. A generalised salinity relationship for these biota is illustrated in Figure 5. The direct association of microfossil assemblages, most specifically brackish water agglutinated foraminifera, with the fossiliferous remains of the other biota requires further commentary.

7.1.1 Phylum Annelida, Class Polychaeta

Polychaete worms are predominantly marine and seldom live in fresh water (Barnes, 1980). Of the more than 5,300 described, living, species of polychaete worms only 12 are reported from North American 'fresh water' environments (Davies, 1991). In fact, the documented habitat for each of these species rarely includes an environment without a direct connection, present or recent, to the sea. Just 2 species; *Ficopomatus enigmatica* Fauvel, 1922, and *F. miamiensis* Treadwell, 1914, secrete straight, unornamented, calcareous tubes (family Serpulidae). These sessile, tubiculous, worms are reported from both fresh and marine environments, however, reproduction is restricted to brackish water (Hartman, 1959).

The stratigraphic range of fossilised hard parts, mineralised soft parts and traces of polychaete worms is PreCambrian to Recent (Howell, 1962; Black, 1979; Barnes, 1980). Marine conditions, more specifically low sea level, are often marked by the presence of bioconstructive organisms such as calcareous algae, and serpulid worms (Kelletat, 1988). Recent representatives of *Spirorbis* are abundant and relatively inconspicuous epiphytes that are frequently attached to intertidal and subtidal algae in coastal, marine environments (Gosner, 1978, Meinkoth, 1981).

Polychaete worm tubes from the family Serpulidae, genus *Spirorbis* (Ordovician-Recent), are common in restricted units of the Sydney Mines Formation, as well as in many

Figure 5: This figure illustrates the relationship between salinity and the protistan (arcellacea and foraminifera) microfossils. Salinity data from Recent environments, populated by brackish water foraminifera and arcellaceans, is used to separate marine, brackish and fresh waters. Ranges of salinity tolerance for the other Carboniferous fauna are also shown. These ranges are based on the co-occurrent find finds of foraminifera and representatives of the other taxa. An unidirectional graded pattern is used for the groups of organisms that occur in either fresh or marine influenced conditions. A positive relationship is inferred by the darker shading. A non-directional graded pattern indicates an uncertain relationship with salinity.

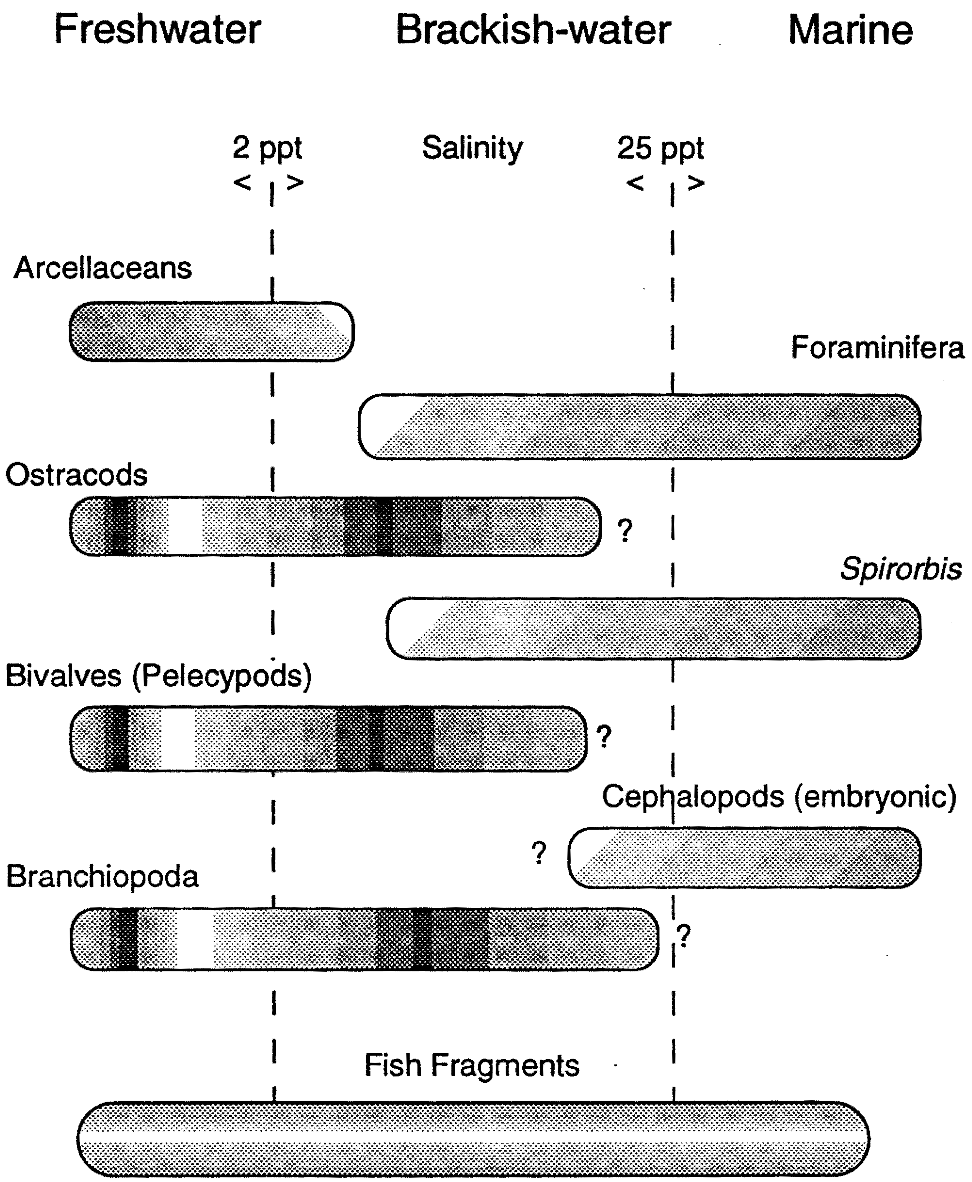

Freshwater
Brackish-water
Marine
2 ppt
< >
Salinity
25 ppt
< >
Arcellaceans
Foraminifera
Ostracods
?
Spirorbis
Bivalves (Pelecypods)
?
Cephalopods (embryonic)
?
Branchiopoda
?
Fish Fragments

Figure 5

other Carboniferous deposits. No detectable morphological variation in the shell, which would suggest speciation due to environmental stress, is discernible in the 'fresh water' Carboniferous spirorbiid representatives (Roger, 1959; Thibaudeau, this study, Plate 9: Figs. 10 and 11). Marine influence is suggested for the spirorbid-containing units (Duff and Walton, 1973; Vasey and Zodrow, 1983) and then negative evidence is used to dismiss this information (Calver, 1968; ; Masson and Rust, 1983, 1984; Best, 1984). Assemblages of estuarine-marine agglutinated foraminifera are found in direct association with the fossil serpulid worm tubes in units QT48a and Q171. These foraminifera provide positive evidence for marine influence, and more specifically indicate a subtidal, estuarine to transitional marine salinity range in the habitat of these biota (Scott, Medioli and Schafer, 1977; Scott, Schafer and Medioli, 1980).

7.1.2 Phylum Conodonta

Thibaudeau (1987) reported a fragmentary phosphatic fossil, phylum ?Conodonta, from a fossiliferous, carbonate-rich unit (QT48a) of the Sydney Basin strata. No representatives of the phylum Conodonta were recovered from the bulk samples that were collected and processed for conodonts (P.H. von Bitter, pers. comm., 1987). These results are inconclusive. Further examination of the acid insoluble residues provided numerous specimens of agglutinated foraminifera that characterise an estuarine-marine habitat. Most specimens are completely flattened but are otherwise in good condition.

7.1.3 Phylum Mollusca, Class Bivalvia (Lamellibranchia; Pelecypoda)

Representative bivalve taxa reported from Upper Carboniferous Morien Group deposits include the following genera: *Anthraconauta*, *Anthraconaia*, and *Naiadites* (Vasey and Zodrow, 1983; Masson and Rust, 1984; White, 1992). The bivalve distribution is restricted mainly to black, laminated, fossiliferous, carbonate-rich, algal mudstones. Bivalve communities are of low diversity and individuals are numerous. Similar generic successions and population assemblages are reported from time equivalent, productive coal measures of Great Britain (Calver, 1968, 1969), as well as from restricted strata in the mid-eastern United States (Eager, 1970, 1973; Wanless, 1969).

These Carboniferous bivalves are currently lumped in a 'non-marine' category due to an inability of researchers to determine the precise habitat for the fossil organisms (Calver, 1969; Wanless, 1969; Eager, 1970). In this study, assemblages of agglutinated brackish water foraminifera are found together with these bivalves. This relationship positively indicates a marine to euryhaline habitat for the bivalves. The environment of deposition for the foraminiferal-bivalve (algae and serpulids) bioconstructive community is interpreted as submarine, estuarine to transitional marine (salinity > 20 ‰), and the depositional environment may be an abandoned delta lobe proximal to the nearshore (Elliot, 1986).

7.1.4. Phylum Arthropoda, Superclass Crustacea, Class Branchiopoda

Branchiopoda (Lower Devonian to Recent) are a morphologically diverse group of small, aquatic crustaceans. Characteristics common to this group include: jointed appendages, merosomatism, and ontogenic similarities. Representative taxa of spinicaudatid branchiopoda produce a thinly calcified, laterally compressed, bivalve carapace that envelopes the entire body. Informally, these organisms are referred to as 'clam shrimps' because the characteristic carapace ornamentation (umbo, growth lines, and two valves) resemble the shell of a bivalve mollusc (Tasch, 1969; Robison and Kaesler, 1987; Dodson and Frey, 1991).

Recent spinicaudatid branchiopoda are frequently reported from small, ephemeral bodies of water, as well as brackish waters and coastal salt pans (Tasch, 1987; Dodson and Frey, 1991). In general, these organisms are relatively tolerant to adverse environmental conditions such as: low dissolved oxygen contents, extreme fluctuations in salinity, high temperatures, and desiccation. Spinicaudatid branchiopoda are, however, intolerant to sustained low temperatures and become non-functional in temperatures lower than 10°C. They are rare inhabitants of Canadian waters (Tasch, 1969; Dodson and Frey, 1991).

Spinicaudatid branchiopoda are relatively slow swimmers that essentially saltate from one potential food source to another. Their abundance in an habitat is controlled by food availability. Trophically, these filter feeders are secondary consumers (detritivorous, herbivorous), occupy the benthic niche, and are prey to larger organisms (aves, pisces) (Tasch, 1969; Dodson and Frey, 1991).

Representative taxa of spinicaudatid branchiopods are frequently reported from Carboniferous aged deposits (Tasch, 1969, 1987; Calver, 1969; Vasey and Zodrow, 1983; Robison and Kaesler, 1987). Genus and species level classification and identification is based mainly on soft part morphology. Specimen identification at the genus level is difficult due to a discontinuous fossil record and the classification bias (Robison and Kaesler, 1987). The fossil carapace extracted from unit QT171 in the study area (Plate 9: Figs. 12 and 13) is tentatively identified as ?*Limnoestheria* sp. Wright, 1920. The co-occurrent taxa extracted from unit QT171 *Trochammina* sp. and *Spirorbis* sp. suggest estuarine-marine salinities in the environment of deposition. This salinity range interpretation is consistent with the interpretation for Carboniferous aged spinicaudatid specimens extracted from coal-bearing deposits in Ireland (Wright, 1920), and from the coal measures in northern England (Calver, 1968).

7.1.5 Phylum Arthropoda, Superclass Crustacea, Class Ostracoda

Two podocopin, cypridacean ostracod genera, *Carbonita* sp. (? Lower Carboniferous; Upper Carboniferous to Permian), and *Candona* (family range is Silurian to Recent; Fresh water to marine), as well as *Darwinula* sp. (Carboniferous to Recent; Fresh water to oligohaline), are present in the bivalve-algal units of the Sydney Mines Formation (White, 1992). The smooth, unornamented valves are both articulated and disarticulated (Masson and Rust, 1983, 1984; Vasey and Zodrow, 1983; Best, 1984).

Recent representatives of these taxa are commonly found in fresh to brackish and ephemeral bodies of water. They are free swimming, benthic dwellers that graze on algae and detrital organic matter (Benson, 1961; Pokorný, 1965, 1978; Brasier, 1980; Delorme, 1991). In general, ostracods are salinity sensitive and reports on ostracod population studies, in waters with >2-10‰ salinity, have shown that abundant valves in a low diversity taphocoenitic assemblage is indicative of salinity stress (Morkhoven, 1972; Pokorný, 1978; Brasier, 1980; Harten, 1986).

The exoskeleton (carapace) morphology and muscle scar arrangement are the primary structures used to make genus level distinctions. Species identification of living specimens is based on morphological characteristics of the soft body parts. In fossil forms, identification at the species level is difficult (Scott, 1961; Pokorny, 1978).

The value of fossil ostracod valves as palaeosalinity indicators is restricted by the fact that members of phyletic lineages have changed their mode and habits considerably over time (Pokorný, 1978). Fresh water ostracod valves are common in transitional marine and coastal marine environments (Morkhoven, 1972; Bless and Prins, 1973; Brasier, 1980; Bignot, 1985). Consequently, ostracod valves are of limited value as palaeosalinity and palaeoenvironmental indicators in Carboniferous aged strata. Assemblages of agglutinated brackish water foraminifera are found together with the ostracod carapaces. The foraminifera indicate a palaeoenvironmental salinity range of 10 to 30‰ (Scott, Medioli and Schafer, 1977; Scott, Schafer and Medioli, 1980). Thus, it is possible that these ostracods tolerated fluctuating salinities (euryhaline).

7.1.6 Chordata, Subphylum Vertebrata, Superclass Pisces

Fish first appeared during the Late Cambrian-Early Ordovician age marine strata (class Agnatha). The fossil record is discontinuous between the Cambrian and Silurian, and all finds are from marine or brackish water environments (Bond, 1979; Mc Farland *et al.*, 1979; Black, 1979; Beerbower, 1985). Late Devonian continental (fresh water) ecosystems include sporadic appearances of sparse, impoverished communities of primary producers with little or no representation by members of higher trophic levels. In fact, the fossil record does not support a fully developed fresh water trophic community at this time. In contrast, a complex, and fully developed brackish water ecosystem, including representation by all major groups of fish, was established by the end of the Devonian (Beerbower, 1985). Therefore, all lineages of fish had developed the requisite physiological adaptations for osmoregulation in waters with fluctuating salinities. No evidence supports a simultaneous loss of the physiological adaptations that are imperative for survival in salt water.

The fragmentary remains of fish teeth and dermal ornamentations reported from units in the study area belong to extinct lineages of chondrichthyan (cartilaginous) and osteichthyan (bony) fish (Masson and Rust, 1984; Best, 1984; Bird, 1987; White, 1992). Information about the habitual behaviours of Palaeozoic chondrichthyan fishes is largely derived from fragmentary evidence. Modern Chondrichthyan lineages first appeared in the Jurassic. Virtually all extant representatives, including the sharks, skates and rays (Elasmobranchs), and the Chimaeras (Chimaeriods), are marine and few tolerate fluctuating salinities (euryhaline). These few species that exist in fresh water can also live, and most importantly reproduce, in fully marine conditions (Hill, 1976; Bond, 1979; Mc Farland *et al.*, 1979).

The extant Osteichthyan lineages (bony fishes) first appeared in the Cretaceous. By concept, these fish are either fresh water (non marine) or marine, however, many groups are actually euryhaline. In fact, the life cycles of many recent teleosts includes some form of diadromous behaviour (Bond, 1979). Palaeozoic Osteichthyans included the Sarcopterygii (lung fishes), Crossopterygii (lobe finned fishes) and Actinopterygii (ray finned fishes). Fragmentary remains of lungfishes are used by White (1992) to argue continental, fresh water conditions. However, early lung fishes (Late Devonian), and their predecessors were marine. In fact, their adaptation to fresh water is considered a relatively recent evolutionary event. Unlike their fossil ancestors, extant lung fish (genera *Neoceratodus*, *Lepidosiren*, and *Protopterus*) exist in fresh and ephemeral bodies of water (Bond, 1979; Mc Farland *et al*, 1979; Beerbower, 1985), as well as rely on lung-like sacs rather than gills for gas exchange (Gorr and Klein, 1993).

The fragmentary remains of crossopterygian fish occur in restricted beds in the study area (Best, 1984; Bird, 1987; White, 1992). Fossil Coelacanths inhabited brackish water environments in the Late Devonian, and it is proposed that they were fresh water inhabitants during the Carboniferous (Mc Farland, *et al.*, 1979; Beerbower, 1985). Crossopterygian fishes were considered extinct, however, since 1938 several specimens were caught from deep marine waters of the South Atlantic and Indian Oceans. Little is known about the habits of the living coelacanth, *Latimeria chalumnae*, except that it is a large, marine predator.

In general, a review of the habitat and life history of recent fishes provides no clear indication on the environment inhabited by their fossil ancestors. In fact, the intercontinental distribution of many fish groups suggests that larger groups of salt tolerant fish are represented in fresh water. The catadromous, anadromous or amphidromous migratory behaviours in the life cycles, of many groups of recent fish, also supports a fresh water distribution of euryhaline fishes (Bond, 1979; Mc Farland *et al.*, 1979). Consequently, the value of fragmentary fish remains, as palaeoenvironmental indicators, is limited. An estuarine-marine assemblage of agglutinated foraminifera are directly associated with the fish fragments (Thibaudeau, 1987; Thibaudeau, and Medioli, 1986; Thibaudeau, Medioli and Scott, 1987, 1988). Brackish to marine conditions are indicated for the environment of deposition, as well as suggest that the fossil fish may have been euryhaline.

7.1.7 Cyanophytes and Cyanobacteria

Stromatolites (Archean to Recent) are organo-sedimentary, often calcareous, bioconstructive structures that are formed by multi-component biological communities. Different growth morphologies (columnar, spheroidal, and stratiform) are linked to variations in environmental hydrodynamic energy. Carbonate secreting cyanophytes contribute significantly to algal stromatolite communities (Meyen, 1987; Kelletat, 1988). Many reports on recent stromatolitic communities are from ecologically stressed marine, less commonly fresh water, environments (Boggs, 1987; Schopf, 1987). Globular masses of, the euryhaline cyanophyte genus, *Chloroglea* are reported from North American fresh water environments (Prescott, 1980).

Cyanophyta are both diverse and abundant in modern environments. They inhabit the photic zone in all aquatic, hypersaline-marine through fresh water, environments (Prescott, 1980; Schopf, 1987). Cyanophyte growth forms range from unicellar and simple filamentous structures to branched and falsely branched colonial masses. Presently, the morphologically simpler forms predominate in fresh water environments (Prescott, 1980).

Laminated (stratiform) and domed (columnar/spheroid) stromatolite-like structures are reported from Upper Morien age Sydney Basin deposits. Algal filaments, similar to the marine algal genera *Grivanella*, *Garwoodia*, and *Ortonella*, were isolated and identified from these fossiliferous beds (Vasey and Zodrow, 1983; Masson and Rust, 1983, 1984). An estuarine-marine assemblage of agglutinated brackish water foraminifera are extracted from the lithologic units containing stratiform-algae (Table 2). This foraminiferal-algal association suggests that the carbonate secreting algae in these units were euryhaline. The environment of deposition is nearshore-prodelta to interdistributary bay with fluctuating salinities.

7.1.8 Macrophytes

Brackish water tolerance has been proposed for some species of Carboniferous plant groups. The suggestion of salt tolerance has largely resulted from comparative morphological studies between the floristic inhabitants of modern coastal environments and Carboniferous macrophyte remains preserved in coal-balls (Cridland, 1964; Ziegler *et al.*, 1981; Phillips *et al.*, 1981; DiMichele, *et al*, 1985; Meyen, 1987). Brackish water foraminifera were isolated from horizons containing root structures in this study. However, the root-types were not identified and no further commentary is warranted.

Conclusions

Arcellacean and foraminiferal microfossil assemblages are extracted from 9 separate lithologic units in Carboniferous aged, Upper Morien Group strata of the Sydney Mines Formation. Assemblages of brackish water foraminifera are present in 8 of 9 separate lithologic units. This distribution positively indicates marine influence for all but one of the environments of deposition. These microfossils can be used positively to distinguish fresh water from marine influenced environments of deposition as well as identify separate transgressive events. The vertical distribution of the marine influenced samples in the outcrop section indicates that more than one transgressive event affected the coastal environment of deposition.

The Carboniferous foraminiferal-arcellacean assemblages compiled in this study are similar in member-genus composition to those reported from recent brackish water environments. The results from this study support the extension of the stratigraphic range of the following foraminiferal genera: *Ammomarginulina*, *Ammotium*, *Miliammina*, *Haplophragmoides*, *Trochamminita*, *?Buccicrenata* and *Textularia* back into the Upper Carboniferous (Westphalian D) (Figure 6). Different forms of *Ammotium* (2 forms), ?*Buccicrenata* (2 forms) and four (4) forms of *Trochammina* are identified. The forms are lumped into groups based on the commonality of the morphological features and the situation or position of those features. An equivalent extension of the stratigraphic ranges, back to the upper Palaeozoic (Westphalian D), is also suggested for two of the three arcellacean genera: *Difflugia* (3 forms) and *Heleopora* (Figure 6). The third genus of arcellaceans, *?Paranebela*, is tentatively identified and a new taxon may be required to accommodate this form.

Genera with long ranging lineages, such as those reported in this study, are potentially very useful tools for palaeoenvironmental interpretations. The results of this study indicate that the ecological requirements of these genera have changed very little through time. Thus, the Carboniferous assemblages of brackish water foraminifera and fresh water arcellaceans have been used positively to identify marine influence, delimit palaeosalinity ranges and be used as

Figure 6: A composite figure to show the stratigraphic ranges of foraminifera, arcellaceans and other biota. The known range for each taxonomic group is shown in black and the pertinent family ranges are identified by a black hair line. The proposed extensions in the stratigraphic range for genera of Arcellinida and Foraminiferida are illustrated with a grey arrowhead and dashed line. These data are compiled from the following sources; Loeblich and Tappan (1964, 1988), Medioli, Scott and Wall (1986, 1990), Tasch (1969), Bensen (1961), Robison and Kaesler (1987), and Black (1979). The grey stipple pattern represents the age of the Sydney Mines Formation (Bell, 1938; Boehner and Giles, 1986). Absolute age is from Harland and others (1990).

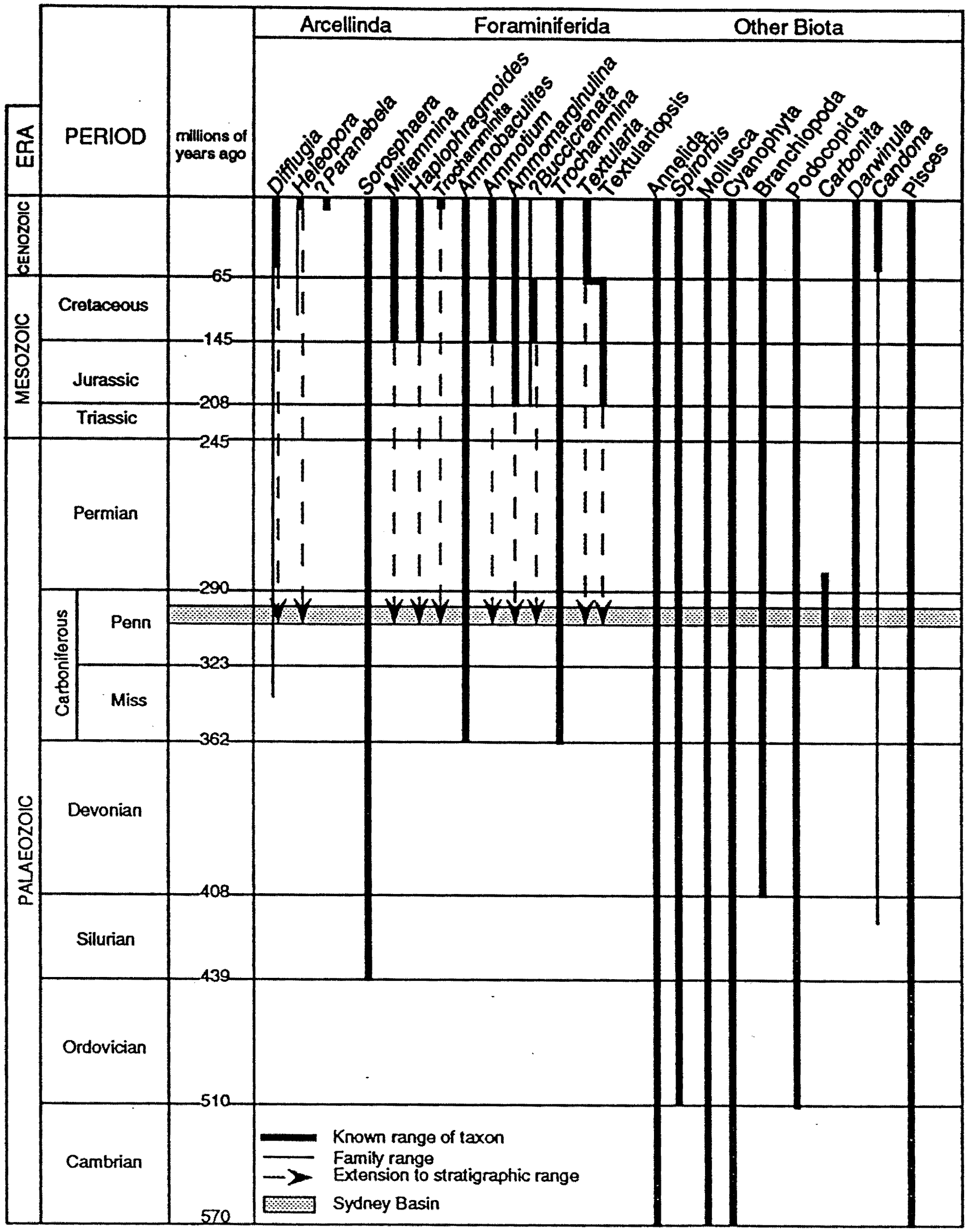

Arcellinda
Foraminiferida
Other Biota
ERA
PERIOD
millions of years ago
Difflugia
Heleopora
?Paranebela
Sorosphaera
Miliammina
Haplophragmoides
Trochamminita
Ammobaculites
Ammotium
Ammomarginulina
?Buccicrenata
Trochammina
Textularia
Textulariopsis
Annelida
Spirorbis
Mollusca
Cyanophyta
Branchiopoda
Podocopida
Carbonita
Darwinula
Candona
Pisces
CENOZOIC
MESOZOIC
PALAEOZOIC
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Penn
Miss
Devonian
Silurian
Ordovician
Cambrian
65
145
208
245
290
323
362
408
439
510
570
Known range of taxon
Family range
Extension to stratigraphic range
Sydney Basin

Figure 6

an aid for interpreting depositional environments. The positive association of the brackish water assemblages of foraminifera and the other biota can also be used to infer tolerance to fluctuations in salinity for the other organisms, as well as to infer that these biota were euryhaline-marine organisms (fish, serpulids, bivalves, etc).

Several different marginal marine, and one fresh water, environment of deposition are identified in this section. In many cases a general, salinity based, zone was identified using the foraminiferal-arcellacean assemblage information. The identification of more specific environments of deposition was facilitated by combining detailed sedimentological data with the microfossil assemblage information. These microfossils are extremely important tools for interpreting the chemical environment of deposition for non-fossiliferous and otherwise homogeneous horizons.

Plate 1: Arcellacea

Difflugia sp. 1

Figure 1. Lateral view (bar = 100µm); 85-NS-SYD-01-Q176a-01-013.
Figure 2. Apertural view (bar = 30µm); 85-NS-SYD-01-Q176a-01-014.

Difflugia sp. 2

Figure 3. Lateral view (bar = 100µm); 87-NS-SYD-09-QT178a-04-009.

Difflugia sp. 2

Figure 4. Lateral view (bar =100µm); 85-NS-SYD-01-Q265a-20-031.

Difflugia sp. 3

Figure 5. Lateral view (bar = 40µm); 87-NS-SYD-11-QT48a-04-007a.
Figure 6. Apertural view (bar = 10µm); 87-NS-SYD-11-QT48a-04-008a.

Difflugia sp. 3

Figure 7. Latero-oblique view (bar = 30^{54}µm); 85-NS-SYD-01-Q176a-11-021.

Heleopora sp. 1

Figure 8. Latero-oblique view (bar = 100µm); 85-NS-SYD-01-Q265a-11-032.
Figure 9. Apertural view (bar = 10^{56}µm); 85-NS-SYD-01-Q265a-11-034.

Heleopora sp. 1

Figure 10. Latero-oblique view (bar = 35µm); 87-NS-SYD-11-QT48a(VB)-28-036b view.
Figure 11. Apertural view (bar = 10µm); 87-NS-SYD-11-QT48a(VB)-28-035b view.

?Paranebela sp. 1

Figure 12. Lateral view (bar = 100µm); 85-NS-SYD-01-Q197a-02-024.
Figure 13. Apertural view (bar = 10 µm); 85-NS-SYD-01-Q197a-02-023.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)

Plate 1

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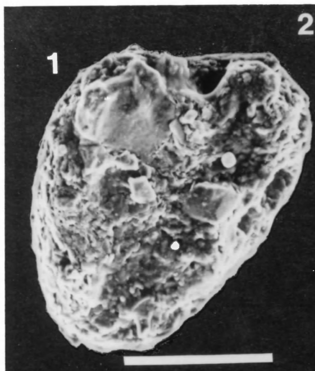

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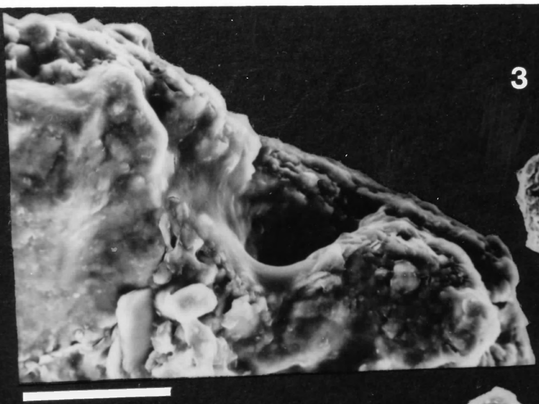

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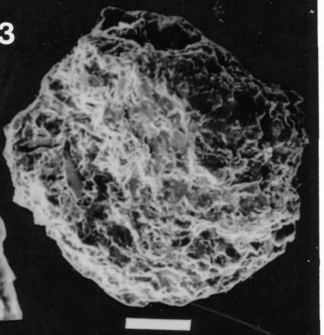

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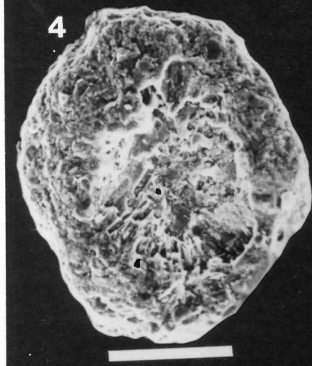

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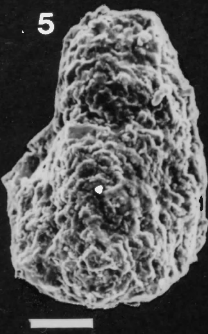

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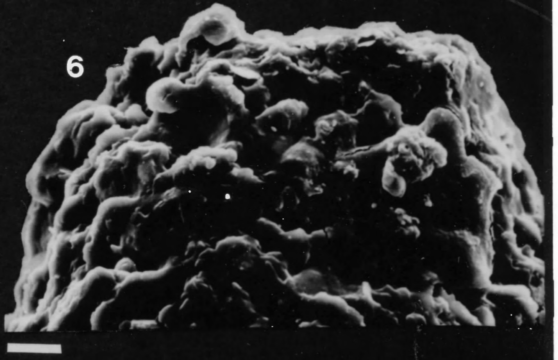

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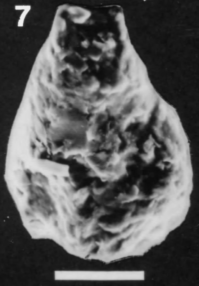

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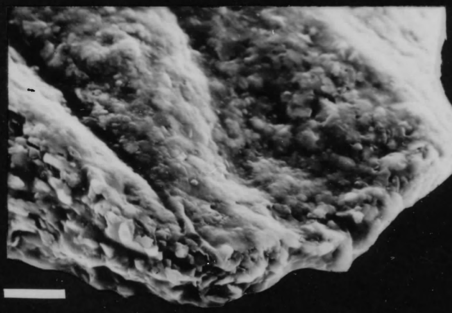

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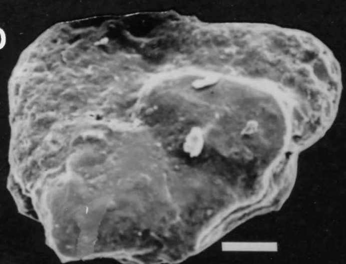

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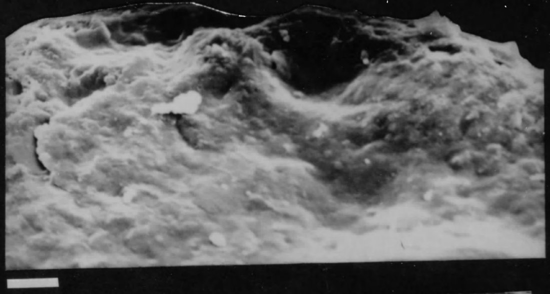

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Plate 2: Foraminifera

Sorosphaera sp. 1

Figure 1.	Intact multichambered specimen (bar = 100µm); 85-NS-SYD-02-Q197a-07-001b.
Figure 2.	Interstitial pore (bar = 20µm); 85-NS-SYD-02-Q197a-07-002b.
Figure 3.	Zoom, Interstitial pore (bar = 3µm); 85-NS-SYD-02-Q197a-07-003b.
Figure 4.	Bipatite wall structure of broken specimen (bar = 50µm); 85-NS-SYD-02-Q197a-07-004a.

Miliammina sp. 1

Figure 5.	Lateral view (bar = 40µm); 87-NS-SYD-11-QT48a(VB)-14-009a.
Figure 6.	Apertural view (bar = 10µm); 87-NS-SYD-11-QT48a(VB)-14-021b.

Miliammina sp. 1

Figure 7.	Lateral view (bar = 100µm); 85-NS-SYD-02-Q129a-03-018.
Figure 8.	Aperture, oblique view (bar = 30^{45}µm); 85-NS-SYD-02-Q129a-03-004.
Figure 9.	Zoom, aperture (bar = 10^{30}µm); 85-NS-SYD-02-Q129a-03-002.

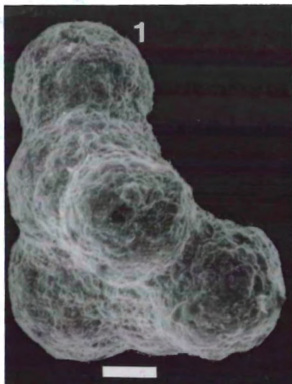
Haplophragmoides sp. 1

Figure 10.	Lateral view (bar = 300µm); 87-NS-SYD-14-QT49a-03-003.
Figure 11.	X-radiographic image (bar = 300µm); 87-NS-SYD-QT49a-03.
Figure 12.	Apertursl virw (bar = 30^{45}µm); 87-NS-SYD-14-T49a-03-004.

Trochamminita sp. 1

Figure 13.	Lateral view, oblique (bar = 100^{30}µm); 87-NS-SYD-11-QT48a(VB)-15-010.
Figure 14.	Aperture, oblique view (bar = 100^{30}µm); 87-NS-SYD-11-QT48a(VB)-15-011.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)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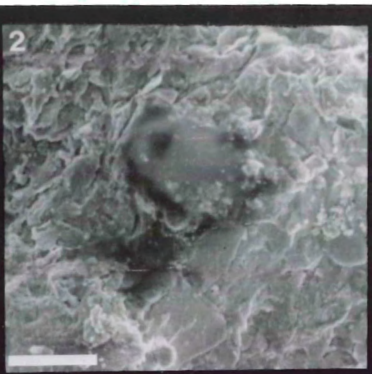
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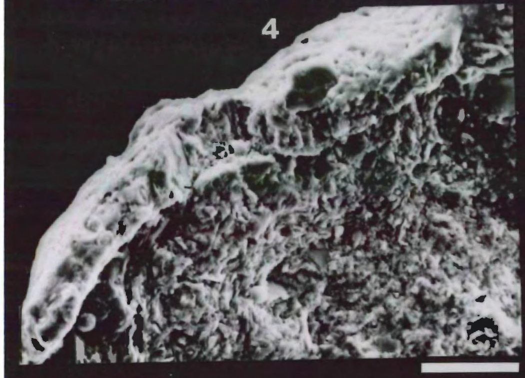
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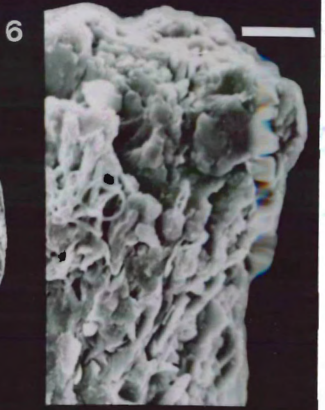
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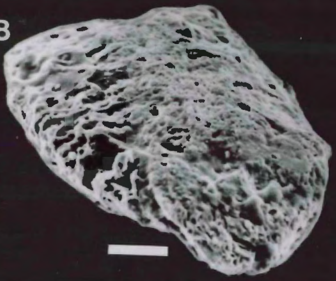
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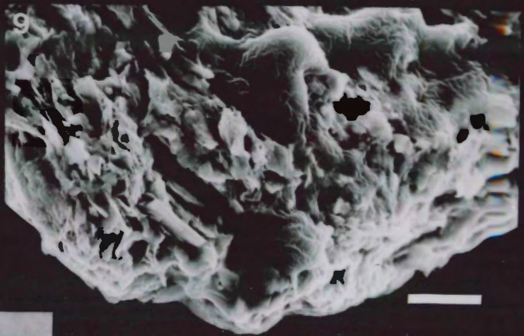
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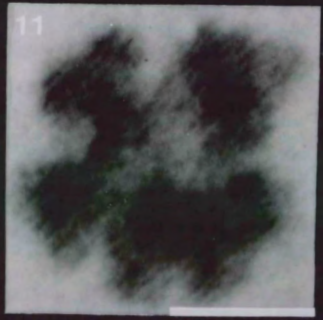
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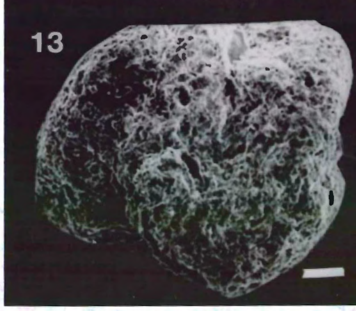
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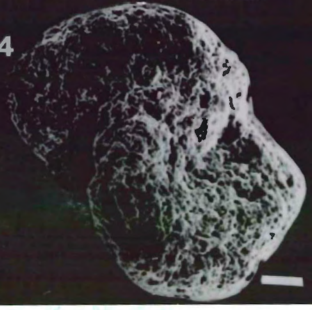
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Plate 3: Foraminifera

Ammobaculites sp. 1

Figure 1. Lateral view (bar = $300^{30}\mu$m); 85-NS-SYD-08-QT178a-14-010.
Figure 2. Apertural view (bar = $100^{30}\mu$m); 85-NS-SYD-08-QT178a-14-011.

Ammobaculites sp. 1

Figure 3. Lateral view (bar = 100μm); 87-NS-SYD-11-QT48a(VB)-27-013b.
Figure 4. Apertural view (bar = 50μm); 87-NS-SYD-11-QT48a(VB)-27-015b.

Ammobaculites sp. 1

Figure 5. Lateral view (bar = 50μm); 87-NS-SYD-14-QT49a-01-001.
Figure 6. Apertural view (bar = $30^{69}\mu$m); 87-NS-SYD-14-QT49a-01-009.

Ammobaculites sp. 1

Figure 7. Apertural view, oblique (bar = $50^{56}\mu$m); 85-NS-SYD-01-QT265a-02-033.

Ammobaculites sp. 1

Figure 8. Lateral view (bar = 100μm); 87-NS-SYD-09-QT178a-09-014b.
Figure 9. Apertural view, oblique (bar = $100^{39}\mu$m); 87-NS-SYD-09-QT178a-09-016b.
Figure 10. Apertural view (bar = $10^{39}\mu$m); 87-NS-SYD-09-QT178a-09-015b.

Ammobaculites sp. 1

Figure 11. Lateral view (bar = 50μm); 85-NS-SYD-01-QT83a-03-010.
Figure 12. Apertural view, oblique (bar = 10μm); 85-NS-SYD-01-QT83a-03-009.

Ammobaculites sp. 1

Figure 13. Lateral view, oblique (bar = $50^{30}\mu$m); 87-NS-SYD-11-QT48a(VB)-05-001.
Figure 14. Apertural view, oblique (bar = $30^{30}\mu$m); 87-NS-SYD-11-QT48a(VB)-05-002.
Figure 15. Periperal pores and septum, neck (bar = $10^{30}\mu$m); 87-NS-SYD-11-QT48a(VB)-05-003.

Ammobaculites sp. 1

Figure 16. Lateral view (bar = 100μm); 85-NS-SYD-09-QT178a-02-007b.
Figure 17. Coiling end, oblique (bar = $20^{40}\mu$m); 87-NS-SYD-09-QT178a-02-018b.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)

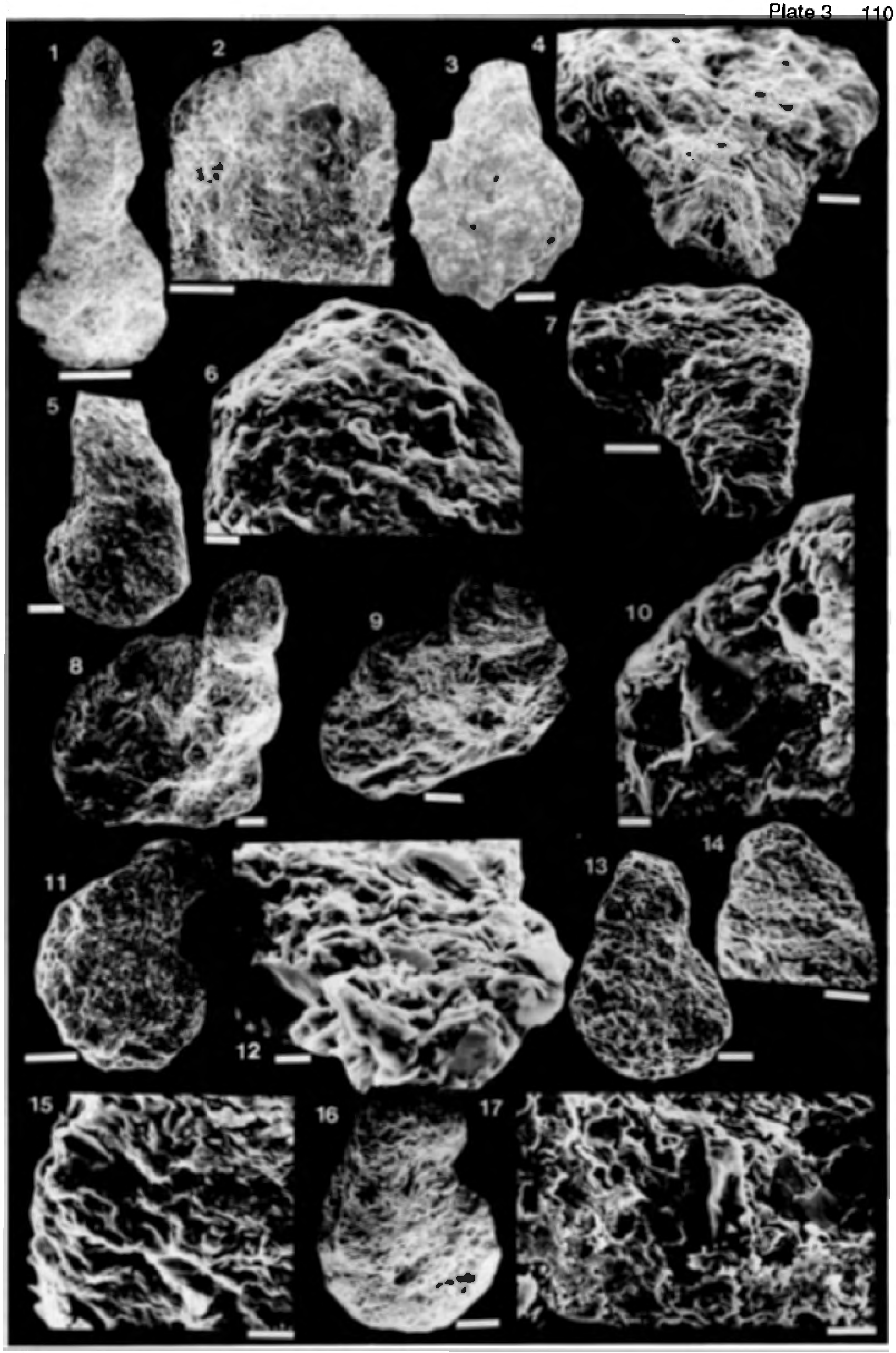
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Plate 4: Foraminifera

Ammobaculites sp. 1

Figure 1. Lateral view, oblique (bar = $50^{30}\mu\text{m}$); 87-NS-SYD-11-QT48a(VB)-25-030.
Figure 2. Oblique apertural view (bar = $20^{30}\mu\text{m}$); 87-NS-SYD-11-QT48a(VB)-25-029.
Figure 3. Proloculus, oblique view (bar = $30^{30}\mu\text{m}$); 87-NS-SYD-11-QT48a(VB)-25-031.

Ammobaculites sp. 1

Figure 4. Lateral view (bar = 300µm); 85-NS-SYD-10-QT83a-01-001.
Figure 5. Prolocular view (bar = 100µm); 85-NS-SYD-10-QT83a-01-003.
Figure 6. Apertural view (bar = 20µm); 85-NS-SYD-10-QT83a-01-008.

Ammomarginulina sp. 1

Figure 7. Lateral view, intact specimen (bar = $300^{56}\mu\text{m}$); 85-NS-SYD-04-QT178-017-001.
Figure 8. Prolocular view, sectioned specimen (bar = 50µm); 85-NS-SYD-05-QT178-017-000.
Figure 9. Septum in prolocular area, sectioned specimen (bar = 10µm); 85-NS-SYD-05-QT178-017-002.
Figure 10. Apertural view, intact specimen (bar = $10^{45}\mu\text{m}$); 85-NS-SYD-04-QT178-017-003.
Figure 11. Apertural view, sectioned specimen (bar = 10µm); 85-NS-SYD-05-QT178-017-003.

Ammotium sp. 1

Figure 12. Lateral view (bar = 50µm); 87-NS-SYD-11-QT48a(VB)-15-010.
Figure 13. Apertural view (bar = 20µm); 87-NS-SYD-11-QT48a(VB)-15-011.

Ammotium sp. 2

Figure 14. Lateral view (bar = 30µm); 87-NS-SYD-10-QT178a-02-023.
Figure 15. Prolocular view (bar = 10µm); 87-NS-SYD-10-QT178a-02-024.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)

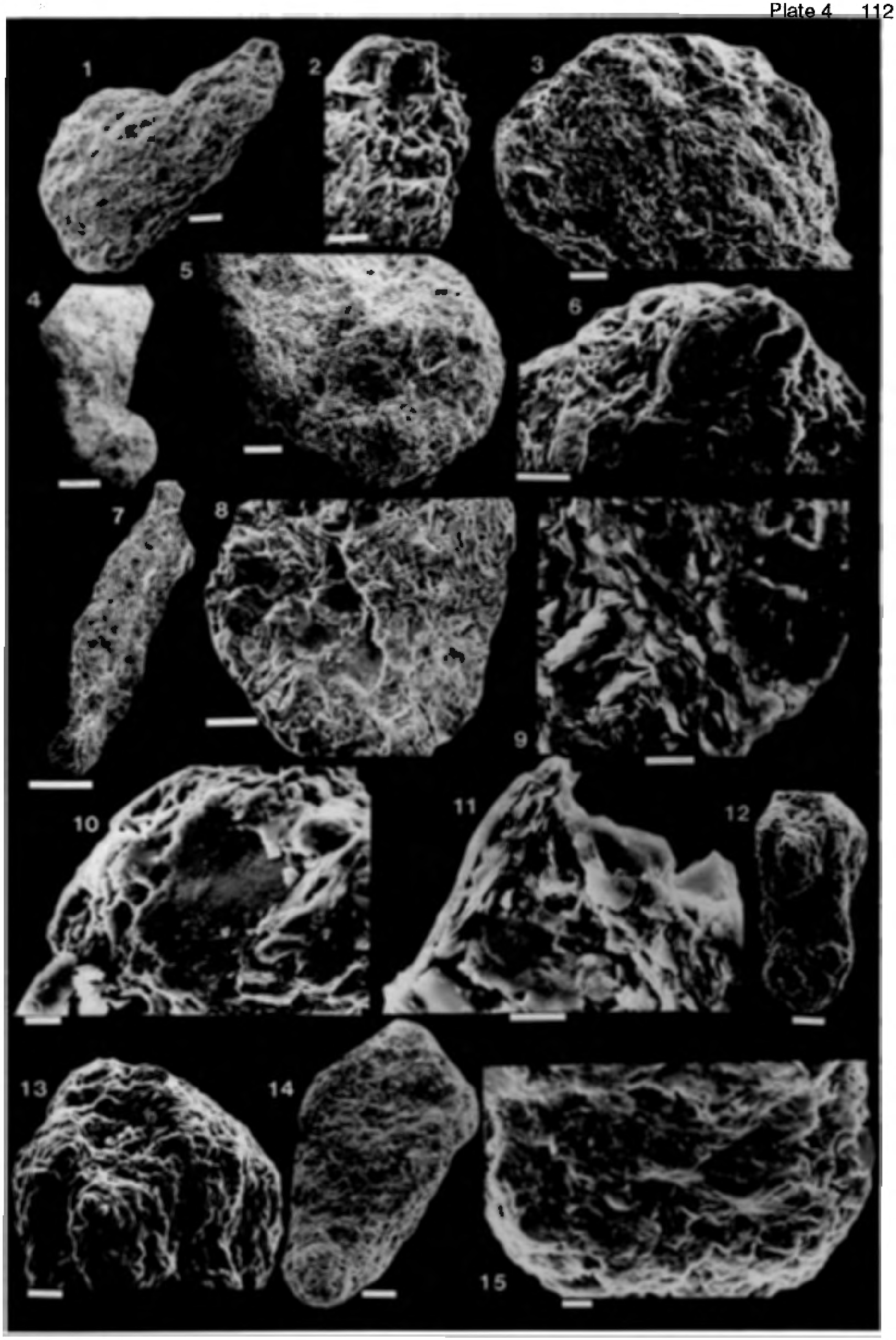
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Plate 5: Foraminifera

Ammotium sp. 2

Figure 1.	Lateral view (bar = 100μm); 87-NS-SYD-09-QT178a-14-008a.
Figure 2.	Lateral view (bar = 100^{33}μm); 87-NS-SYD-09-QT178a-14-011a.
Figure 3.	Lateral view, apertural face (bar = 50^{43}μm); 87-NS-SYD-09-QT178a-14-006b.
Figure 4.	Zoom, lateral view, apertural face (bar = 10^{43}μm); 87-NS-SYD-09-QT178a-14-005b.

Buccicrenata sp. 1

Figure 5.	Lateral view (bar = 50μm); 87-NS-SYD-11-QT48a(VB)-02-002a.
Figure 6.	Apertural view (bar = 10μm); 87-NS-SYD-11-QT48a(VB)-02-004a.
Figure 7.	Zoom, aperture (bar = 5μm); 87-NS-SYD-11-QT48a(VB)-02-006b.
Figure 8.	Zoom, alveolar wall (bar = 10μm); 87-NS-SYD-11-QT48a(VB)-02-005a.
Figure 9.	Coiling end, oblique view (bar = 30^{40}μm); 87-NS-SYD-11-QT48a(VB)-02-005b.

Buccicrenata sp. 2

Figure 10.	Lateral view (bar = 50^{30}μm); 87-NS-SYD-11-QT48a(VB)-47-044b.
Figure 11.	Zoom, aperture and alveolar wall (bar = 20^{30}μm); 87-NS-SYD-11-QT48a(VB)-47-045b.
Figure 12.	Zoom, alveolar wall, suture, chomata-like mound (bar = 10^{30}μm); 87-NS-SYD-11-QT48a(VB)-47-046b.

?*Buccicrenata sp.* 2

Figure 13.	Lateral view (bar = 50^{30}μm); 87-NS-SYD-11-QT48a(VB)-43-043b.
Figure 14.	Zoom, umbilicus; bottom centre (bar = 20^{30}μm); 87-NS-SYD-11-QT48a(VB)-43-042b.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)

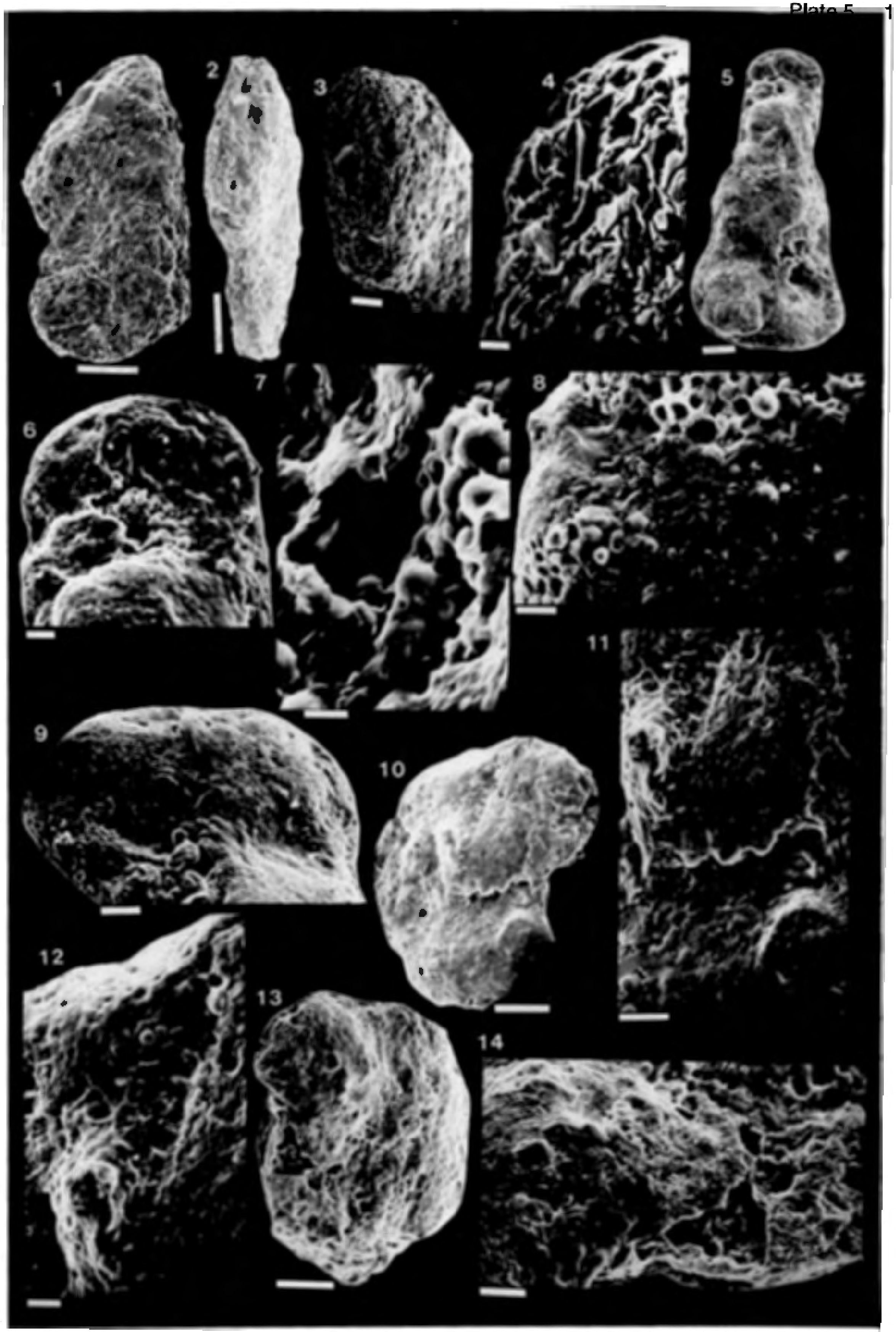
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Plate 6: Foraminifera

Trochammina sp. 1

Figure 1. Ventral view (bar = 35^{30}µm); 87-NS-SYD-11-QT48a(VB)-30-033b.
Figure 2. Zoom, chambers and suture (bar = 10^{30}µm); 87-NS-SYD-11-QT48a(VB)-30-034b.

Trochammina sp. 1

Figure 3. Dorsal view (bar = 100µm); 87-NS-SYD-14-QT49a-04-007.
Figure 4. Ventral view (bar = 100µm); 87-NS-SYD-10-QT49a-05-010.
Figure 5. Ventral view, oblique (bar = 100^{48}µm); 87-NS-SYD-10-QT49a-05-015.
Figure 6. Zoom, aperture, peripheral area (bar = 5^{48}µm); 87-NS-SYD-10-QT49a-05-011.

Trochammina sp. 2

Figure 7. Dorsal view (bar = 30^{30}µm); 87-NS-SYD-07-QT171-01-002.
Figure 8. Zoom, chambers and suture (bar = 50µm); 87-NS-SYD-07-QT171-01-001.

Trochammina sp. 2

Figure 9. Ventral view (bar = 40^{30}µm); 87-NS-SYD-11-QT48a(VB)-36-038b.
Figure 10. Ventral, umbilical view (bar = 20^{30}µm); 87-NS-SYD-11-QT48a(VB)-36-039b.

Trochammina sp. 3

Figure 11. Dorsal view (bar = 50^{30}µm); 87-NS-SYD-10-QT49a-13-021.
Figure 12. Proloculus and aperture (bar = 30^{30}µm); 87-NS-SYD-10-QT49a-13-026.
Figure 13. Zoom, apertural face (bar = 30^{30}µm); 87-NS-SYD-10-QT49a-13-027.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)

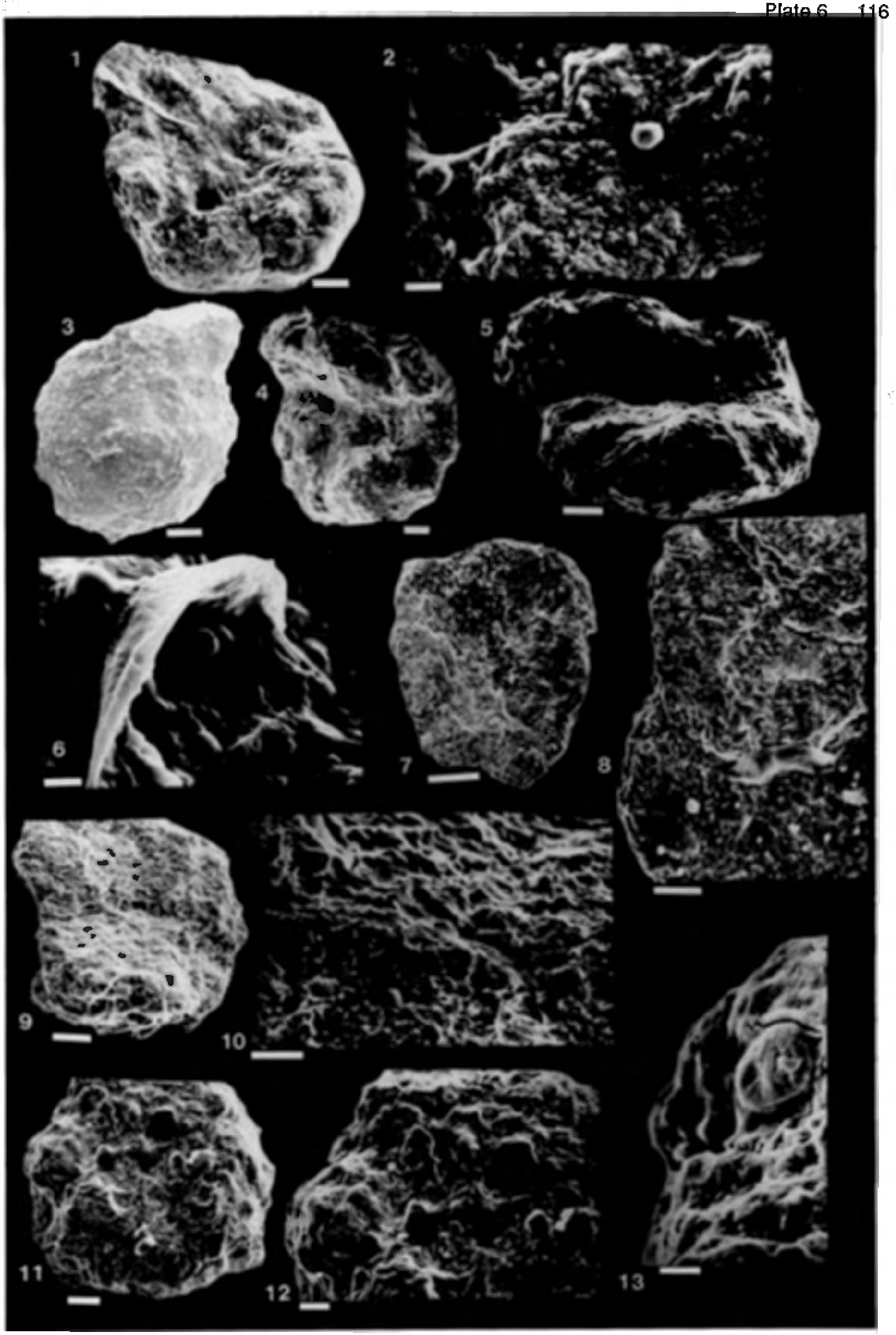
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Plate 7: Foraminifera

Trochammina sp. 3

Figure 1. Ventral view (bar = 40µm); 85-NS-SYD-10-Q129a-02-019.
Figure 2. Dorso-terminal chamber, oblique (bar = 40^{48}µm); 85-NS-SYD-02-Q129a-09-014.
Figure 3. Dorsal view (bar = 40µm); 85-NS-SYD-02-Q129a-09-011.
Figure 4. Zoom, dorsal view (bar = 10µm); 85-NS-SYD-02-Q129a-09-012.

Trochammina sp. 3

Figure 5. Dorsal view (bar = 50^{30}µm); 87-NS-SYD-11-QT48a(VB)-12-015b.
Figure 6. Proloculus, oblique (bar = 25^{30}µm); 87-NS-SYD-11-QT48a(VB)-12-013b.
Figure 7. Zoom, proloculus (bar = 20^{30}µm); 87-NS-SYD-11-QT48a(VB)-12-014b.

Trochammina sp. 3

Figure 8. Dorsal view (bar = 100µm); 86-NS-SYD-09-QT178a-10-012b.
Figure 9. Zoom, proloculus (bar = 20µm); 86-NS-SYD-09-QT178a-10-013b.

Trochammina sp. 3

Figure 10. Ventral view (bar = 100^{30}µm); 86-NS-SYD-09-QT178a-02-012a.
Figure 11. Dorsal view (bar = 100µm); 86-NS-SYD-10-QT178a-03-004.
Figure 12. Zoom, proloculus (bar = 40^{48}µm); 86-NS-SYD-10-QT178a-03-005.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)

Plate 7

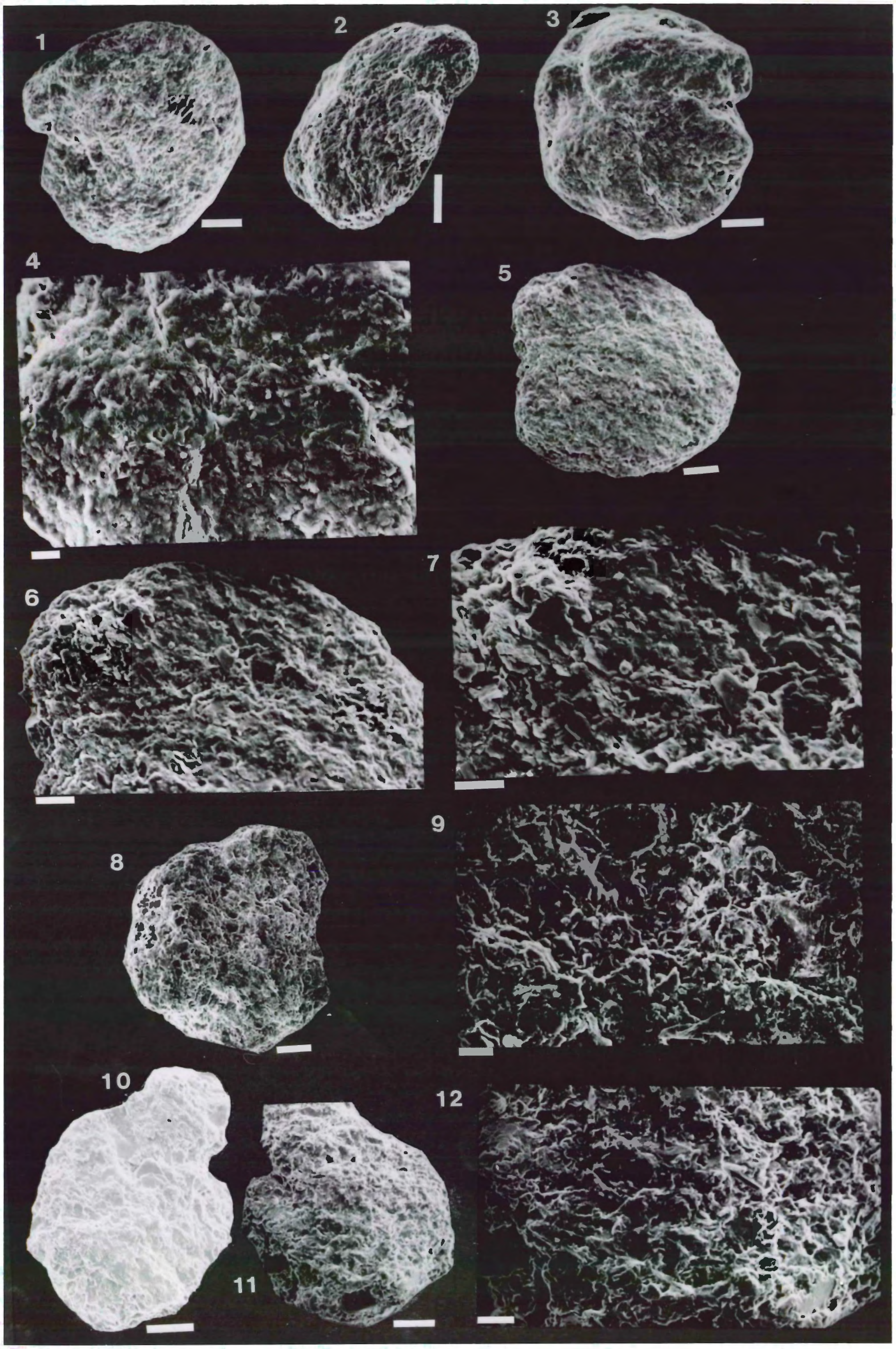


Plate 8: Foraminifera

Trochammina sp. 3

Figure 1. Dorsal view (bar = $150^{30}\mu$m); 86-NS-SYD-10-QT178a-02-022.
Figure 2. Zoom, proloculus (bar = $50^{30}\mu$m); 86-NS-SYD-10-QT178a-02-025.
Figure 3. Zoom, apertural area (bar = $5^{30}\mu$m); 86-NS-SYD-10-QT178a-02-023.

Trochammina sp. 4

Figure 4. Dorsal view (bar = $35^{30}\mu$m); 87-NS-SYD-11-QT48a(VB)-38-040b.
Figure 5. Apertural view (bar = $10^{30}\mu$m); 87-NS-SYD-11-QT48a(VB)-38-041b.

Trochammina sp. 3

Figure 6. Dorsal view, oblique (bar = $35^{40}\mu$m); 87-NS-SYD-11-QT48a(VB)-06-011b.
Figure 7. Apertural view (bar = $10^{40}\mu$m); 87-NS-SYD-11-QTa48(VB)-06-009b.

Trochammina sp. 4

Figure 8. Dorsal view, oblique (bar = $35^{30}\mu$m); 87-NS-SYD-11-QT48a(VB)-20-025b.
Figure 9. Apertural view (bar = $10^{30}\mu$m); 87-NS-SYD-11-QT48a(VB)-06-024b.

Trochammina sp. 4

Figure 10. Dorsal view, oblique (bar = $35^{26}\mu$m); 87-NS-SYD-11-QT48a(VB)-13-017b.
Figure 11. Zoom, proloculus (bar = $10^{26}\mu$m); 87-NS-SYD-11-QT48a(VB)-13-019b.
Figure 12. Zoom, apertural area (bar = $5^{26}\mu$m); 87-NS-SYD-11-QT48a(VB)-13-020b.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)

Plate 8

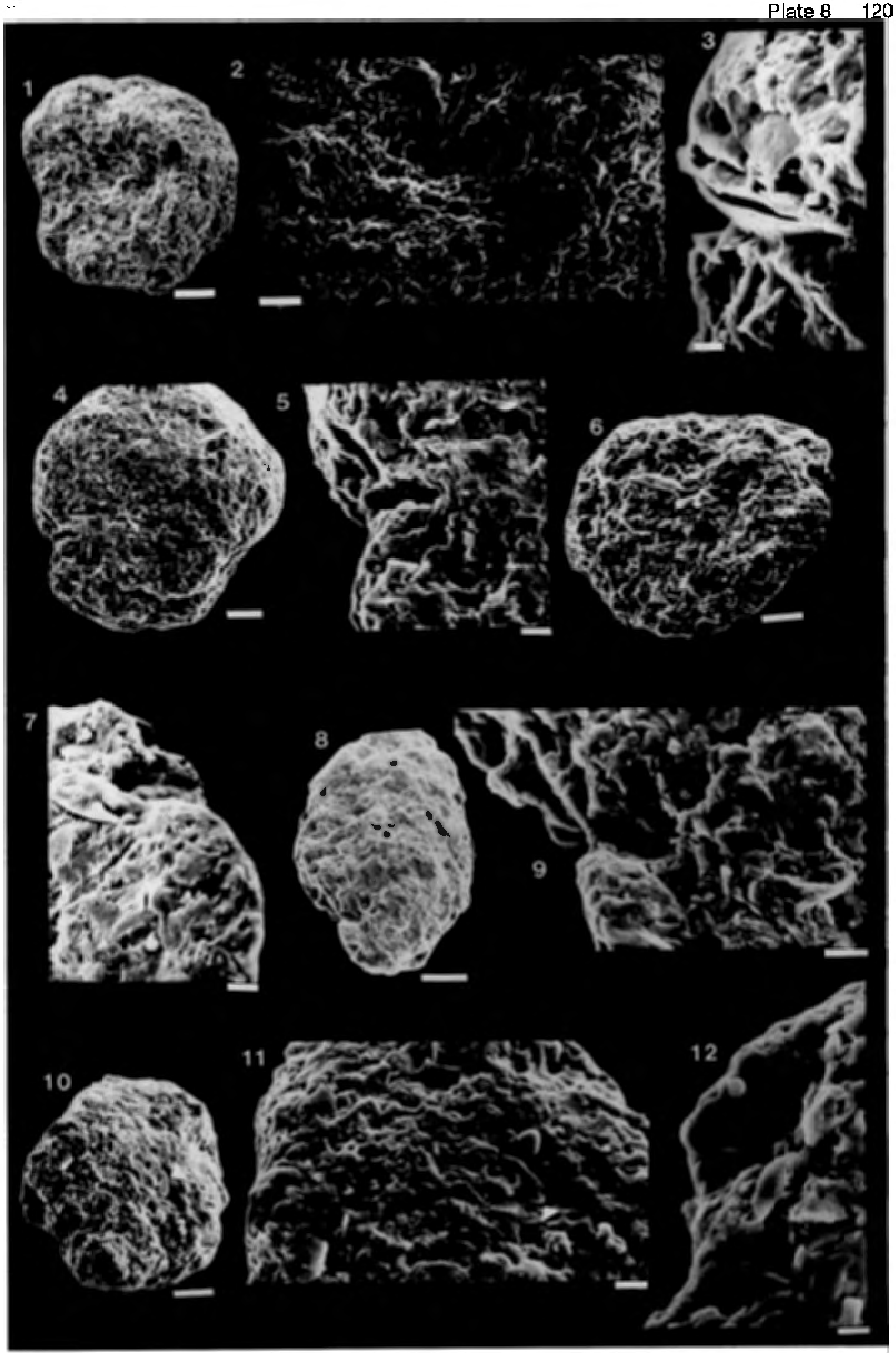


Plate 9: Foraminifera and Miscellanea

Trochammina sp. 3

Figure 1. Dorsal view (bar = 50µm); 86-NS-SYD-09-QT178a-17-017.
Figure 2. Dorsal view, oblique (bar = 50^{30}µm); 86-NS-SYD-09-QT178a-17-018.

Trochammina sp. 3

Figure 3. Dorsal view, oblique (bar = 50^{30}µm); 87-NS-SYD-11-QT48a(VB)-34-037b.

Textularia sp. 1

Figure 4. Lateral view (bar = 40µm); 87-NS-SYD-11-QT48a(VB)-03-006a.

Textularia sp. 1

Figure 5. Lateral view (bar = 40^{30}µm); 87-NS-SYD-11-QT48a(VB)-07-012b.

Miliammina fusca Brady, 1870

Figure 6. Lateral perspective, recent specimen, internal chamber arrangement, hand sectioned, Prospect Bay, Nova Scotia (bar = 100 µm); Stub 09, specimen 01, photo 001b.
Figure 7. Autogenous cement and agglutinated wall, recent specimen, Prospect Bay, Nova Scotia (bar = 30 µm); Stub 09, specimen 04, photo 004.

Trochammina inflata Montague, 1808

Figure 8. Dorsal perspective, Recent specimen, hand sectioned, Prospect Bay, Nova Scotia (bar = 100 µm); Stub 09, specimen 01, photo 001.
Figure 9. Dorsal perspective, Recent specimen, hand sectioned, internal structures, Prospect Bay, Nova Scotia (bar = 100 µm); Stub 09, specimen 03, photo 003.

Spirorbis borealis

Figure 10. Intact, Recent specimen, Prospect Bay, Nova Scotia (bar = 350 µm); Stub 12, specimen 02, photo 002.

Spirorbis sp. 1

Figure 11. Carboniferous specimen (bar = 200 µm); Stub 12, QT171, specimen 01, photo 001.

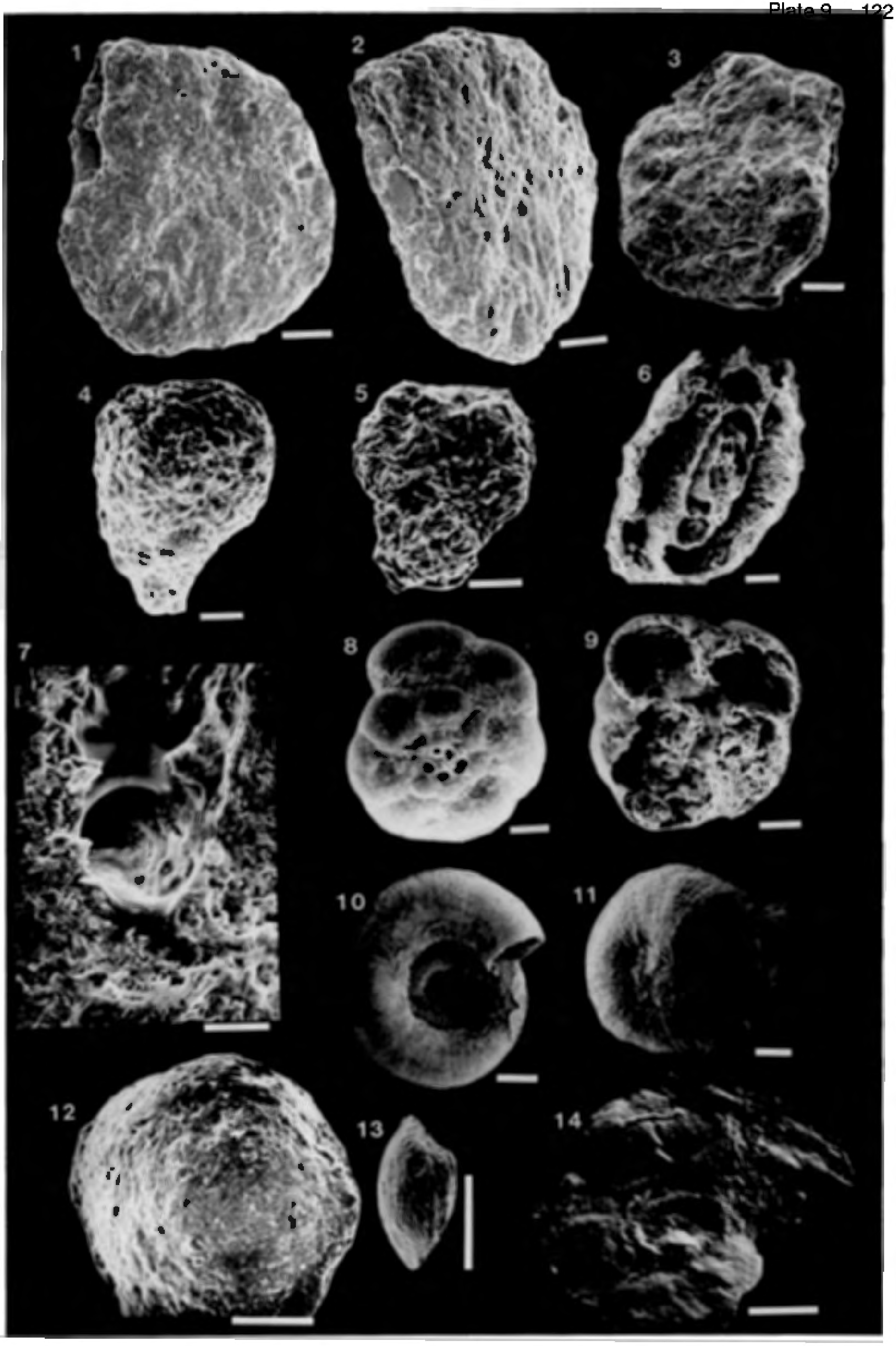
?*Limnestheria sp.* 1

Figure 12. Ventral perspective (bar = 100 µm); Stub 7, QT171, specimen 02, photo 003.
Figure 13. Posterior perspective (bar = 300^{30}µm); Stub 7, QT171, specimen 02, photo 004.

?Cephalopoda sp. 1

Figure 14. Lateral view (bar = 300 µm); Stub 6, QT48a, specimen 01, photo 002.

(* NOTE: THE SUPERSCRIPT VALUE ASSOCIATED WITH THE SPACE BAR SIZE INDICATES DEGREES OF TILT ON THE SEM STAGE.)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